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WORKING PAPER

ECONOMIC BENEFITS OF FMS (EAST-WEST COMPARISON)

Milan Maly

October 1987
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International Institute
for Applied Systems Analysis
A-2361 Laxenburg/Austria

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FOREWORD

One of the important tasks of the CIM project is to study and to reveal the main strategic goals, prerequisites, conditions of implementation and consequences of CIM adoption.

Flexible manufacturing systems, as a part of CIM, have already been adopted in many countries and companies. The present paper analyzes one part of FMS adoption, i.e. the comparison of its economic consequences in centrally planned and in market economies. The data for the comparison are based on the existing literature. This paper is the second one of its kind -- the first was written by R. Sheinin and I. Tchijov, entitled "Flexible Manufacturing Systems (FMS): State of Art and Development".

The comparison gives us interesting results and new impulses for our work. On the other hand, the database is limited. The only way to extend our investigations into the fields of management, society and logistics is to start with in-depth case studies in selected companies, having adopted FMS, through the use of questionnaires and interviews. Such an effort is, of course, only possible with the future assistance of the network of collaborating institutions in NMO countries, and IIASA is a unique place to carry out such interesting comparisons as East-West, small-large companies, small-medium-large companies, different industry sectors, in all above-mentioned areas. This database will allow us to arrive at new conclusions which will help decision makers at different levels in their strategic considerations concerning CIM adoption.

Prof. Jukka Ranta
Project Leader
Computer Integrated Manufacturing

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1. INTRODUCTION

The new computer-based technologies and systems like NC, FMC, FMS, CAD/CAM, CIM and IR are widely predicted to have fundamental implications on the socio-economic benefits of the discrete production.

During the period of almost 30 years from the first commercial introduction of the above-mentioned technologies, starting with NC-machines, many surveys on that particular topic -- mainly as a comparison of FMS with conventional systems-- have been conducted, e.g. by ECE [ECE 86], Furukawa [Furukawa 84], Ranta and Temmes [Ranta & Temmes 84], Bessant and Haywood [Bessant & Haywood 86], Willenborg [Willenborg 87], Primrose and Leonard [Primrose & Leonard 84], and predictions have been made on the socio-economic benefits of different technologies and systems, e.g. by Merchant [Merchant 84], Dudnikov [Dudnikov 87].

Moreover, some comparative studies have been carried out, mainly of a West-West or East-East typology (see e.g., Jaikumar [Jaikumar 86], Dudnikov [Dudnikov 87], Stanek and Jezek [Stanek & Jezek 83], Yoshikawa, Rathmill, Hatvany [Yoshikawa & 81]).

In this paper we concentrate our attention on Flexible Manufacturing Systems (FMS) and on the East-West comparative analysis of economic benefits of these systems. Our hypothesis is that different economic rules (centrally planned economy vs. market economy) can influence the preconditions of adoption of FMS and the results of the implementation. Analyses of the similarities and differences of economic impacts of FMS can reveal the ways of taking advantage of the experiences made with the adoption of FMS and of transferring positive experiences from one system into another.

The main objective is to infer from this analysis the main prerequisites for FMS adoption, the conditions of such an adoption and the main expected socio-economic consequences, i.e. the benefits of FMS, in order to create the descriptive model of adoption of FMS.

2. METHODOLOGY OF THE COMPARISON

It is evident that for the cross-country comparative analysis and the specification of the main areas of the socio-economic benefits in different political, social and economic conditions, the main methodological problem is to specify the list of signficiant and comparable indicators.

To guarantee the availability of the data the indicators were specified by means of the real data collected from literature sources, statistics and reports. More than 50 indicators were collected from approximately 220 existing FMS in Western countries and 25 FMS in Eastern countries.

The first evaluation of real data showed that the occurrence of different indicators varied substantially, different authors used different names for the same indicators, and the authors used different measures; thus it was necessary to combine some indicators into one and to transfer the different values into one common measure, usually the percentage.

Some of the indicators occur very often, like:

- machine number reduction
- personnel (operator) number reduction
- in process time reduction (lead time)
- decrease of work-in-progress
- pay-back time

- machining time reduction
- reduction of required floor space
- product family range (variety)
- batch size
- operating rate
- maximum continuous unmanned time.

The other indicators are not so frequent and some of them occur only once or twice. Table 1 shows the number of frequency of individual indicators, divided into two columns, Western and Eastern implementation of FMS (W, E). Indicators are gathered into four main groups of variables:

1. Labor saving
2. Capital saving
3. Flexibility increase
4. Quality increase

in accordance with the conclusions of the Meeting on Technology Forecast, held at IIASA in May, 1987.

In some of the indicators for which the data are not available, the real value was substituted by the estimated value (indicated by E, mainly Eastern data).

Labor saving

The labor saving group of variables consists of indicators describing direct saving of personnel (operators), as well as labor cost saving and labor (manufacturing) productivity. Some of the indicators in this particular group could as well be included into other groups, as their contents is not unambiguous

Table 1

Frequency of Individual Indicators

Labor saving	W	E
- personnel number	52	0
- labor (manufacturing) productivity	7	4
- maximum continuous unmanned time	24	
- unproductive time fraction	E	
- labor costs (labor saving)	4	9
- machines/per operator/ per shift	1	
- automation of assembly operations	2	
- total production costs	10	
- unit costs	1	E
- operating rate	74	8
Capital saving		
- number of machine tools	35	8
- machine tools utilization	6	1
- floor space, factory area reduction	11	E
- operation number per part	1	
- pay-back time	26	E
- inventory and W-I-P	14	
- material savings	4	
- total gross output (turnover)	2	E
- number of machining processes	2	
- reduction of tools	2	
- capital investment	2	
- production capacity	4	2
- in process time (raw stock - finished product)	24	
- throughput time	5	7
- machining time	11	
- manufacturing time	2	
Flexibility increase	W	E
- set-up time	13	
- new product lead time (design - initial productions for sale)	1	E
- tendering time	1	
- cycle-time	4	
- delivery time (receipt of order - shipment)	2	
- product family range (variety)	161	13
- batch size	29	2
Quality increase		
- number of customer claims	--n.a.--	
- reject fraction	--n.a.--	
- tolerance	--n.a.--	

(e.g. machines per operator per shift, total production costs, unit costs, operating rate).

Capital saving

Indicators describing capital saving can be divided into two groups: direct and indirect saving of capital.

The typical direct saving indicators are the reduction of machine tools, floor space, factory area and land reduction, inventory and W-I-P, raw material saving, reduction of tools and capital investment.

The indirect saving indicators are machine tools utilization, increase of total gross output, pay-back time, in process time, manufacturing time, machining time, throughput time reduction, etc.

Flexibility increase

The general definition of flexibility, achieved through automation, is the adaptivity to new conditions. Some authors consider flexibility as the main characteristic of FMS.

Many authors feel that flexibility has to be defined more precisely than in the broadest sense of the word. Flexibility must be seen as a complex variable, describing different aspects of the production process.

Mandelbaum [Mandelbaum 78] observes that flexibility can be characterized by two forms:

- action flexibility;
- state flexibility.

He defines action flexibility as the capacity for taking new action to meet new circumstances. State flexiblity is defined as the capacity to continue functioning effectively in spite of changes in the environment.

In addition, Buzacott [Buzacott 82] divides state flexibility into two classes:

- job flexibility, which he defines as the ability of the system to cope with changes in the jobs to be processed by the system;
- machine flexibility, as the ability of the system to cope with changes and disturbances at the machines and work stations.

Jaikumar [Jaikumar 84] distinguishes three kinds of flexibility:

- process flexibility, which includes flexibility with regard to different routings, machine redundancy, tool redundancy, improved speed of operations, etc.
- program flexibility, which means that a system is able to run virtually untended during the second and thrid shifts. Inspection, fixturing and maintenance are performed during the first shift.
- product flexibility, by which he means the total incremental value of new products that can be fabricated within the system for a defined cost of new fixtures, tools and part programs.

Willenborg [Willenborg 87] distinguishes:

- product flexibility, which allows for changes in product design;
- process flexibility, which allows for changes in process plan;

- production flexibility, which allows for changes in production.

Bessant and Haywood [Bessant & Haywood 86] introduce six different types of flexibility:

- product flexibility as the ability to change to produce new products or families;
- volume flexibility as the ability to economically accomodate changes in volumes produced;
- routing flexibility as the ability to process parts via different routes within the plant in response to break-down or other factors;
- machine flexibility as the ability to change in order to make different parts within a product family;
- operation flexibility as the ability to vary the sequence of operations within the manufacturing system;
- process flexibility, as the ability to produce a product family in different ways, possibly using different materials.

A group of authors [Browne 84] defines eight types of flexibilities:

- machine flexibility as the ease with which the machines in the system can be reset for processing parts in a given family of parts;
- process flexibility as the ability to produce a given set of part types, each possibly using different materials, in several ways;
- product flexibility as the ability to change to the

production of a new product or set of products very economically and quickly;

- routing flexibility as the ability of the system to continue operating through alternative routing of workpieces;
- volume flexibility as the ability to operate an FMS profitably at different production volumes;
- expansion flexibility as the capability of building a system, and expanding it as needed, easily and modularly;
- operation flexibility as the ability to interchange the order of several operations for each part type;
- production flexibility, the universe of part types that the FMS can produce.

Table 2 illustrates the frequency of different types of flexbility by different authors. From this table we see, in the course of time, that the authors started with 2 types, then increased them up to 8 (in 1984) and again went back to a more simple division (Willenborg in 1987 presents 3 types of flexibility).

Analyzing the definitions of different types of flexibility we really see that there are duplicities in different types, e.g. the group of authors specifying eight types of flexibility uses process, routing, and operation flexibility, which are very similar, as well as machine and production flexibility. Moreover, we meet with big diffferences in trying to find the indicators which can express different types of flexibility.

Our findings show that there are only two real types of flexibility, which are at present measurable:

- product flexibility

Table 2

Frequency of Flexibility Types

	Author Type of Flexibility	Mandel-baum 1978	Buzacott 1982	Jaikumar 1984	Group of authors (Browne et al.) 1984	Bessant & Haywood 1986	Willen-borg 1987	Frequency
	action	x						1
	state	x						1
x	product			x	x	x	x	4
x	process			x	x	x	x	4
	production				x		x	2
	job		x					1
x	machine		x		x	x		3
	program			x				1
	volume				x	x		2
	routing				x	x		2
	operation				x	x		2
	expansion				x			1
	SUM	2	2	3	8	6	3	

- production flexibility.

We can assume that these particular types of flexibility are the most important ones. One more type -- process flexibility-- seems to be important as well, because it expresses the ability to produce the same product in different ways and by using different materials. Unfortunately the indicators expressing these features are not available.

Our task is now to specify the indicators describing the above-mentioned two types of flexibility. Flexibility is mostly connected with time.

In the literature we can find again different types of time and their definitions (i.e. Jaikumar [Jaikumar 84], ECE [ECE 86], Willenborg [Willenborg 87], Yoshikawa et al. [Yoshikawa & 81]). A detailed analysis showed big differences not only in the definitions of different types of time, but also in the different conception of the interrelation among the different types of time. Our interpretation of the contents and interrelations of different types of time, which will not necessarily fit into the definitions of other authors, but which are important for an easier understanding of our ideas, is described in Figure 1.

Product flexibility can be defined as the ability to change in order to produce new products.

This property of the system can be expressed by indicators such as:

- new product lead time
- tendering time
- delivery time.

The lower the value of the indicators, the higher will the product flexibility be.

Figure 1

TIME DEFINITIONS

TENDERING TIME: receipt of order ——> acceptance

DELIVERY TIME: Acceptance of order ——> shipment

NEW PRODUCT LEAD TIME: Design ——> initial production for sale

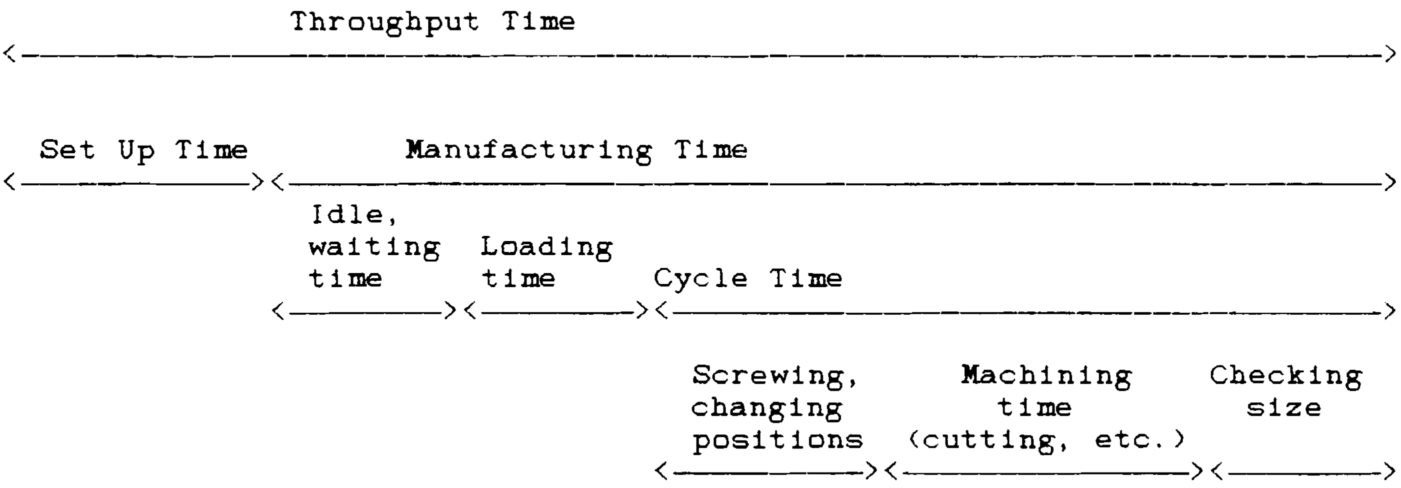
IN PROCESS TIME: Raw stock ——> finished product

THROUGHPUT TIME: Setup time + manufacturing time

MANUFACTURING TIME: Idle, waiting time + loading time + cycle time

CYCLE TIME: Screwing, changing position + machining time + checking size

MACHINING TIME: net time for metal cutting, etc.



Production flexibility is defined as the ability to change in order to make different products within a product family. This type is expressed by the following indicators:

- product variety (product family range)
- batch size
- set-up time
- cycle time.

The higher the product variety (product family range), the higher is the production flexibility. On the other hand, the lower the value of the rest of the indicators (batch size, set-up time, cycle time), the higher is the production flexibility.

In the Meeting on Technology Forecast, held at IIASA in May, 1987 very promising indicators were suggested. The software/hardware ratio can describe the flexibility of a system in a new, very original way. Unfortunately, so far the real data have not been available in existing FMS.

Quality increase

The very important variable, which some authors, e.g. Ayres [Ayres 86], regard as the main reason for adoption of FMS in the future, is quality increase. In the Meeting mentioned above two indicators were specified for this variable: reject fraction and tolerance. In the prognosis of economic benefits of CIM, the indicator "reduction of customer claims" is mentioned.

Unfortunately, again we have not found any real data from literature, so we have to find other ways to gather the necessary information.

3. FINDINGS - SIMILARITIES AND DIFFERENCES

The average value of more than 30 indicators was calculated in three main groups of variables:

labor saving

capital saving

flexibility increase.

Table 3 contains the values of Western and Eastern applications of FMS separately. From that survey we can now analyze similarities and differences of economic benefits in each of the different economic systems, market and centrally planned economies. We have to take into account that the percentage illustrates the comparison of real value of indicators in conventional and FMS systems in each group of the countries, i.e. we do not compare the real values but the value of changes.

The first piece of knowledge is that the statistical basis of Western FMS is incomparably richer and wider than that of the Eastern FMS. From the total of 33 indicators only 13 are available in Eastern countries. This means that in the group of variables LABOR SAVING we can compare 4 indicators, in the group CAPITAL SAVING 6 indicators and in the group of FLEXIBILITY INCREASE 3 indicators.

In the group of <u>labor saving</u> the results are almost the same with regard to the indicators operating rate and labor costs. The average value of the indicator labor (manufacturing) productivity increase in Eastern FMS in only about 70% of the value in Western countries and the biggest difference is in unit costs (25% of the Western value).

In the group of <u>capital saving</u> almost all indicators have very similar average values. The difference is not greater than

Table 3

Average Values Indicators of Economic Benefits - East-West Comparison

VARIABLE	W	E
Labor Savings		
- personnel number reduction	63%	ND
- labor (manufactuirng) productivity increase	320%	230%
- maximum continuous unmanned time	17 h	
- unproductive time fraction	forecast: 75%	
- labor costs (labor saving)	57%	63%
- total production costs	26%	
- unit costs	40%	10%
- machines/per operator/per shift	1.8 pieces	
- automation of assembly operations	80%	
- operating rate (shifts, hours/per day)	20.3 h	20.5 h
Capital Savings		
- number of machine tools	54%	56%
- machine tools utilization	61%	57%
- floor space, factory area, land reduction	54%	E 50%
- operation number per part	6%	
- inventory and W-I-P	50%	
- raw material savings	30%	
- total gross output (turnover)	400%	375%
- pay-back time	3 years	E 2.2 y
- number of machining processes	58%	
- reduction of tools	56%	
- capital investment	+10%	
- production capacity	123%	
- in-process time	64%	
- manufacturing time	77%	
- machining time	50%	
- throughput time	60%	80%
Flexibility Increase		
- set-up time	90%	
- delivery time	60%	
- tendering time	85%	
- cycle time	80%	
- new product lead time	96%	E 40%
- product variety (product family range)	157	45
- batch size	95	1450
Quality Increase		
- reduction of customer claims	n.a.	n.a.
- reject fraction	n.a.	n.a.
- tolerance	n.a.	n.a.

10%. Higher differences can only be observed in pay-back time (however, the Eastern value of 2.2 years is only an estimation) and in throughput time (the Western value amounts to 75% of the Eastern value).

The biggest differences can be seen in the group of flexibility increase. The Western values are much higher (higher flexibility) than the Eastern average values. The biggest difference is in batch size, where the Eastern value is over 1500 percent higher (reversed relation!). The Eastern indicator of product variety is only 28 percent of the Western indicator and the Eastern reduction of new product lead time as a result of FMS adoption is 40% compared with 96% of the Western value.

From above-mentioned results we can conclude that the main differences are in the group of flexibility variables, both in product flexibility and production flexibility. In production flexibility the difference is more distinctive (batch size, product variety) and these results illustrate very convincingly that the Western FMS are far more flexible than the Eastern FMS.

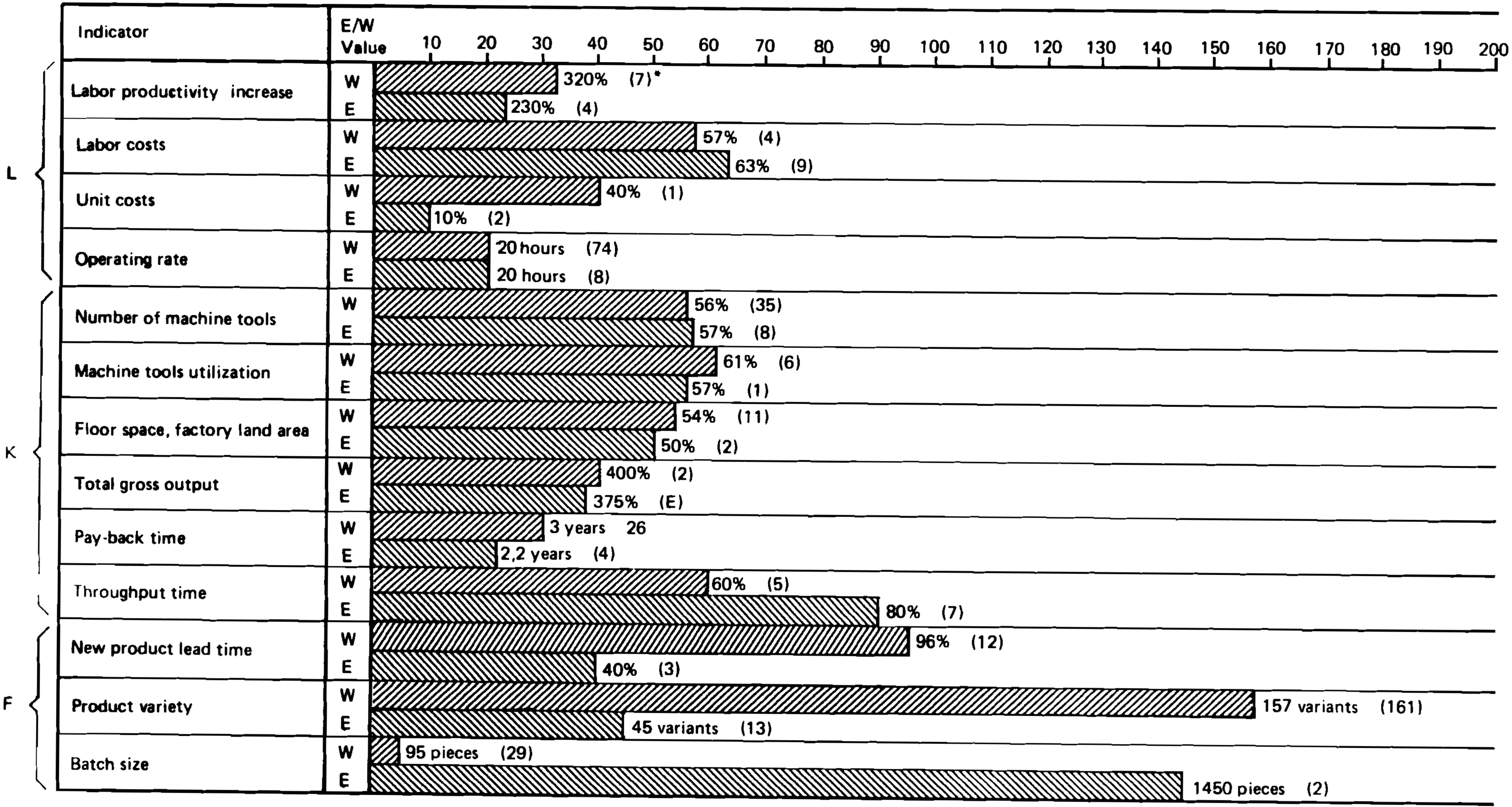
The main reason is probably the lower push of market conditions and competition and, on the other hand, strict long-term targets in the centrally planned economies, which can not fit the real short-term consumer needs. One of the main goals of economic reforms in all Eastern countries nowadays is to increase the speed of response of suppliers to consumer needs.

The graphical survey of the similarities and differences in indicators of benefits in East and West is given in Table 4.

On the basis of the results of the above-mentioned analysis and from other literature sources and discussions with specialists we can infer the desirable preconditions for the

Table 4

E/W COMPARISON



*Figures in brackets mean the frequency of indicator, E = estimation.

adoption of FMS, the deteminants or conditions which guarantee the successful implementation, and the implications of this particular adoption. The result is the so-called _Descriptive Model of Adoption_, as shown in Table 5. This model has to be taken as an open system, which will be completed and made more precise, in accordance with the growth of our knowledge, the extension of our data base, and the increasing quality of our data as well as the increasing experiences with the adoption and practical application of FMS.

Table 5

Descriptive Model of Adoption of FMS
Description of Preconditions, Determinants, Consequences

PREREQUISITES	CONDITIONS	CONSEQUENCES
- discrete production - high part varity, different products (product variety) - low production volumes, piece and small batch size production - frequent product change requirements - quality improvement requirements - high labor costs - lack of skilled workers in metal-cutting, forming, etc. - hard work - dangerous work - monotonous work - skilled workers for programming - high quantity of work in progress - good financial position for investment - good conditions for retraining of operators - skilled suppliers by automation devices - short and reliable delivery time of raw materials and almost 100% quality assurance - experience with NC-machines & computers - proper management background	- job rotation - remaining of designers of the FMS project after implementation - relations with suppliers become more continuous - reciprocal interdependence between designers and production engineers - maintenance becomes more complex and critical (shifts from mechanical to electrical maintenance and programming) - group technology layout (instead of process type layout) - build small teams of highly competent engineering-oriented people with line responsibility for day-to-day operations - operators involved in design process and taking part in design team - build quality circles - training, retraining of operators & engineers	- capacity augmentation - productivity increase - labour saving - capital saving - quality increase - flexibility increase - reduction of monotonous, hard, and dangerous work places - increase of educational level of workers - changes in occupation figures - changes in working and rest system (flexible working hours, periodical rest) - changes in reward system - changes in work content - integration of jobs, functions and processes - Decentralization of information and responsibility - Simplification of product structures and handling operations - external logistics changes (e.g. inventory values reduction at supplier and customer, less subcontractors, new division of tasks in the logistics chain, etc.)

CONCLUSIONS

Despite of the data base gathered from literature sources and the above-mentioned results, we face a lack of data for a statistically significant comparison between East and West, which is mainly due to the shortage of Eastern data.

Moreover, we see that the data describing the other sides of the impacts of FMS, such as social, managerial aspects and logistics, are very scarce. In the literature we find very interesting, but usually unique indicators, whose analysis and comparison would be of great value for decision makers and strategic management with regard to the adoption of FMS, because the explanatory power of the indicators is very high.

We have to concede that our conclusions drawn from the insufficient data base are as yet reasoned conjectures rather than well researched subjects. However, this seems to be a promising area of study. For that reason we started to create list of indicators for these particular areas (see Table 6 containing social indicators, Table 7 managerial and Table 8 logistics indicators).

Our task is now to gather a richer data base, permitting a meaningful comparison such as the comparison of FMS in East and West, large - small countries, different industries, large-medium - small companies, including all prerequisites, conditions and consequences. From this point of view it seems that the way to arrive at more convicing results is to conduct in-depth case studies by means of questionnaires, interviews, expert assessments and personal contacts with the people from the companies having adopted FMS. The underlying assumption is to create a network of collaborative organizations, starting with a

Table 6

Social Indicators

1. Skilled/unskilled workers ratio (unskilled worker has no special education or training).
2. College-educated engineers/production workers ratio.
3. Direct/indirect labor ratio (direct labor means immediate system-machine operators, other machine personnel).
4. Length of the training, retraining for operators and for engineers.
5. Specification of training methods (without interrupting the work, interrupting the work, in-house training, outside company in special training organization, other specification of:
   contents of training courses, schedule of subjects, division of teaching time, theory and practical training ratio, etc.).
6. Training/retraining costs per operator and engineer.
7. Non-adaptable workers (engineers) ratio, their average age (separately number of workers - engineers rejecting to be retrained and main reasons).
8. Change of the number of employees in different occupations (if possible, with using ISCO classification).
9. Hard-work places (number).
10. Monotonous work places (number).
11. Dangerous work places (number).
12. Flexible working hours (kind and number, percentage of personnel).
13. Periodical rest for employees (e.g. sabbaticals, other).
14. Improvements in system after implementation as a result of initiative of workers, material supplier and customer involvement (kind, figure).
15. Changes in work content (simple or qualified labor, limited or large task content, many or few interfaces).
16. Manpower turnover ratio (fluctuation).
17. Sick leave ratio.
18. Reward system.
19. Operation rate (number of shifts per day) and total of man-working hours per week.
20. What are the basic problems to integrate manpower with the system.

Table 7

Managerial Indicators

1. Number of hierarchical levels.

2. Small teams' work number (organized around product, process and procedures), number of workers in small self-managed teams.

3. Job rotation (number of rotated places).

4. Quality circles (number, area).

5. Are the designers continuously working with the system after implementation, how and how long.

6. Organization of maintenance (mechanical to electrical maintenance ratio).

7. Responsibility for initial design and realization of system (name of department and its organization chart).

8. Integration of jobs, functions and processes (reduce the number of interfaces, wasted organizational effort, lead times, cut overhead costs, etc.).

9. Decentralization of information and responsibility (small and fast control loops, delegate management tasks, employees' involvement, separation of man and machine in production, etc.).

10. Simplification of product structures and handling operations (simplify/modularize structures of products and processes, containerization of material, etc.).

11. Role of top management in system adoption (direct, indirect participation, what organizational forms).

12. Organization of project implementation (system realized mainly by in-house design team, system vendor, consultant company, customer, supplier, other).

13. Operators involved in design process and taking part in design team.

14. Process-planning time for daily production (man/hours).

Table 8

Logistics Indicators
(External Logistics for the Plant where FMS is Installed)

1. Just-in-Time scheme (% value).
2. Electronic Data Interchange of Orders (computer to computer - % value).
3. Average order cycle time (tendering + delivery).
4. Service level (% order value supplied/delivered within stated delivery time).
5. Custom orders (% order value produced directly to orders).
6. Total shipment ton per year.
7. Average shipment size.
8. Utilization of ISO container, palletized, other.
9. Average length of handling: routing through wholesaler, field warehouse, direct from supply or to customer (% ton).
10. Number of suppliers/customers.
11. Average distance to supplier/customer.
12. Percentage of the purchase of materials and supply and sale of finished products by domestic dealers/consumers and other countries or group of countries (e.g. CMEA, EEC, USA and Canada, Japan, etc.).
13. Stock value (replacement cost or current prices).
14. Warehousing cost.
15. Transport cost, percentage of rail, hired truck, own truck, by sea, air, etc.

pilot study (the comparative analysis of two countries, one from the East, one from the West). In our case it is suggested to start with the comparative analysis of Finland-Czechoslovakia, and, as a second step, to extend the number of countries. The subject of the proposed study is a limited number of operating FMS in Finland and of almost the same number in Czechoslovakia. The main objective is to test the possibility of collecting data in this way. Moreover, the goal is to restructure the suggested list of indicators, excluding data not avialable and, on the other hand, to add new indicators.

We do not intend to estimate only real data. In the first period after the adoption of advanced technologies we are usually faced with the fact that the reliability of the input data is not highly verified or that real data are not even available. In such a case we suggest to reduce uncertainties by relying on expert assessment. Expert analysis of advanced technologies is one of the ways to obtain missing data for forecasting the impacts of new technologies.

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