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Flexible Manufacturing Systems (FMS) - Diffusion and Advantages (Part 1)

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FLEXIBLE MANUFACTURING SYSTEMS (FMS)
DIFFUSION AND ADVANTAGES
(Part I)

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FOREWORD

IIASA and VNIISI, Moscow, have made a one-year cooperative effort to prepare a statistical data bank in order to analyze flexible manufacturing systems in the world. For the time being the IIASA CIM data bank consists of 400 systems in the world and their detailed technical and economic description. This is about 60-70% of the world stock of FMS -- estimated to be 500-600 last year.

This is the first of three papers describing the analysis made from the data bank. It presents diffusion trends and basic economic advantages gained by the implementation of systems. It includes new structural data and gives a detailed insight into many impacts; it also proves some hypotheses as well as reveals a completely new type of hypothesis.

Prof. Jukka Ranta
Project Leader
Computer Integrated Manufacturing

1. INTRODUCTION

The preliminary analysis of FMS installations throughout the world, published by the authors [29], was based on the ECE statistical data publication [28] with some corrections and revisions according to [10]. It includes 227 FMS, mainly in the USA, in Japan and in some European countries with market economies. The last year of the observations was 1985.

During this year we have collected some additional information from national and international publications [2, 3, 25, 26, 34, 35], special experts' estimates, prepared within the collaboration with IIASA's Computer Integrated Manufacturing (CIM) Project [9, 17, 27], as well as information from occasional publications with descriptions of some specific systems [1, 15].

As a result, our FMS data base includes more than 400 cases, but only 394 are under consideration, because there are no appropriate data on the other cases, except for their names or identification (user, vendor, country). Unfortunately, we practically do not have any adequate detailed information from the USSR (only several cases), Hungary and the NIC. We also suspect that in some cases a duplication takes place due to the use of different sources with unsatisfactory identification. For example, in spite of the exclusion of FMC from consideration, possibly some of them might be mentioned among the British or French cases.

Now we have almost complete information up to 1985 and approximately 50% of the data for 1986 and 1987.[1] The collected data bank for FMS is now the biggest in the world and consists of much more cases than [5, 7, 10, 12, 16, 20, 28] and other international collections.

It is true that the increase of the number of cases was accompanied by a rather restricted spectrum of the factors. For the purpose of a further analysis we concentrated mainly on economic features of the systems, but not on technical features.

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[1]The estimated number of FMS in use is between 350 [28] and 550 [4] for the year 1985. According to our latest estimates these were about 500 FMS installed in the world by the end of 1986.

2. DATA BANK DESCRIPTION

As we originally based our work on the FMS data base published in [28], we had to use the same variables (or factors) in adding new information. This is why we followed the original bank structure with some modifications. The following data were collected for each FMS.

I. System Identification:

1. "Country" - name of country where FMS is allocated.
2. "Company" - name of user.
3. "Vendor" - name of main producer.
4. "Year" - year of installation.

II. Application:

5. "Industry" - industry of application (1 - final metal products + non-electrical machinery + transportation equipment; 2 - electrical machinery and electronics + instruments).
6. "Applic" - application area (machining, assembling, manufacturing, metal forming)

III. Technical Complexity:

7. "MC" - number of machining centers.
8. "NCMT" - total number of numerically controlled machine tools (including MC).
9. "Robots" - number of robots (excluding transportation robots and manipulators).
10. "Trans" - type of transportation system (1 - conventional conveyor or crane; 2 - automated guided vehicles or computer-controlled carts).
11. "Storage" - type of storage system (1 - automated storage and retrieval system; 2 - computer-controlled warehousing system).
12. "Inspec" - type of inspection (1 - manual or automated measuring and final inspection; 2 - automated maintenance and monitoring system).

IV. Economic and Operation Data:

13. "Oprate" - operation rate (number of shifts a day).
14. "Unmanop" - number of shifts of unmanned operation.
15. "Bsize" - batch size (maximum weighted average).
16. "Prodvar" - product variation or part family (number of products produced by FMS).
17. "$ Invest" - investment cost in million US $ (converted according to the exchange rate for the year of installation).
18. "PB time" - pay-back time (years).

V. Relative Advantages:

Reduction of, by a factor of:

19. "Leadt" - lead time.
20. "SUT" - set-up time.
21. "IPT" - in-process time.
22. "WIP" - Work-in-progress.
23. "Mtime" - machining time.
24. "Invent" - inventory.
25. "Pers" - personnel.
26. "Flsp" - floor space.

Increase in, by a factor of:

27. "Product" - productivity.
28. "Prodcap" - production capacity, or capacity utilization rate.

Of course, complete data on all variables do not exist in all the cases. For example, there are a lot of empty spaces in the columns of "relative advantages". Nevertheless, a high enough quantity of such data was collected to use statistical approaches for their analysis.

3. FIRST ADOPTERS AND FURTHER DIFFUSION

The first case of a FMS installation, registered in our data bank, was the Sundstrand Aviation (Rockford) system, installed in 1965[2] [28] for pump parts and aircraft speed drive housing

[2]An alternative estimate is 1967 [10].

production. In 1969/1970 another US company, Ingersoll Rand, installed its first FMS, and the Heildelberger Druckmaschinenfabrik did the same for printing press precision parts production.

Before 1976 eight Japanese companies (Fuji Xerox - 1972, Hitachi Seiki - 1972, Toyoda - 1972, Yammer Diesel - 1972, Toyota - 1973, Yamatake Honeywell - 1974, Fanuc - 1974, Kawasaki Heavy Industry - 1975) had installed FMS mainly for car engine and machine tool parts production. There were four US first adopters, which used FMS mainly for cast iron truck/tractor parts production. Among the Eastern countries the GDR was one of the first adopters, according to the rather limited information we have got in the data bank. The FMS installed in 1972-1973 (7 October, Fritz Hekert, Herman Mateen and Werkzeugmaschinen-kombinat) were used for machine tool parts production.

A wider diffusion of FMS began after the 1974-1975 recession in Western countries and the annual number of installations was growing up to 60 in 1985 (see Figure 1). The incomplete preliminary data for 1987 do not demonstrate a change in this tendency, because the coverage of the inventory for these years does not exceed 50% of real installations.

The geographical distribution of FMS, installed up to 1987, is demonstrated in Figure 2. The main users of this technology are the USA and Japan. In reality there are more FMS installed in the Japanese industry than in the US industry, but in our data bank not all Japanese cases are represented (73 systems). We also think that more British cases are taken into consideration than actually exist. This is due to the use of several different sources, sometimes without clear system identification. Some companies provided data without their names or vendors. This is why the share of the UK is considered to be overestimated.

Generally speaking, it is possible to define a group of main FMS users (approximately 50-100 FMS installed).

There is Japan, the USA, the USSR (not shown in the bank), the UK, the FRG and France in this group. The second group includes countries with approximately 10-20 FMS in use: the CSSR, Finland, the GDR, Italy, Sweden. Finally, there are several newcomers -- countries which adopted FMS for the first time at the beginning of the 1980's.

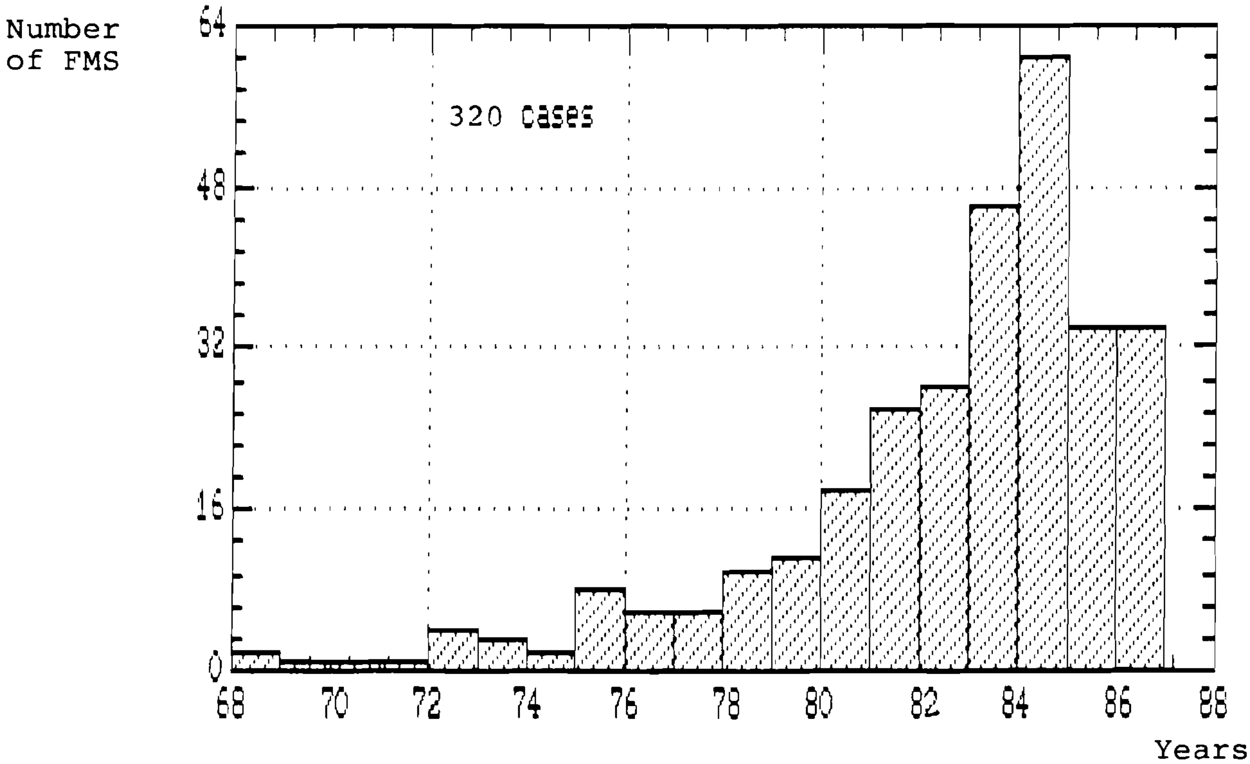


Figure 1. Number of FMS installations over time

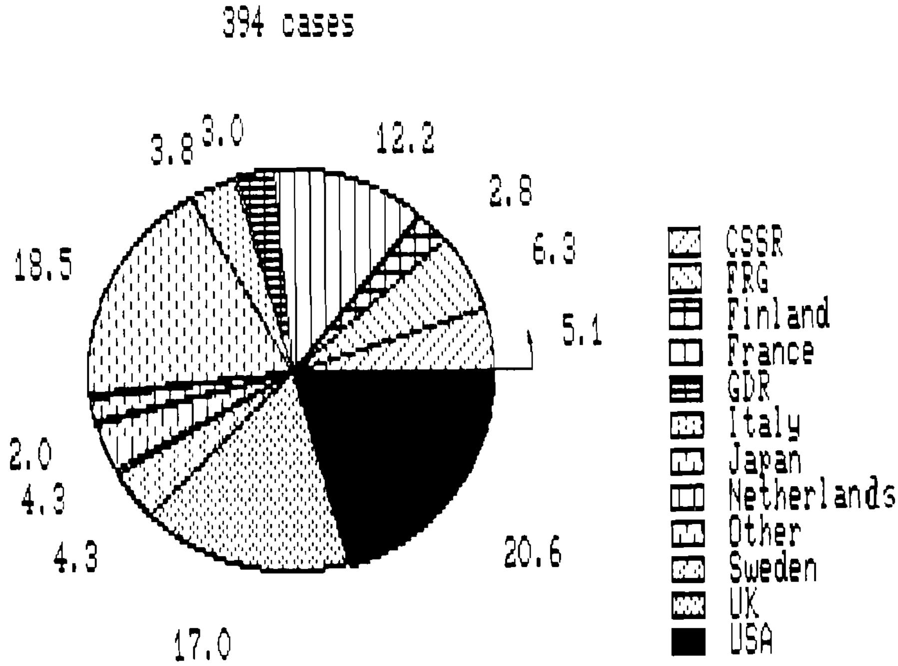


Figure 2. Percentage distribution of FMS installed by countries.

4. APPLICATION

As in the cases of the first adopters, the majority of FMS in the world are used in a few metalworking industries: transportation equipment, non-electrical and electrical machinery. Among the approximately 300 FMS identified according to 3-digit industries of application, 50% were used in transportation equipment production, mainly for iron cast parts such as cylinder blocks, differential and gear boxes, as well as for steel parts (valves, crank shafts).

The second main user in this industry is the high-tech aerospace industry where FMS are used for precision production of rotational and prismatic parts (fixtures, control systems, jet parts). There are also several FMS in locomotive production and ship building.

Another FMS user is non-electrical machinery where 30% of the systems are allocated. They are used for machine-tools production (rotational parts and cast iron boxes), agricultural and construction machinery, etc.

The specific features of FMS use in these two 3-digit industries are as follows:

- rather big cast iron, steel, aluminum parts with rotation or prismatic forms;
- many surfaces to be developed;
- limited product variation (flexibility);
- limited batch size;
- high precision in some cases.

The third 3-digit industry, electrical machinery (including electronics) owns 15% of the FMS installed. They are mainly used in electronics: electronic components, fixtures for electronic goods production, consumer electronics.

There are some exceptions to the use of FMS in this industry. These FMS are applied for electrical machine parts production, such as rotors, fixtures, etc. These systems are similar to the ones used in non-electrical machinery, but their share in the total number of FMS in the industry is very low.

Finally, 6% of all FMS are used in the precision instruments industry. The main fields of their application are electrical control devices, optics, etc.

There are some common features of the use of FMS in these two industries, namely:

- micro and mini-parts;
- high accuracy of assembling;
- high precision of electronic components;
- big batch size;
- high flexibility.

Though such a division is conditional (sometimes FMS are used for precision mini-parts production in non-electrical machinery, and vice versa, or big rotors and other rotational parts for electrical machines are produced by FMS in electrical machinery) we have, for further analysis, clustered all FMS described in our data bank into two parts: heavy machinery (non-electrical machinery and transportation equipment) and precision production (electrical machinery and electronics as well as instruments).

Among the 375 identified cases, 83% were defined as FMS for machining, 12% for manufacturing, only 5% for assembling, and less than 1% for metal forming.

5. TECHNICAL COMPLEXITY

The technical production complexity of a FMS can be described by a number of machining centers (MC) or a total number of NC-machine tools (NCMT) and by a number of robots used in the system. The complexity, connected with transportation / communication within an FMS, storage, quality control / inspection depends on the types of the respective systems.

Normally a FMS includes one or more multi-functional MC. A most typical configuration (see Figure 3) has 2-4 centers. It applies to 56% of the 272 systems with MC. Another group of FMS has 5-8 machining centers each. Its share is 28%. One can observe that there are 28 systems with more than 8 MC, and only 15 systems have one center supplemented by other NC-machines.

Such systems, as, e.g. Mazda (1987), Fanuc (1981) and Yamazaki (1983) (all in Japan) include 21, 23 and 27 machining centers, respectively. The technically most complicated FMS for car engine assembling, installed by Fiat Auto in Termoli,

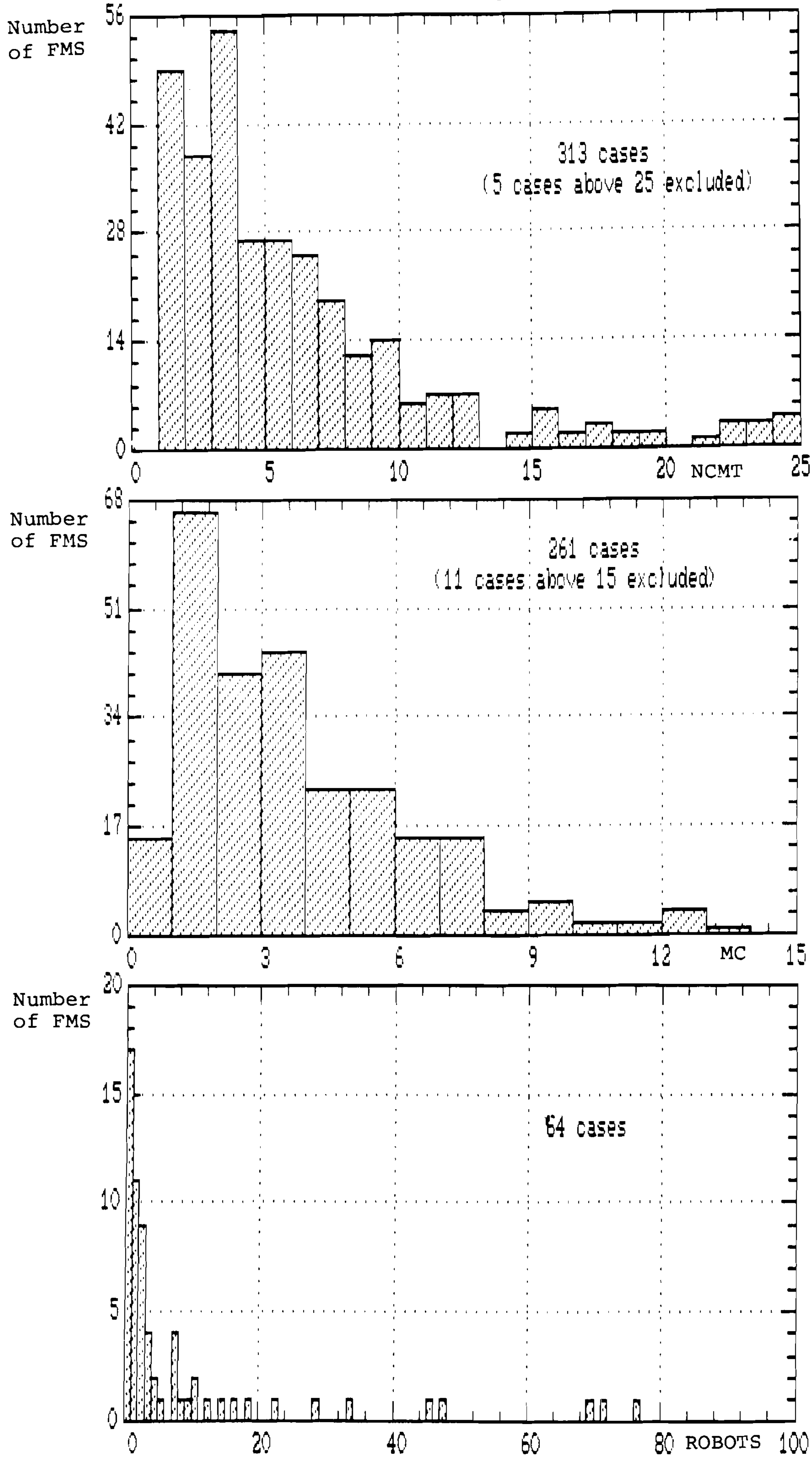


Figure 3. Distribution of FMS by their technical complexity. Number of FMS over numerically controlled machine tools (NCMT), machining centers (MC), and robots, respectively.

includes 72 automatic stations for complete cylinder-block assembly.

Some FMS are based on MC use only, but in other cases the centers which usually substitute for drilling, milling and boring machines are accompanied by NC turning, grinding and other machines. The distribution of the FMS by the total number of NC machine tools (including MC) is shown in Figure 3.

The first group (41% of the total) includes rather primitive systems with 2-4 NCMT. The second group (40%) includes sophisticated FMS with 5-10 NC machine tools. The residual 19% represent very heterogenous systems with more NCMT, up to the case of 38 CNC-machines installed at the Yamazaki plant. Totally, five FMS (or 1.6%) use more than 25 NCMT.

According to the collected data the use of industrial robots (IR) was shown only in 64 cases and 17 FMS included 1 robot. Twenty systems use 2 or 3 industrial robots, four systems use 4 or 8 robots. There are several FMS with 13 and more IR. Three companies (Casio, Toshiba -- both in Japan --, and IBM in the USA) have FMS with 70, 72, 77 industrial robots, respectively. All of them are used for electronics production.

The main conclusion that can be drawn from these data is that the majority of FMS in use are relatively simple from the viewpoint of production-technical complexity.

Approximately 30% of the 181 FMS, where there is information on transportation systems, use a traditional conveyor or crane connection between the working places, NC-machines, production and storage areas. The other 70% have automated guided vehicles or computer-controlled carts.

Data on storage systems were reported only in 42 cases. 37 (or 82%) FMS used an automated storage and retrieval system and only in 5 cases a computer-controlled warehousing system was installed.

The same situation is encountered for information on inspection systems -- we could collect only 33 cases with such data. In 25 cases a manual or automated measuring and/or final inspection was reported. In 8 cases (4 of them were shown in Finnish FMS) there was an automated maintenance and monitoring system.

The data on these three supplemented systems show that only the transportation system is sufficiently developed, the storage and inspection systems are rarely sophisticated.

6. ECONOMIC AND OPERATION DATA

About one half of the cases on our data bank consists of information on the cost of a system, usually in national currencies. These data have been recalculated into US dollars according to the exchange rates of the years of installation. As shown in Figure 4, the FMS price does not exceed 50 million dollars, and the majority of the FMS (97%) cost less than 20 million dollars.

Looking at more detailed data, it will be found that 15% of the FMS cost 1 million dollars and less, 24% from 1 to 2 million, and 16% from 2 to 3 million dollars. This means that more than 50% FMS cost no more than 3 million dollars.

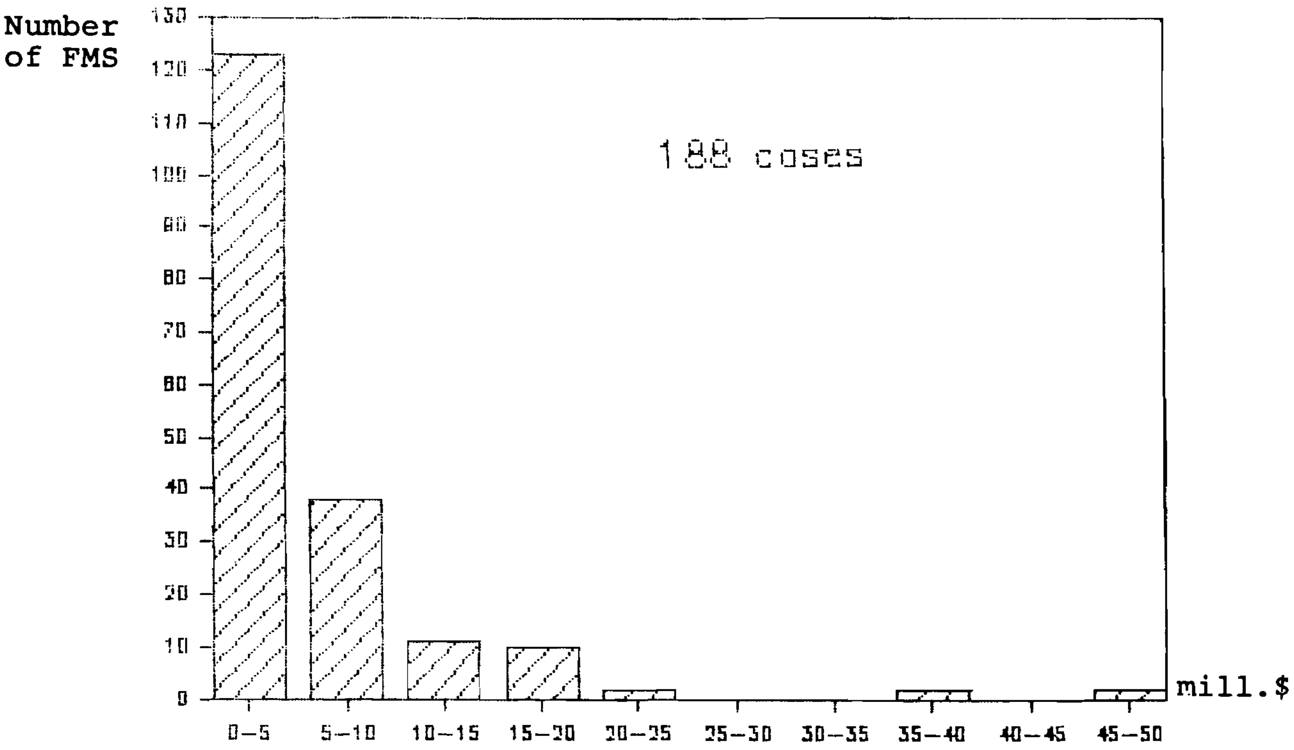
Among the observed cases one can find several FMS with very high investments. Approximately one tenth of the US systems cost 18-25 million dollars, the Messerschmidt FMS investment also reached 50 million and the total investments in the Italian FIAT automated assembly plant for the FIRE engine were about 300 million dollars.

The international comparison shows that European FMS are usually relatively cheap, especially in the Scandinavian and East European countries.

In spite of the high price of FMS in comparison with conventional equipment, the pay-back time was reported in 44 cases as relatively short (from 2 to 4 years in the majority of the cases). A seven-year peak appeared when a set of Czechoslovak data was taken into consideration (see Figure 5).

This distribution can be treated as close to normal, but we suspect that in reality the observed maximum of the normal distribution curve (4 years) may be slightly shifted. There are two reasons explaining this shift. The looser's propensity to report on their failures is very low, and, furthermore, the majority of the FMS have not yet passed through a pay-back period, and its advance estimation is not very reliable.

The FMS flexibility, illustrated in Figure 6, is expressed by a number of products produced by each system. In spite of a



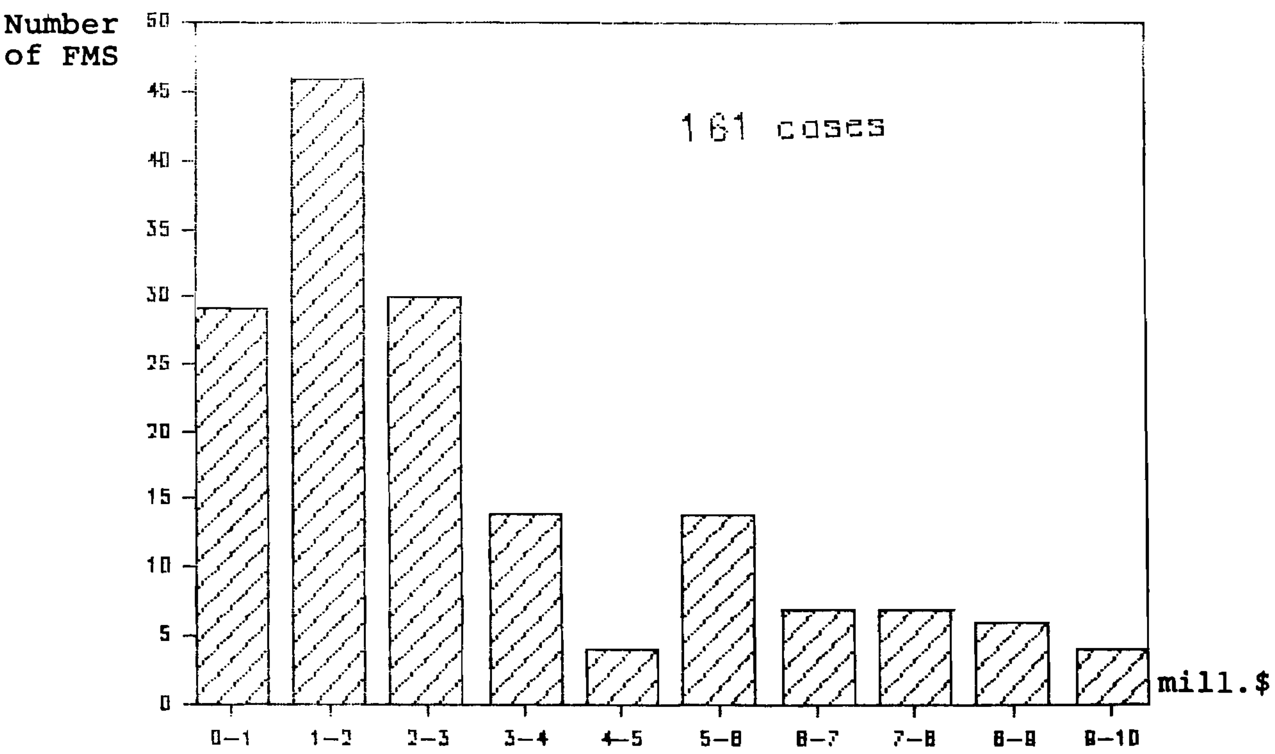


Figure 4. FMS distribution over investment cost.

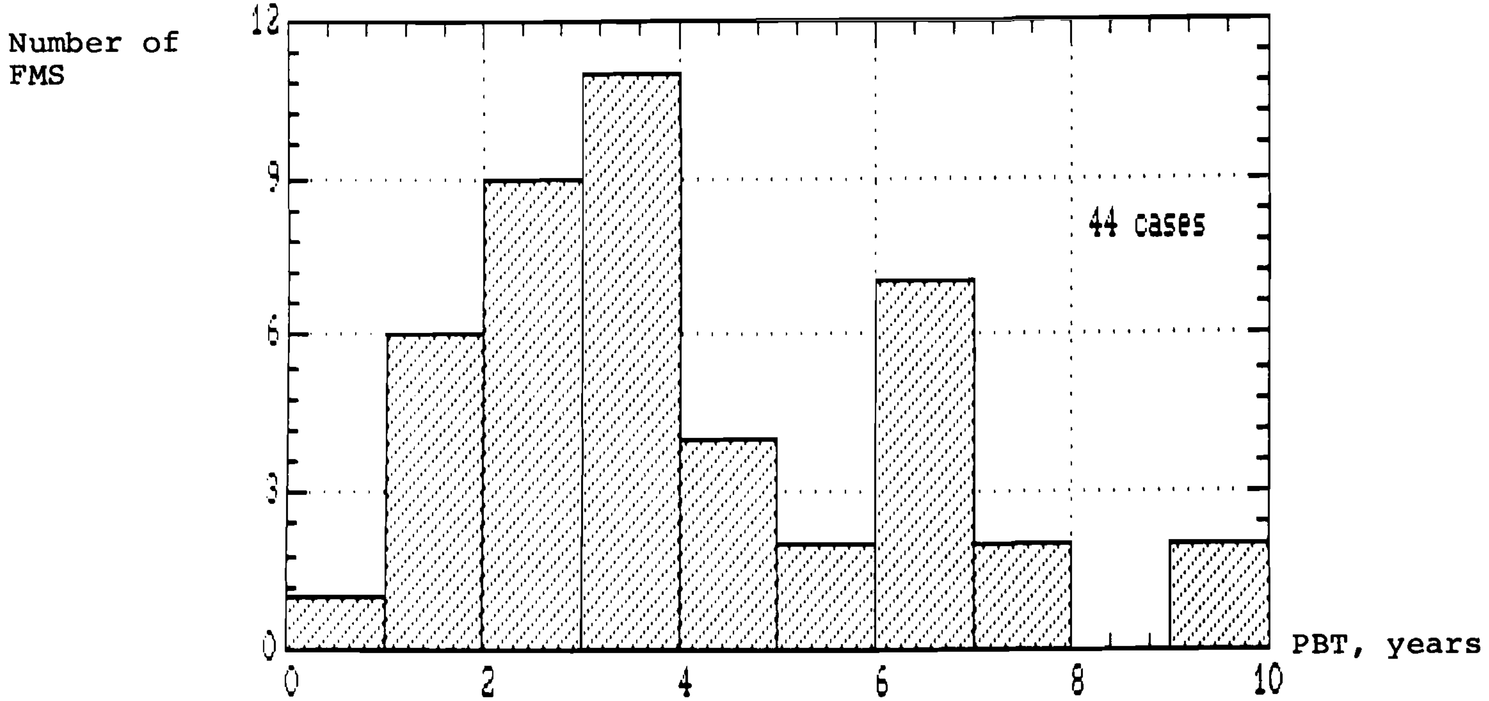
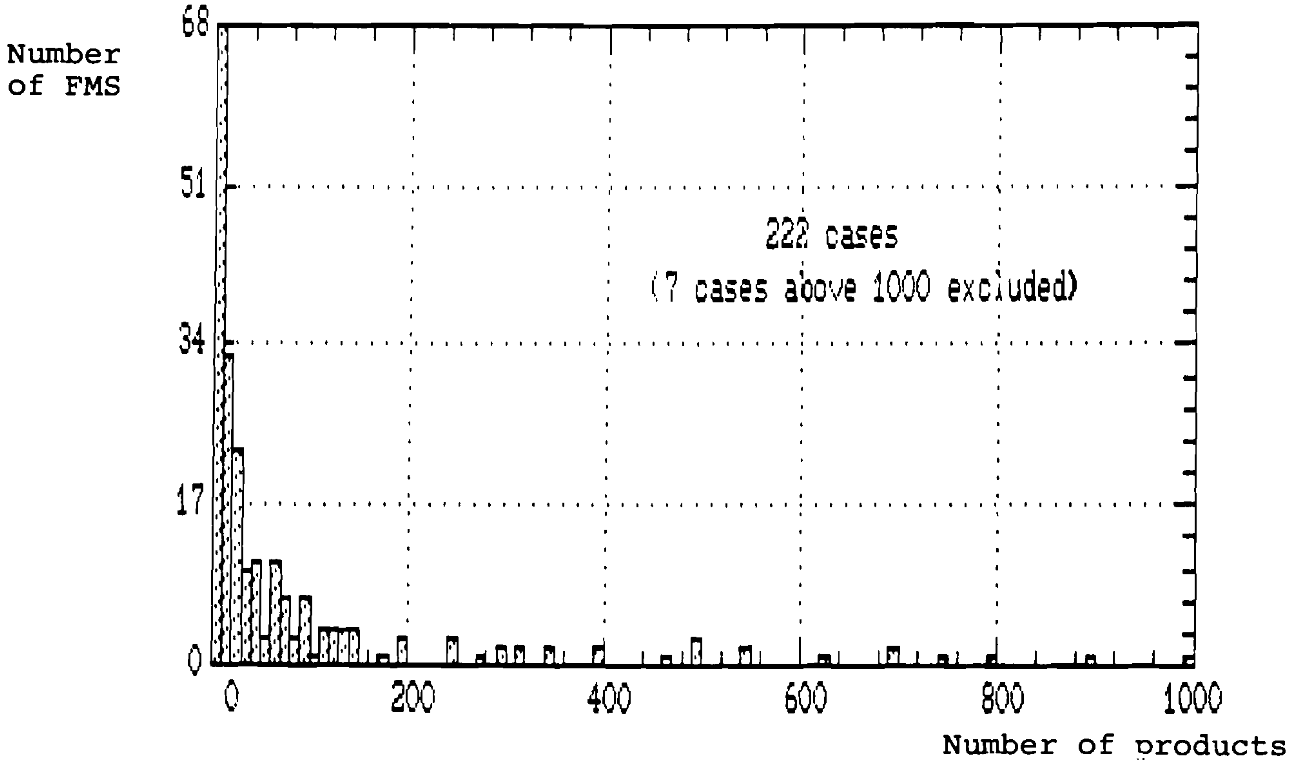


Figure 5. FMS distribution over pay-back time.



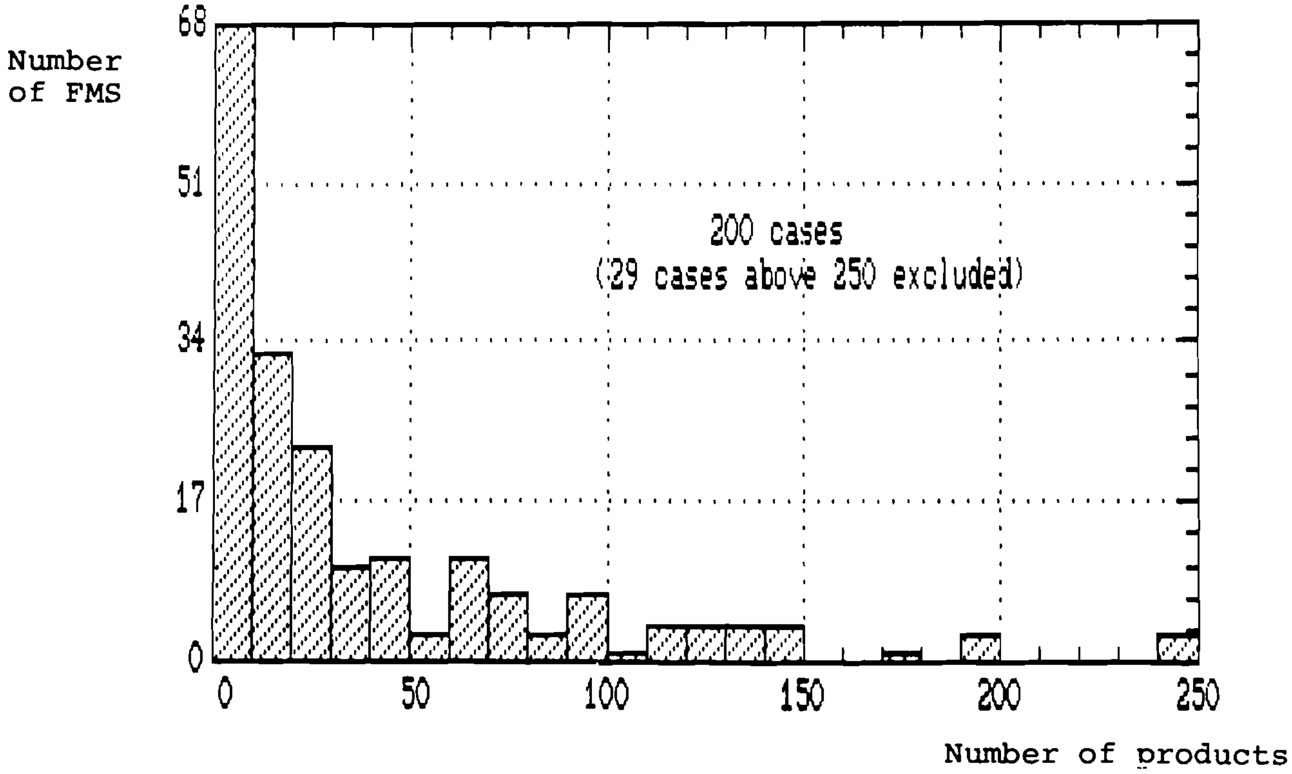


Figure 6. FMS flexiblity (FMS over number of products).

very wide spectrum of the data, the majority of the cases are within a concentrated, narrow area -- 30 products and less.

One third of the FMS produced no more than 10 products, in 14% of the cases they produced from 11 to 20, and in 10% from 21 to 30 products.

There are several highly flexible systems in the data bank. For example, the British Aerospace FMS produces 2000 variants of small aircraft structural parts by batches of 5 to 10 units each. One Toshiba FMS produces 3000 variants of switch boxes and another small components with 1-20 units a batch. Still another FMS of the same company has a flexibility of 4000 milling cutter bodies with batch sizes from 2 to 20.

The leaders in flexibility are two Czechoslovak systems producing 5000 variants of parts with a maximum batch size of 300, and 40 on the average in one case, and 2000 (maximum)/260 (average) in another.

The batch-size distribution (see Figure 7) shows that in the majority of the cases (60%) the size ranges from 1 to 50 parts in each batch. Nine FMS out of 89 cases produce 51-100 parts, six produce 101-299 parts, and eight produce 200-500 parts. Maximal batches for certain parts reach sometimes 5000 units and the average is 2000 units. Almost all of such cases were reported by Czechoslovak and GDR FMS. This does not mean mass production by nature, but production of rather simple parts.

As is shown in Figure 8, the operation rate of FMS is much higher than that of conventional equipment. More than 60% of them are in use during 3 shifts a day, and 5 or 6 days a week. Sunday shifts and sometimes 2 shifts on Saturdays are usually used for servicing. 11% of the systems work between 2 and 3 shifts a day (usually 2.5) and 22% during 2 shifts. The third shift is normally used for servicing or setting up of a system.

Only 6% of 115 FMS are used less than during 2 shifts a day (1-1.5), which means either unsatisfactory performance of such systems, a lack of demand for their products, or a low capacity utilization rate.

In spite of the very high average operation rate, only 44 cases with unmanned operation were reported. Among them 12 FMS could work automatically during 0.5, and 29 during 1 shift a day. Two systems operated without human interference during 2 shifts

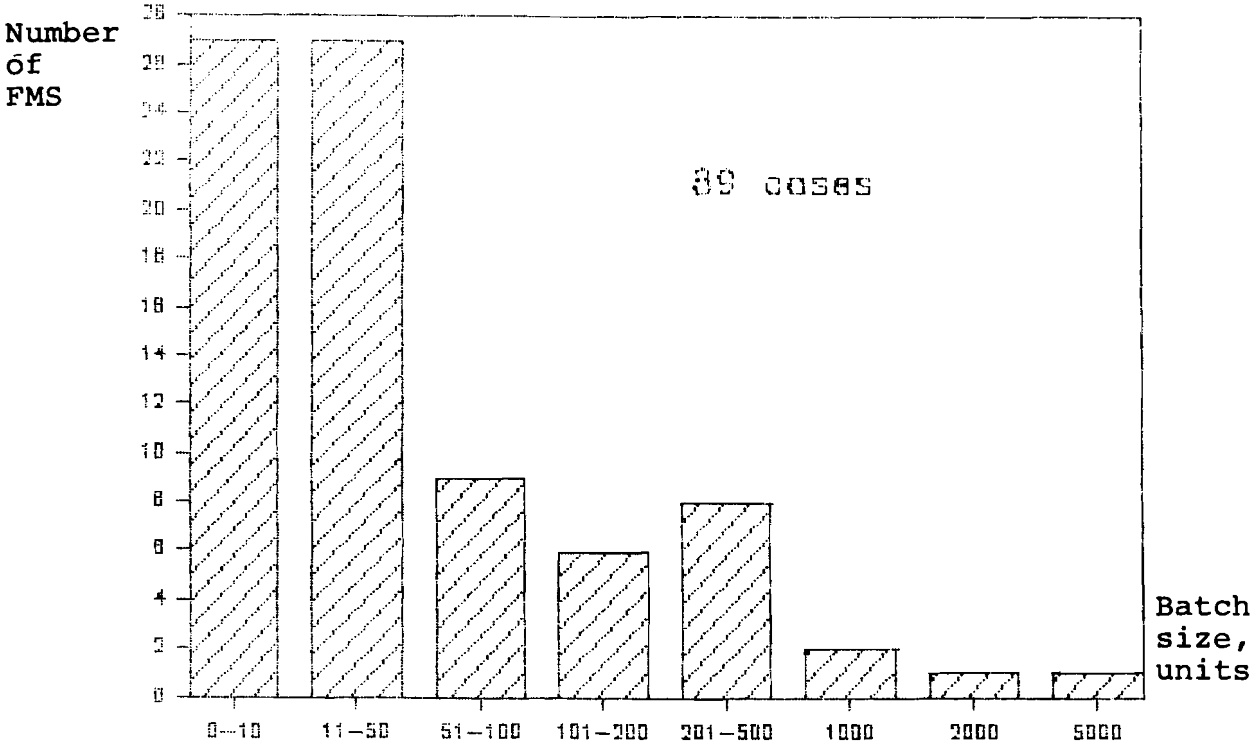


Figure 7. FMS distribution over batch size.

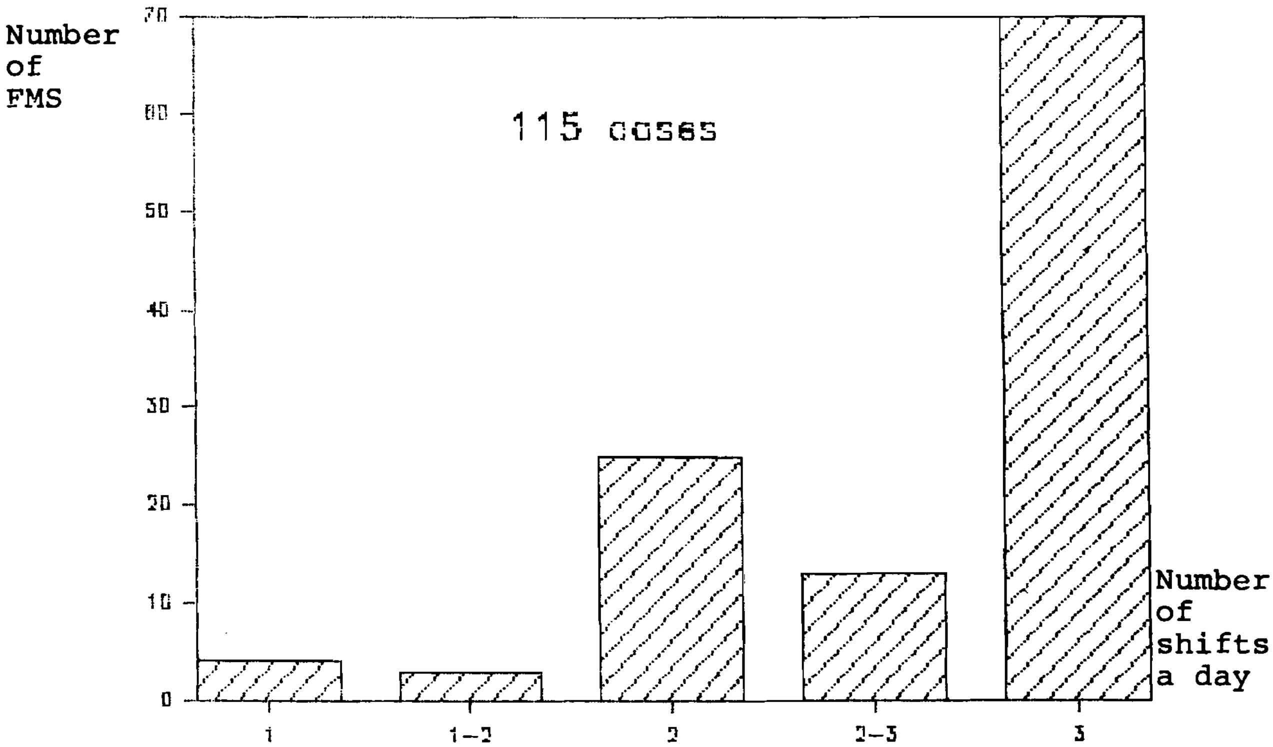


Figure 8. FMS distribution over operation rate.

and one (Niigata Internal Combustion Engine Plant) was used 21 hours a day in the unmanned regime (with a total operation rate of 3 shifts a day).

7. RELATIVE ADVANTAGES OF FMS

The total production time can be divided into several sub-periods, namely:

- set-up time, which is necessary for setting up equipment to prepare a system for a new part production;
- in-process time, which is spent for part production from a first operation up to final operation;
- machining time, in which equipment is used for the part production;
- lead time is the period from the order to the delivery to a customer.

Unfortunately a very limited number of data bank cases (26-45) consists of the information on time reduction, but the number is still sufficient to estimate the most typical reductions in comparison with conventional technologies. The set-up time reduction has been reported for 26 FMS, 19 of them were Czechoslovakian FMS (see Figure 9). In two Canadian cases there was no SUT reduction. One Japanese and one Dutch FMS reduced this time by a factor of 4, a US company reported a reduction by a factor of 6, and for the Remington FMS this reduction was shown to be 12. The most typical SUT decrease was between 1 and 2 (less than 50%).

In-process time (see Figure 10) was 50% and less in 20 FMS (two third of 33 reported cases) as compared to conventional technologies. Among these 20 FMS, fifteen systems are installed in the CSSR industry. Four FMS demonstrated a reduction equal to 2-3. The other cases show different results. The maximum cycle-time reduction (24) was reported for the General Electric FMS, manufacturing motor frames and gear boxes for locomotives. The machining time reduction was shown only in 26 cases (see Figure 11) and was not so high -- in 22 cases it did not exceed 1/3. For two FMS this reduction reached 2.5-2.7, and the Anderson Strathclyde FMS (UK), producing parts for mining machinery, demonstrated a machining time decrease by a factor of 10.

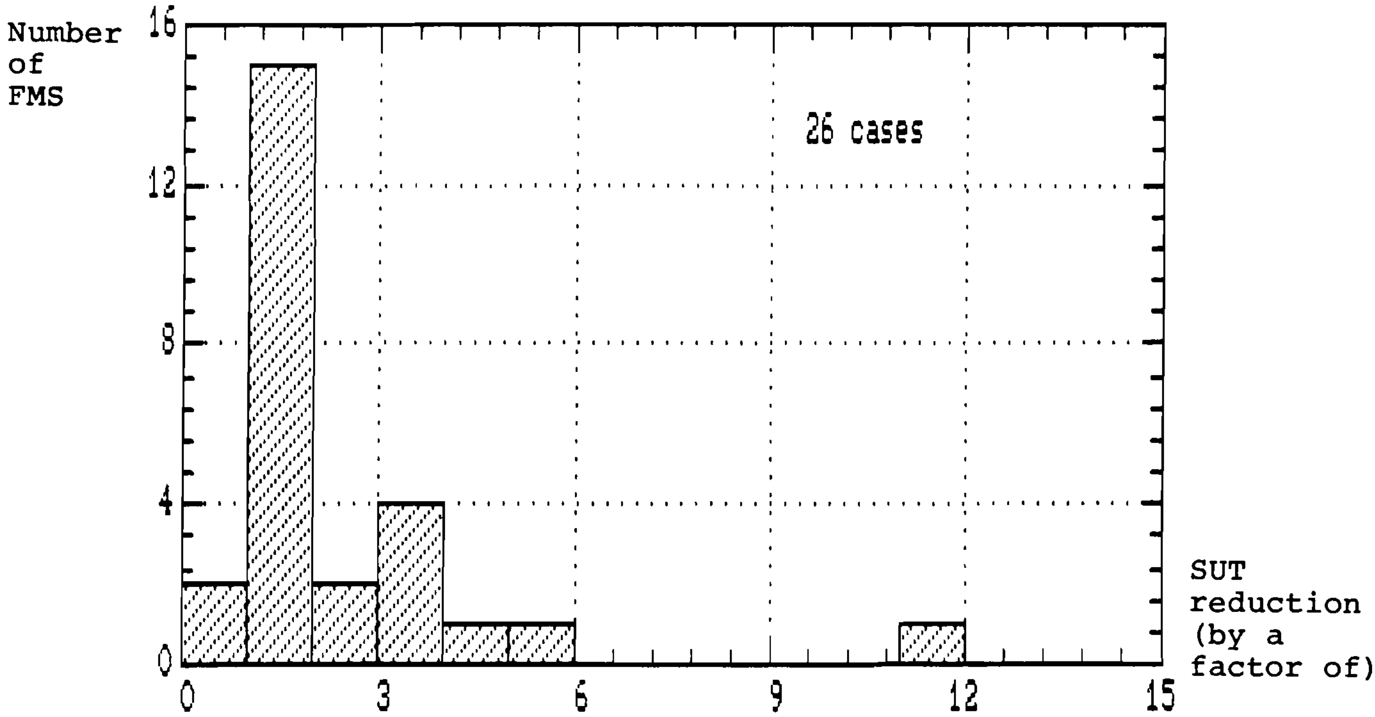


Figure 9. FMS distirubtion over set-up time reduction.

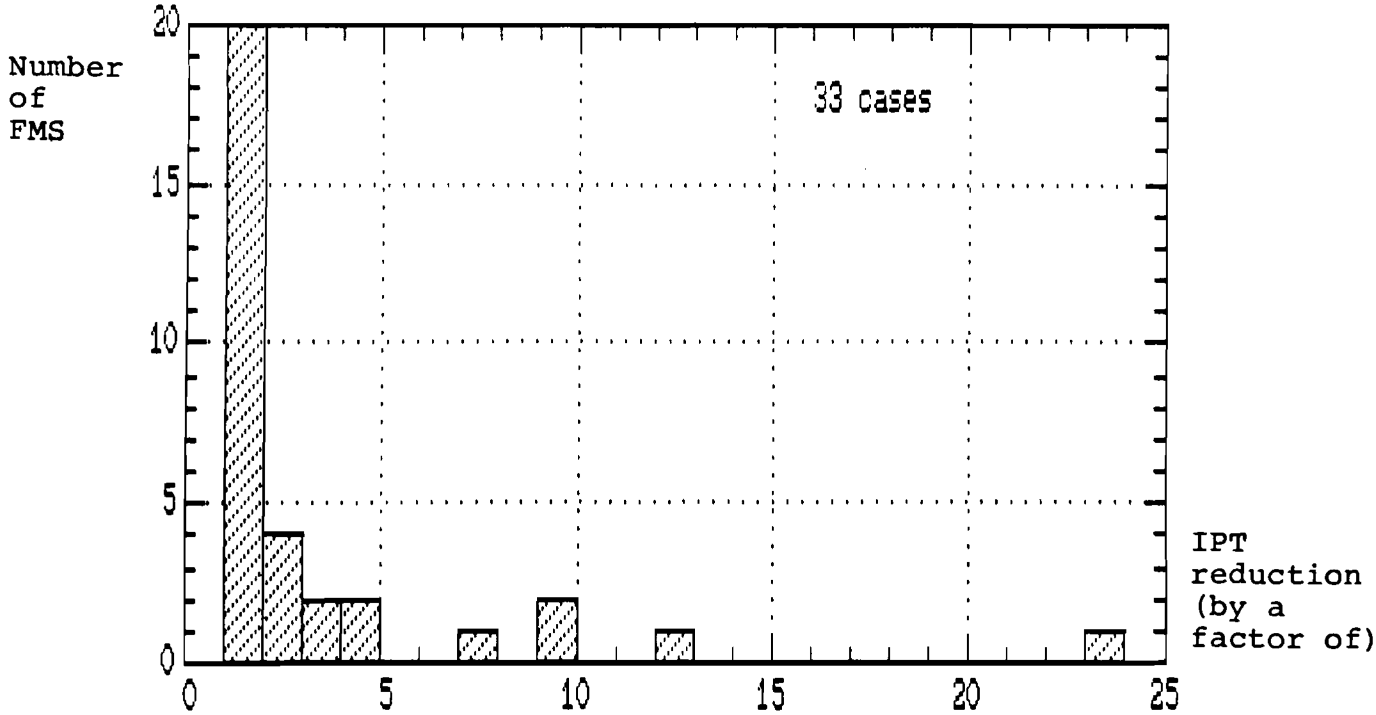


Figure 10. FMS distribution over in-process time reduction.

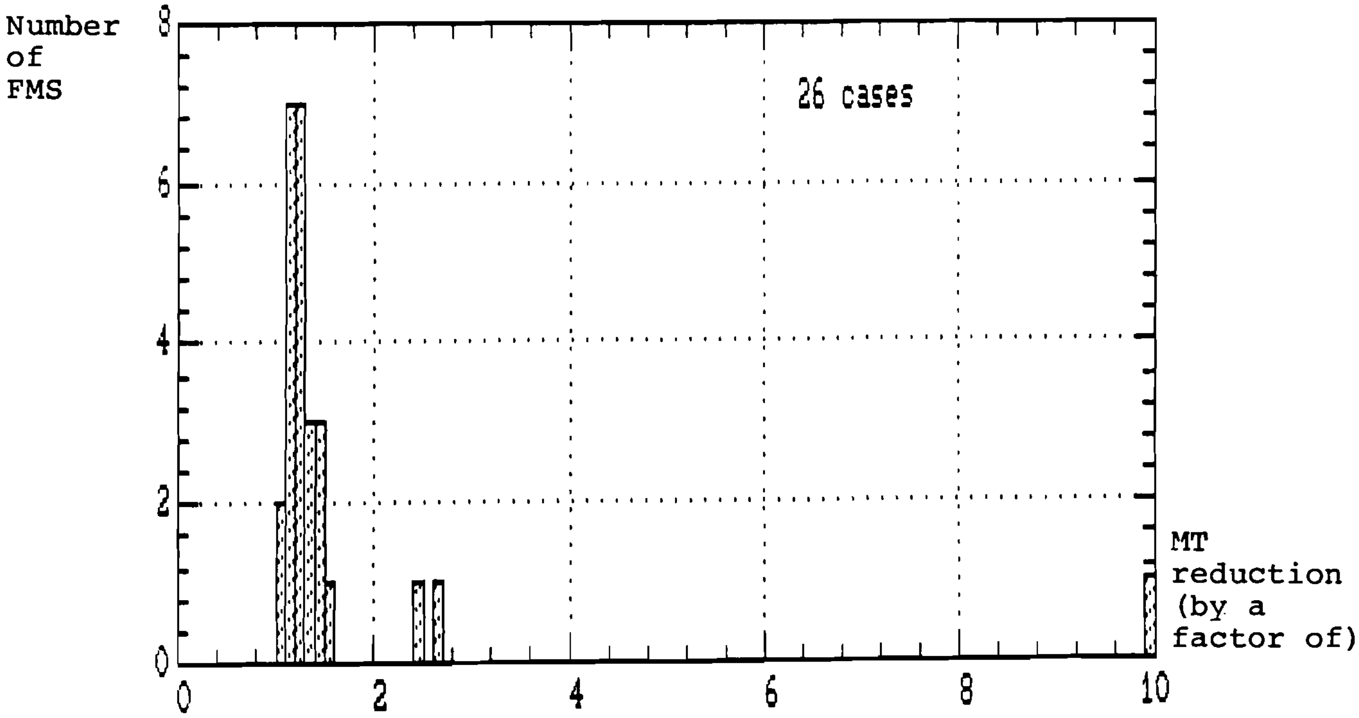


Figure 11. FMS distribution over machining time reduction.

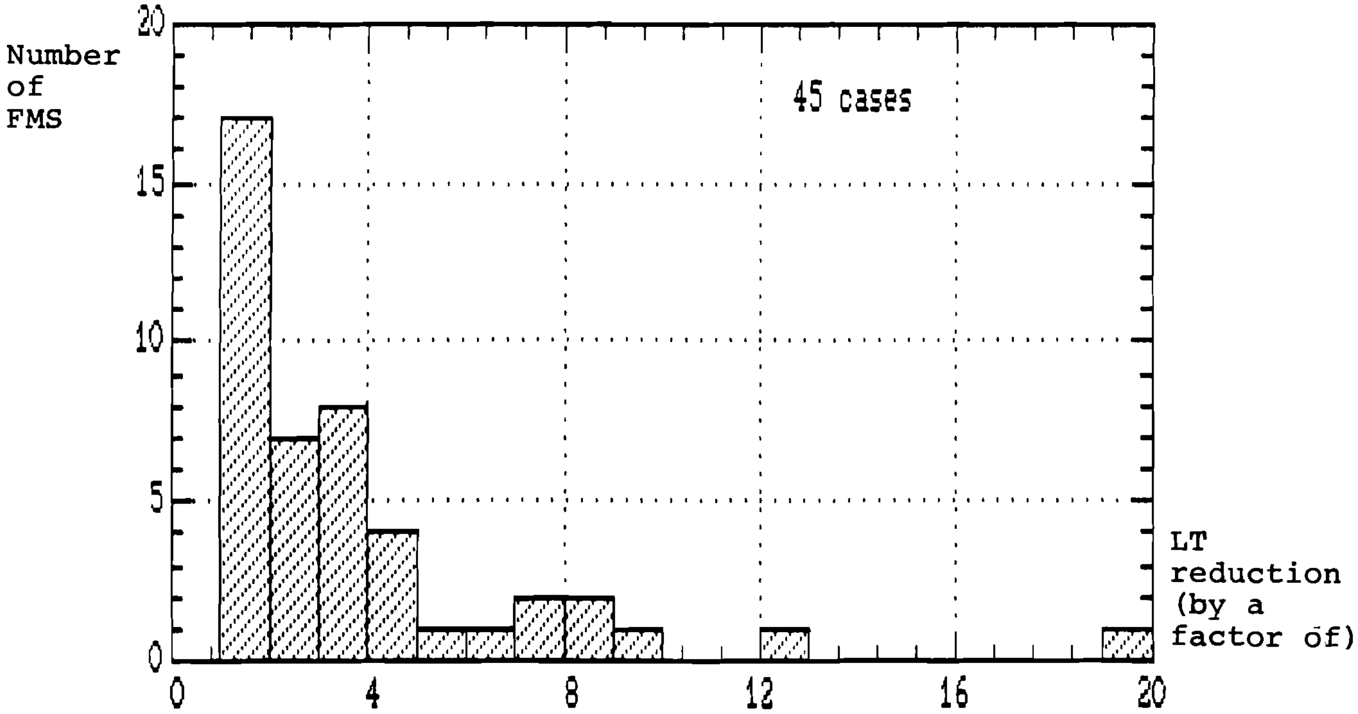


Figure 12. FMS distribution over lead time reduction.

In 45 cases we have collected data on lead-time reduction, which is one of the most important indicators of FMS flexibility. In 17 cases the LT decrease was 50% or less, among them 13 FMS belonged to the CSSR industry. The next 19 cases had a LT reduction by factors of 3-5 and there were several systems with a higher reduction (see Figure 12). The most exotic case was the Westinghouse sheet-metal FMS for punching, marking and shearing of panels, where the lead-time reduced from 2-3 weeks to 30 minutes.

The time reduction, when using an FMS, influences the logistic elements of production at a high rate. We analyzed two types of such elements -- work-in-progress and inventory changes, which, in their turn, play an important role in the total production cost formation.

Almost all cases of WIP reduction in our data bank were reported by three countries: the CSSR, Finland and the UK. But in the first group (see Figure 13), where the reduction did not exceed 50%, the Czechoslovak share was very high -- 12 out of 17 cases.

In 7 Finnish FMS the WIP was cut by a factor of 4 on the average, and Valmet's system recorded the maximum reduction by a factor of 10, which was also recorded in the case of the British FMS, installed by Victor Product for manufacturing connectors. On the average the reduction in 14 British FMS was by a factor of 4.

Inventory reduction was reported only in 23 cases (see Figure 14) and the distribution is as follows (mainly for Finnish and British systems). The average reduction was 75%, or by a factor of 4, which was typical for 40% of the cases. The highest decrease (90%) was reported by a Finnish company -- Palomex. Almost in all observed cases inventories were reduced by factors of 2-5 in comparison with conventional technologies.

Exact estimates of the personnel reduction can only be made under the condition that there is a strict comparison between conventional and flexible production technologies. This means that the results illustrated by Figure 15 are very approximate.

The average decrease in personnel for 20 Czechoslovak FMS was only 36%. At the same time the number of persons was reduced by a factor of 3 (or 67%) for 7 Finnish and 8 Dutch systems, and

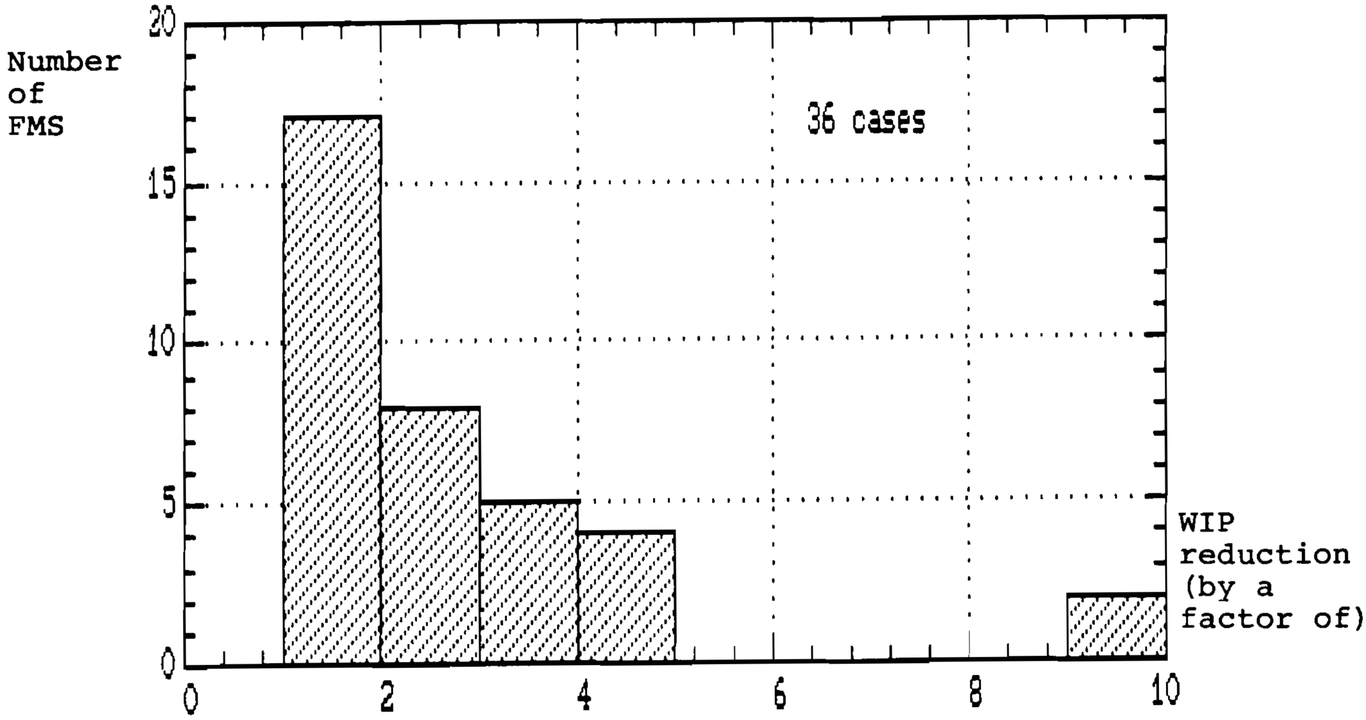


Figure 13. FMS distribution over work-in-progress reduction.

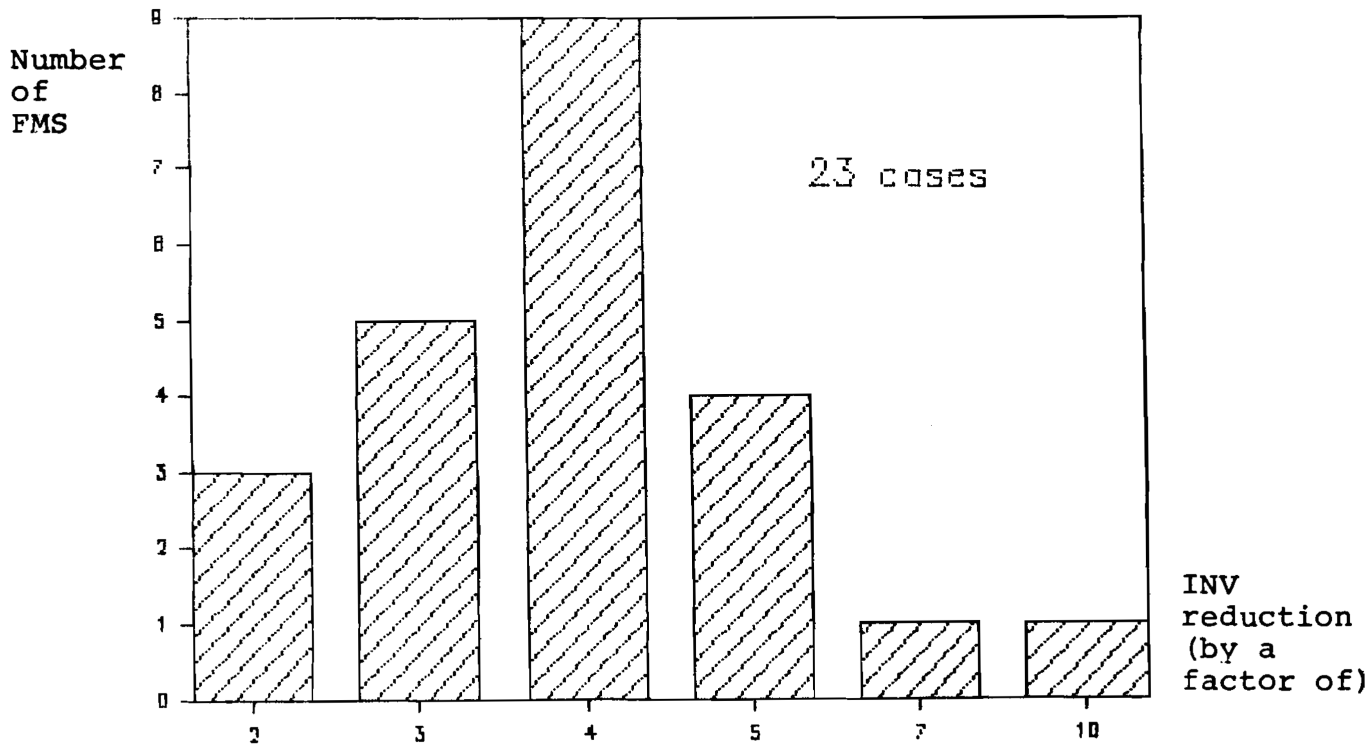


Figure 14. FMS distribution over inventory reduction.

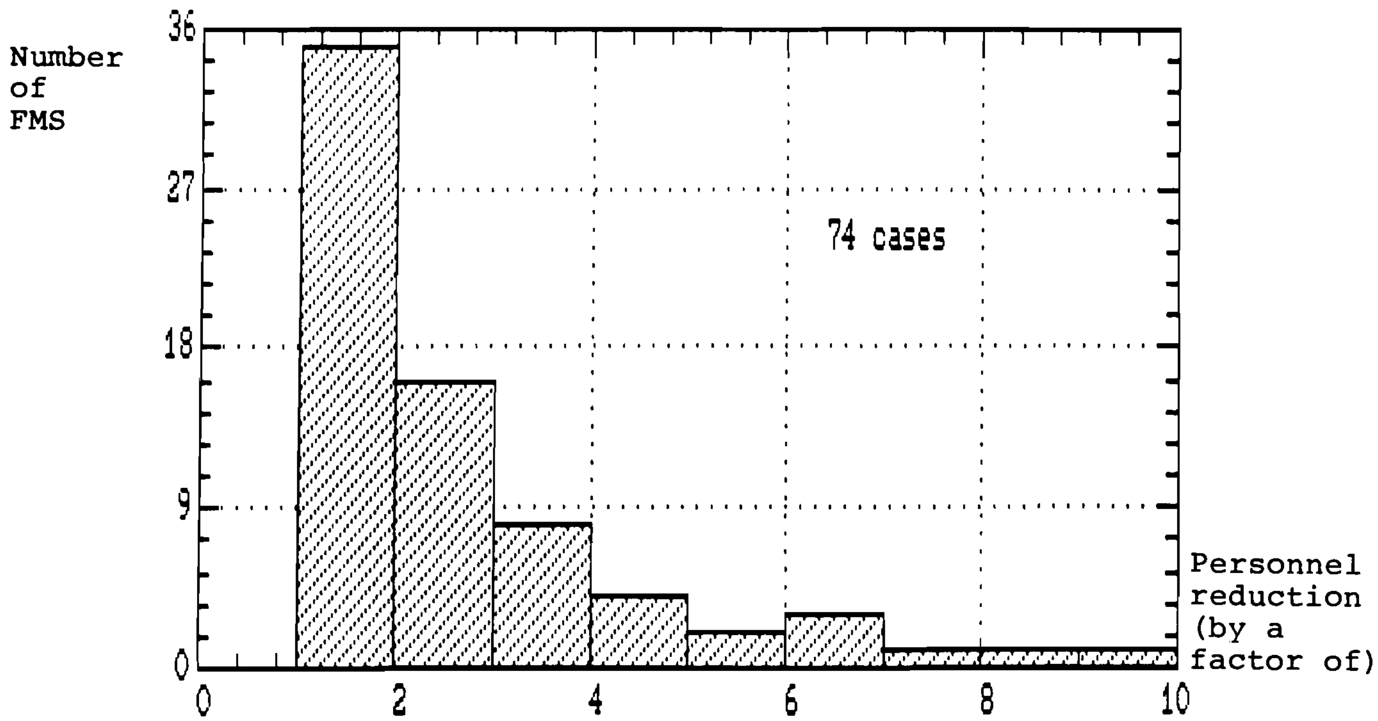


Figure 15. FMS distribution over personnel reduction.

Figure 16. FMS distribution over increase in productivity.

by a factor of 6 (or 83%) for 16 Japanese systems. The majority of the cases show a reduction by factors of 2-4, but the Swedish company AB SKF reported that after the FMS installation for ball-bearing production two operators substituted for 200 workers at the old manned line, at a higher production.

A productivity increase of no more than by a factor of 2 was the most typical for 33 FMS (see Figure 16), where these data were reported. There are some exceptions showing a higher productivity growth in the GDR, Finland and the CSSR. The highest achievement was 5.6. The capacity utilization rate increased by 50% on the average.

According to this analysis FMS usually demonstrate strong advantages in comparison to conventional technologies. Exclusively high achievements can be explained, as a rule, by specific types of production (small parts, metal-forming processes, etc.). But we think that only successful appliers reported these data. This is why the real advantages are usually less impressive.

8. FORECASTING OF FMS DIFFUSION

There are several publications concerning the future FMS diffusion into different countries, as for example [13, 26, 28, 36]. But it is difficult to find any quantitative forecasts of the world FMS population. The published data by countries are very contradictory. For the six main FMS users (Japan, the USA, the FRG, France, Britain and Italy) 650 systems in use are forecasted for 1990 [13]. The Western European market of FMS is predicted to be 500-750 million dollars in 1990 [28]. In Bulgaria 110 systems are to be installed by 1990. In the USSR about 2000 FMS and FMC will be produced by 1990 [26].

The statistical information collected in our data bank describes concrete systems at a technological level and it is impossible to interrelate the FMS features (such as price, productivity, different economic advantages, etc.) with the industrial or macroeconomic development. Moreover, even a diffusion share cannot be measured explicitly in quantitative or value terms.

Another group of problems is connected with national, industrial and production specific features. For example, a cheaper labor force in some countries devaluates such a driving force of FMS implementation as labor saving. A lower discount rate in some cases decreases stimuli connected with inventory reduction.

The FMS application in different industries shows a rather contradictory situation. In the car engine production high flexibility is not necessary, higher accuracy and set-up time saving are much more important. But in the electronic goods production a high variety of small parts plays an important role and flexibility is necessary.

FMS for metal cutting, metal forming, and assembling, are completely different and there are no universal approaches to forecasting their diffusion. In spite of obvious advantages of FMS in some respect, there are a lot of obstacles to their implementation. Among them one can observe a lack of labor force with appropriate qualifications, a low rate of standardization of FMS elements at the national and international levels. These limitations are difficult to be taken into account in forecasting a potential diffusion.

Now there is some information available on the first FMS implementations in some NIC, like South Korea or Taiwan. But it is difficult to predict the real expansion of this new technology in the countries outside the industrially developed world.

The forecasting method based on a preliminary estimation of potential niches for a new technology [24, 32] is hardly applicable for FMS forecasting. It is clear that small and medium batch production is such an appropriate niche, but concrete and specific features of different goods production make the determination of a total FMS niche too complicated and difficult.

This is why a rather simple statistical extrapolation will be used here to estimate the future diffusion of FMS. It is based on the life-cycle concept. According to the theory each technology passes through the phases of childhood, adolescence, and maturity, reaching its saturation level, and declines afterwards. At each moment the diffusion process is measured by, e.g., the share of a new technology in the total production of a certain good, see, e.g., [31]. Usually the process is described by a S-shaped curve, of a logistic or other type.

But for the case of FMS it is impossible to measure the diffusion process in relative units. We had to describe the diffusion trajectory in absolute values -- FMS world population, measured as an accumulated number of installations, year by year.

At present there are no data in statistical sources concerning the discarding process in the FMS population. It is obvious that some FMS installed 10-15 years ago are out of use and have possibly been scrapped. But their share in the total FMS population is very small, and all specialists consider the accumulated number of installations as the current population.

Unfortunately, not all the cases in the data bank give information on the year of installation. Moreover, in many cases the definition of the date is not exact, sometimes different sources provide contradictory information on the year of installation [10, 28]. A simple summary of all cases with the installation year reported provided 240 FMS in 1985. Because of incomplete data for 1986 and 1987 we considered the 1986 level as a sum of the data for these two years, equal to 320.

The difference between this estimate and the real number of FMS in use throughout the world is not very big. We missed some adopters in several countries, and did not take some other countries into consideration because of unavailability of appropriate statistical data. But, on the other hand, we did not subtract a certain amount of scrapped systems. If we consider a 10-year life time for a FMS, the discard is more than 50 systems.

Using the logistic curve (see Figure 17, curve A):

$$y_t = \frac{N_{sat}}{a + be^{-ct}}$$

where:

y_t - FMS population at moment t;

N_{sat} - saturation level;

a, b, c - parameters;

we estimated the potential saturation level to be 1790 FMS in use in the world in 2005. In 1990 this demonstrates 770-780 FMS (see Figure 17), which corresponds to 650 systems in the six main user countries [13], see page 22. The annual growth rate for the

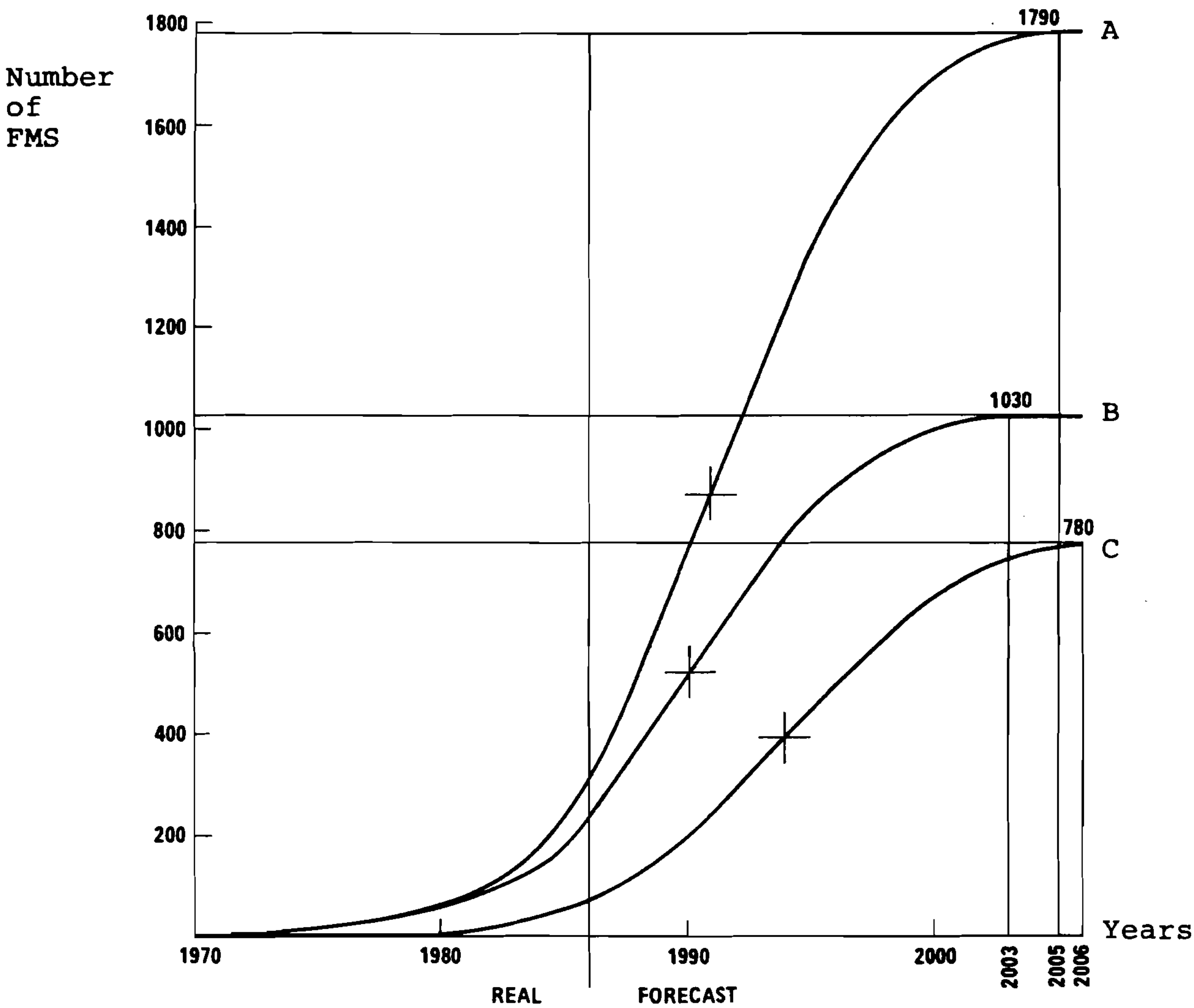


Figure 17. Forecasts of FMS diffusion.

whole period is forecasted as 10%. To confirm the result, a clustering approach was used. For this purpose we have chosen the technical complexity as a clustering criterion. The principle component method provided the following weighted technical complexity function:

$$TC_i = 0.74\ NCMT_i + 0.40\ IR_i$$

where:

$NCMT_i$ - number of NC-machine tools,

IR_i - number of industrial robots in the i-th system.

$$RTCC_i = TC_i / TC_{av}$$

where TC_{av} - average value of TC_i for all 320 FMS.

The systems where $TRCC_i \leq 1.21$ were treated as technically simple systems. The systems with $RTCC_i > 1.21$ were considered as sophisticated ones. The value 1.21 was chosen according to the FMS distribution over $RTCC_i$.

Logistic-type extrapolations were made for both subsets of the FMS population. The results are shown in Figure 17 for simple and sophisticated systems (curves B and C, respectively).

According to these results, the simple FMS starting at the end of the 1960's passed the point of 235 installations in 1986 and will reach a saturation level (1030 systems) in 2003. This corresponds to an annual growth rate equal to 9%.

The sophisticated FMS appeared in the middle of the 1970's. In 1986 their number reached 85 and the logistic-type extrapolation predicts the saturation level equal to 780 in 2006. This means that starting later than the simple systems, the sophisticated FMS will diffuse faster, by 12% annually. The inflection point will be passed by the sophisticated systems in 1994, four years after the simple systems have passed this point.

The exact data forecasted up to 2003-2006 are not very reliable. The saturation for simple systems seems to be reasonable, but for the sophisticated systems nobody has enough information to draw such a conclusion. Taking this fact into consideration and correcting the 1986 starting point up to 500 FMS, as well as correcting the discard rate, we can conclude that in the year 2000 the total FMS population will reach 2000-2500 systems in the world.

Now it is clear that the most wide-spread type of FMS in use is as follows:

- rather cheap (less than 2 million dollars each);
- technically simple (2-4 machining centers and no more than 8 NC-machine tools, with simplified supporting systems -- transportation, control, storage, sometimes without robots at all);
- they are used mainly for metal cutting in non-electrical machinery and transportation equipment.

These generations will diffuse intensively up to the beginning of the next century. The sophisticated FMS are experimental now and their real diffusion will take place in several years.

The forecast of the total FMS population will have to be revised by taking the following factors into consideration:

- new adopters (countries and industries);
- compatibility improvement through standardization;
- getting experience according to the learning curve, and higher advantages as a result;
- higher qualification of workers and managers in this sphere;
- overcoming of social problems connected with FMS introduction;
- general tendencies in industrial development.

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