WORKING PAPER

FLEXIBLE MANUFACTURING SYSTEMS (FMS):
STATE OF ART AND DEVELOPMENT

Roman L. Sheinin, VNIISI, USSR
Iouri A. Tchijov, IIASA

February 1987
WP-87-017

IIASA
International Institute
for Applied Systems Analysis

NOT FOR QUOTATION
WITHOUT PERMISSION
OF THE AUTHOR

FLEXIBLE MANUFACTURING SYSTEMS (FMS): STATE OF ART AND DEVELOPMENT

Roman L. Sheinin, VNIISI, USSR
Iouri A. Tchijov, IIASA

February 1987
WP-87-17

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

Foreword

One of the most perspective and sophisticated forms of computer-integrated technologies functioning is a Flexible Manufacturing System (FMS). A typical FMS includes several machining centers and NC-machines connected by computerized control, transportation and storage systems. It costs several million dollars.

From the macroeconomic view point, FMS is an exotic technology which is in an embryonic phase of its life-cycle. That is why there is no regular statistical information on FMS production, use and relative advantages. Now we can account for approximately 250 FMS's installed all over the world.

In order to estimate economic parameters of FMSs reliably, their relative advantages and to forecast the future development of this new technology, and its diffusion in metalworking industry, the authors have to collect all data available at that time. Inspite of lack of some data, they still could describe and analyze the main economic features and economic interrelationships of FMS's.

Of course, the paper is the first step within the CIM project (TES program) on the way of analysis and forecasting of FMS technology. After the period of additional data collecting the investigation will be repeated on the wider basis. Thus all contributions adding to our statistical data base (see Appendix 1) will be appreciated.

Prof. Robert U. Ayres
Project Leader
Computer Integrated Manufacturing

Abstract

The available descriptions of more than 220 FMS installed up to 1986 in all developed countries (mainly of a market type) were collected into a data bank, systematized and analyzed. In addition to the traditional data, such as country distribution, time-distribution of installations, common economic features-investment cost, pay-back time, labor/capital/time reductions-were investigated. Some dynamic tendencies as well as interrelationships were found within the framework of the analysis provided by the authors.

1. INTRODUCTION

All new technologies can be divided into two broad categories: embryonic and expansive technologies [14]. Among the main statistic features of embryonic technologies there is a lack of regular statistical data on national or industrial levels, occasional information about their economic aspects, low reliability and comparability of the data. From the economic viewpoint the embryonic technologies are pioneer technologies and do not yield a scale effect, their profitability may be negative by standard calculations, the relative advantages are not confirmed by mass observations.

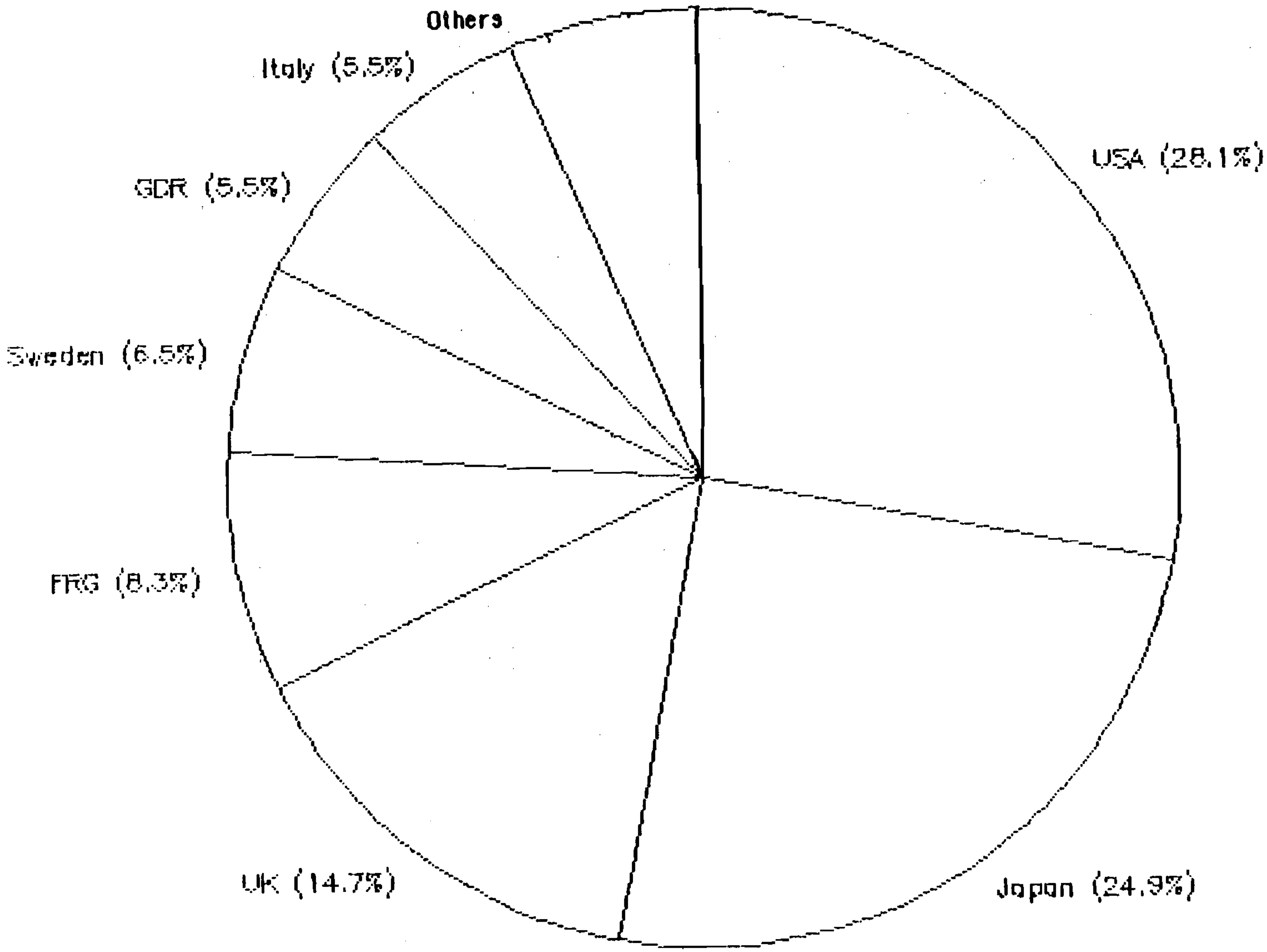
That is why there are a lot of speculations around the embryonic technologies: from super-optimism up to an extremely negative attitude. Unfortunately, the lack of reliable statistical time-series does not permit the investigators to use the traditional methods of statistical analysis such as regressions, factor analysis, etc.

The main sources of the data are on the firm level, predominantly on the production side. The estimates of potential advantages of the new technologies made by their producers usually differ from the consumers' estimates. This happens because of the relatively low reliability of new techniques, their limited compatibility with conventional production systems. This is why one of the most widely used sources of information for the economic analysis of new technologies is interviews or questionary replies of the firms where the technologies are really used.

Flexible Manufacturing Systems (FMS) are the typical example of a new technology which is in the embryonic phase of its diffusion. The total amount of FMS installed all over the world up to 1986 is approximately 230-250. There are 28% in the USA, 25% in Japan and 15% in the UK of the total installations (see Figure 1). From the industry viewpoint one half of FMS is in nonelectrical machinery, one third in transportation equipment. 45% of FMS are used for casing, 13% for shafts, cranks and axles production [15].

There is a certain amount of publications on FMS, mainly addressed to business and engineering communities, for instance [1-5]. But there is also definite lack of publications reporting results of the statistical analysis of currently available data

Figure 1. Installations across Countries
(in % of total amount)



on FMS installations. This is why the objectives of this research were formulated in the following way:

1. To develop a data base containing available data on FMS installltions.
2. To find out some general statistical attributes of the above mentioned data.
3. To try to reveal some (if any) trends in FMS development over time.
4. To try to describe some (if any) interrelations between what we would like to call "internal" and "external" features of FMS installations.

2. WHAT IS FMS?

Unfortunately, nowadays no consensus on the FMS definition does exist. As an example, in [7] a primary notion of Flexible Manufacturing Technology was introduced which split into three catagories: stand-alone machines, a flexible manufacturing cell (FMC), and a flexible manufacturing system (FMS). The latter was defined as having at least three basic elements: a number of work stations, an automated material handling system, and system supervisory computer control. On the other hand, in [8] FMC is considered as "a small FMS".

As the US National Bureau of Standards' definition runs: "...an arrangement of machines (usually numerical machining centers with tool changers) interconnected by a transport system. A central computer controls both machines and transport system. Flexible manufacturing systems sometimes process several different workpieces at any time" [11]. The definition of the US National Electrical Manufacturers Association says: "Four or more machines, with fully integrated material handling, controlled by a computer or programmable controller" [11].

These (and many other) definitions focus attention on technological components of FMS. Let us call such an approach "a designer's view on FMS".

The other way to define FMS is to take into consideration not the technological features of a system, but to evaluate its utility. Let us call this approach "a user's view on FMS". One example of the latter is [3] where FMS is defined as "a production unit capable of producing a range of discrete products with a minimum of manual intervention". Another example is [10].

FMS is referred there as a vehicle to meet the demands of production with a middle-to-low volume and high-variety situations.

The following definition is usually used in the USSR: "A FMS is a system of computerized machines, which can produce within the limits of its capabilities any workpiece at random, in any quantity, in any time by request of the assembly department and at cost of mass production or lower" [11].

Keeping in mind such diversity of definitions we had to elaborate a new one which would be relevant to the objectives of the study. The purpose of this definition is purely pragmatic: to have a criterion while searching literature for necessary information.

The definition used is the following. FMS is a system which:

1. consists of robots or/and machining centers or/and numerically controlled machine tools,
2. has some sort of computer control over the whole production cycle,
3. may be an automated materials handling system, linking the machine tools and other equipment in the system together,
4. is quite suitable for middle-to-low volume production in non-stable environment in the sense of demand.

We tried to obtain data which meet this criterion, but it is possible that some of the entries in our data base slightly deviate from the conditions imposed by the above-mentioned criteria.

3. DATA BASE

The structure of the data base may be designed according to the objectives of the study. Records in the data base correspond to different FMS installations. Every record has a similar number of similar fields. These fields are:

1. A company where the FMS is installed.
2. A country where the FMS is located.
3. A year of installation.
4. An application area of the system, namely machining, assembly, manufacturing, metal-forming or welding.
5. A vendor or main contractor.
6. A number of general-purpose industrial robots. Thus,

neither specialized robots (or manipulators) attached to certain machine tools for workpiece or tool change, nor material transport equipment are included.

7. A number of general-purpose machining centers (MC) in the system.
8. A total number of numerically controlled machine tools (machining centers included). This statstics includes only major numerically controlled machines. Thus, smaller machines and stations such as deburring and grinding equipment and washing stations are excluded.
9. A type of material transport equipment: conveyors, automated guided vehicles (AGV) or computer controlled carts.
10. A type of warehousing subsystems: automated storage and retrieval systems (ASRS) or computer controlled warehousing systems.
11. A type of inspection equipment: automated measuring and inspection system or automated maintenance and monitoring system.
12. An operation rate as a number of shifts per day.
13. A number of shifts of unmanned operation.
14. A number of products, including product variants, that the system has been designed to manufacture. Various products should be able to be manufactured in a more or less random order with short set up time.
15. A batch size.
16. Investment costs in US $.
17. Pay-back time (in years).
18. Lead-time reduction.
19. Work-in-progress reduction.
20. Inventory reduction.
21. Personnel reduction.
22. Set-up time reduction.
23. In-process time reduction.
24. Machining time reduction.
25. Floor space reduction.
26. Increase in productivity.
27. Increase in production capacity.
28. Production costs reduction.

As one can see, fields 1 to 5 contain some general information on FMS, fields 6 to 15 represent data on technical features of systems, while fields 16 to 27 give us information on some properties which are important from the final user's point of view.

Information collecting according to the above framework is not completely a routine task. We will mention only one issue to clarify this point because listing them all would lead us too far away from the main scope of the paper.

This is the problem of measurement scale. For instance, investment costs are usually given in currency of a country where a user company is located. Thus the problem of unified investment costs scale arises. Naturally, we have chosen the U.S.$ scale and used an average currency exchange rate of the year the installation was put into operation. By this procedure the influence of exchange rate variations can be mostly eliminated.

Searching through literature we have chosen [11] as a main source of relevant information. The data contained in this survey was checked and supplemented whenever possible by using other sources. A few examples of the latter are [7, 10. 12].

Total information on 227 FMS installations (mainly located in the U.S., Japan and Western Europe) was gathered and fed into a computer. It should be stressed that practically every record in the data base had some (or many!) empty fields because of the lack of information. Thus, every data processing procedure dealt not with 227 records but with a fewer number of records, the latter being dependent upon a particular aspect of the analysis.

In some cases available information on FMS installations was consciously dropped and not fed into a computer because it characterized only some general aspects of the installation and was of no use in connection with the objectives of our study. In spite of this we consider the number of records in the data base a satisfactory result, having in mind that the total number of FMS installations throughout the world may be estimated to be equal approximately to 200 in the middle of 1985 [7].

In order to demonstrate two contradictory elements of the published data we compared the distribution of installations by years from our data base versus Edquist and Jacobsson's data [6], see Table 1.

Table 1. Years of installations for FMS up to 1984 (developed market-economy countries)

Year	E & J	Our Estimates	Year	E & J	Our Estimates
pre-1970	2	-	1977	1	4
1970	3	-	1978	5	5
1971	2	1	1979	9	7
1972	4	0	1980	18	8
1973	0	3	1981	14	14
1974	4	1	1982	4	17
1975	12	0	1983	30	22
1976	7	6	1984		27
			Total	115	115

We got the same total amount (115 units) as Edquist and Jacobsson, but there is a sufficient difference in time distribution. The average age of FMS in Edquist and Jacobsson is 5.1 years and 2.9 years in our case.

Additionally, some information in our data base is connected with systems which are to be put into operation in 1986 and 1987. Such information is of course preliminary.

4. RESULTS OF DATA ANALYSIS

The first results of the data analysis on FMS installations are to be described below. As the whole study has not been completed yet, these results should be considered only as preliminary ones. We do hope to report the final pattern of FMS installations in the nearest future.

A. Installations across countries

As the data base indicates, the number of FMS installations varies significantly across countries. The illustration of this fact is Figure 1. Most FMS installations are located in the U.S. (more than 28% of the total amount) and in Japan (almost 25%). These two countries have more FMS than all the other countries taken together. The UK has almost 15% of all FMS, while four other European countries (namely the FRG, Sweden, the GDR and Italy) have approximately the same number of installations with a respective share from 8.3% to 5.5%. Another three countries (Belgium, Bulgaria and Canada) have just a similar number of FMS (3 installations or 1.4% each). Four countries (the USSR, the CSSR, Finland and Norway), with each less than 3 installations, are combined into the category "others" with a total share of 2.3%.[1]

B. Distribution of installations by years

Another general characteristic of available data is the distribution of FMS according to the dates of their installations. The reliability of the data has already been demonstrated in Table 1.

According to Figure 2, after the early embryonic phase in the 1970s with cyclically unstable dynamics of installations in the first half of the 1980s, linear growth of a number of installations began.

The correlation between the time and FMS variables is equal to 0.995 which is sufficient. It seems reasonable to assume that this linear interrelation can be extrapolated to the next few years. If this assumption is correct, then according to the regression forecasting procedure 36 FMS have to be installed in 1986, 40 in 1987 and 45 in 1988.

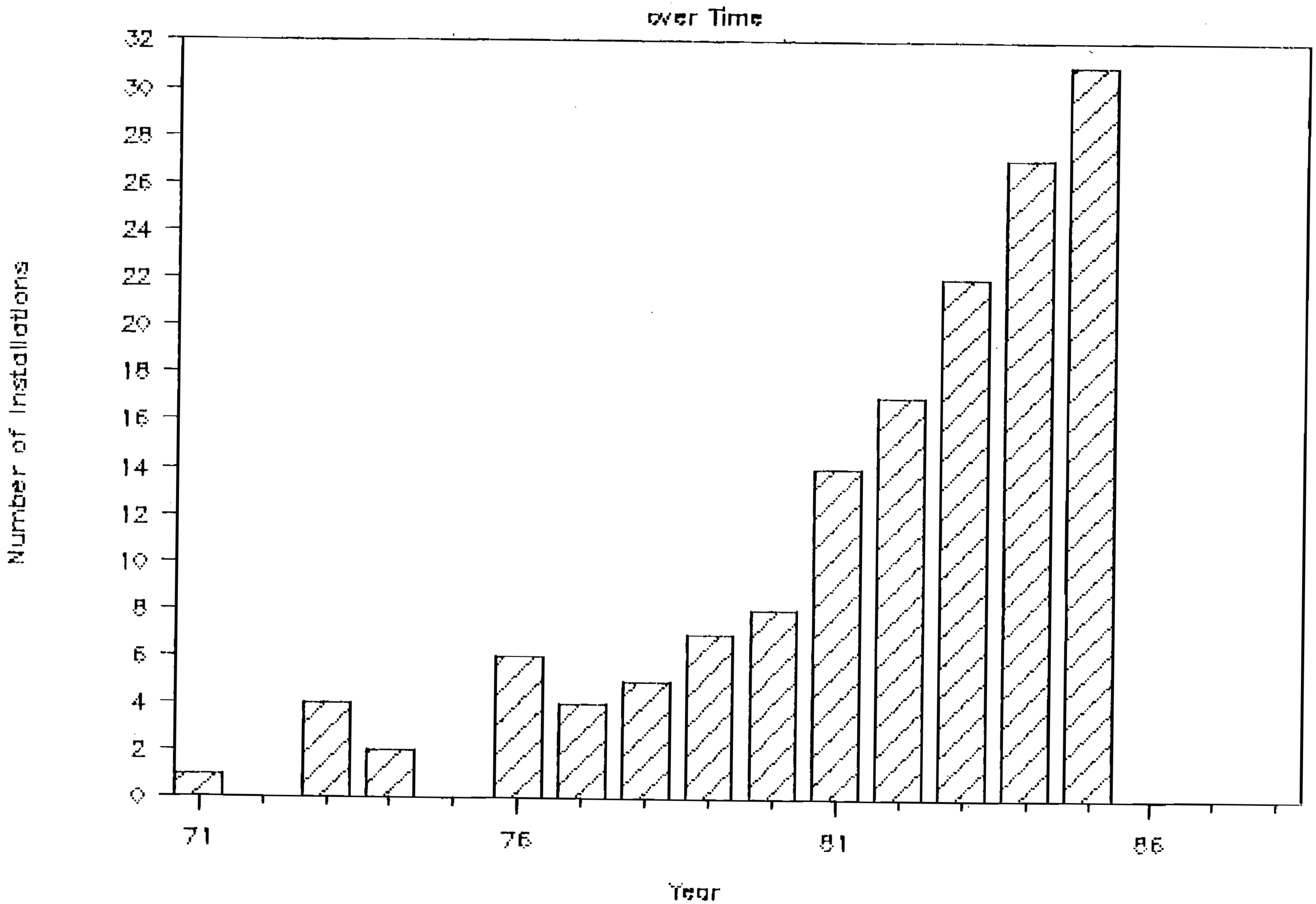
But the cyclical instability of the diffusion rate during an embryonic phase [14] as well as preliminary information for 1986 and the outlook for 1987 permit to conclude that after the rapid growth of installations of the current generation of FMS there will be a deceleration and a certain period of stabilization of annually installed FMS.

Another point to be mentioned in connection with Figure 2 is that the dependence of the FMS number over time on the 1976-85 time interval seemed similar to a logistic curve. We have checked this assumption because we think that there are now too few data points for such an estimation: we should at least have complete data for the next several years.

---

[1] It is obvious that the latter does not correspond to the real situation in these countries and it can be explained by the lack of adequate statistical information from them.

Figure 2. Distrubution of Installations



C. Distribution of FMS costs

One of the very important aspects or dimensions of FMS is scale. By scale we mean here an aggregate feature which characterizes a size of FMS. It seems reasonable to suppose that such a parameter as investment cost reflects the notion of scale relatively well. Thus it would be of interest to consider the distribution of FMS installations by values of this variable. The respective information is presented in Figure 3.

One can see that very few installations have investment costs over 50 million dollars (only 5 cases among 227 FMS). Practically every such an FMS is an exceptional case which should be studied in detail on a different methodological base than other subsets of data. For instance, the most expensive FMS in our data base with investment cost of 300 million dollars is really a whole automatized factory for the assembly of FIAT FIRE engines in which 80% of assembly operations are automated. It is clear that the decision-making process and economic analysis connected with such large-scale projects differ significantly from those related to small-scale projects.

Moreover, we consider that the total amount of FMS can be separated into several subsets. The highest one (the most expensive one) includes purely experimental and very sophisticated systems which demonstrate rather future capabilities and development directions than the currently economically acceptable systems. They are being developed by several powerful monopolies in manufacturing. The lowest vintage includes quite simple and cheap systems recognized by a lot of consumers. The growth of this vintage will determine the total diffusion of FMS in the nearest future.

Theoretically it is possible to imagine the intermediate vintage of FMS, which includes rather sophisticated systems which are not profitable now, but they are expected to be recognized on a mass level in 5-10 years.

Concerning the data shown in Figures 3 and 4, the lowest group of FMS has an average cost from 1 to 5 million dollars, the second one has a cost range from 2 to 20 and the highest one--more than 20 (up to 300 now) million dollars.

Figure 4 represents a part of the distribution, namely relating only to installations with investment costs of less than

Figure 3. Distribution of Installations

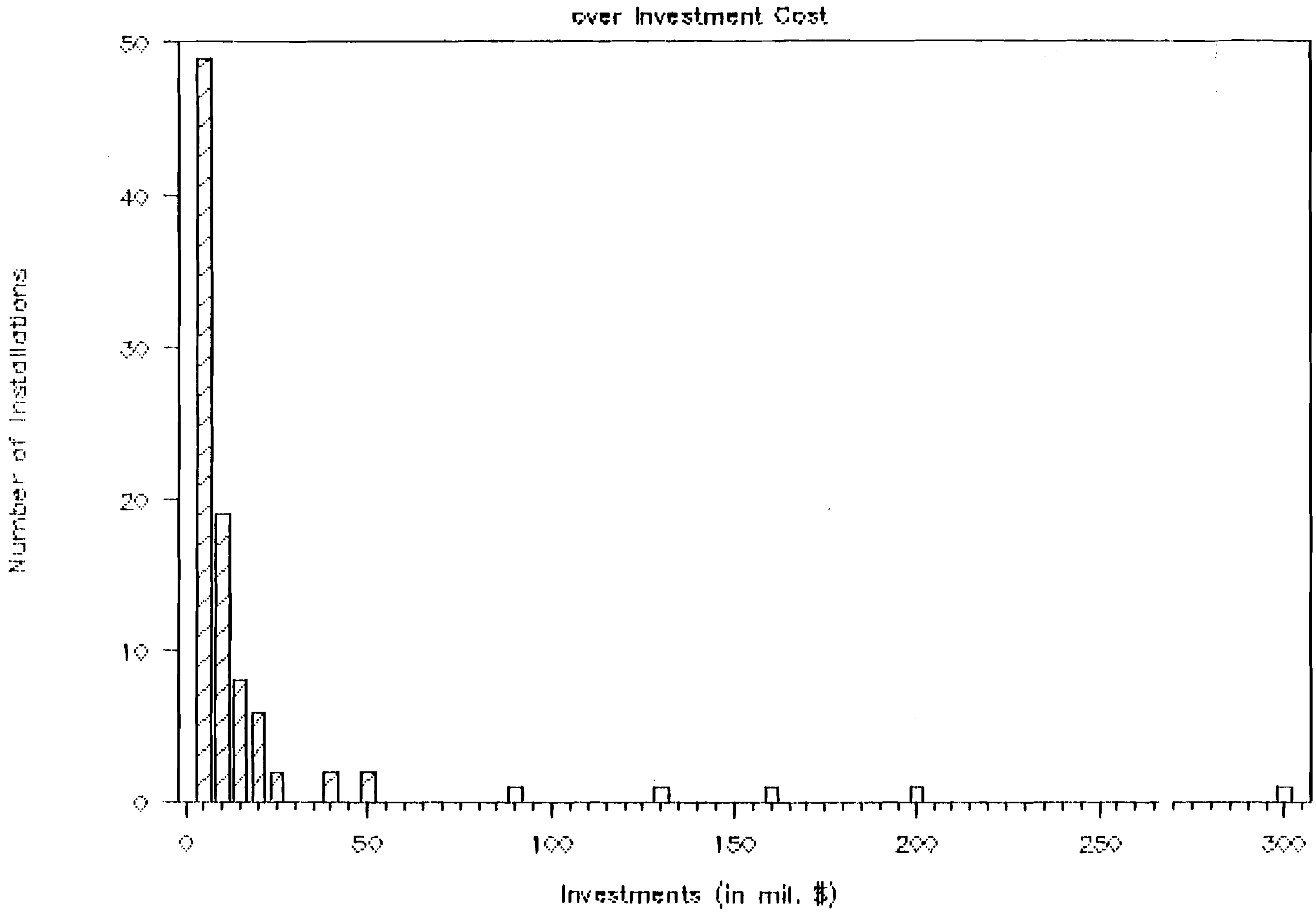
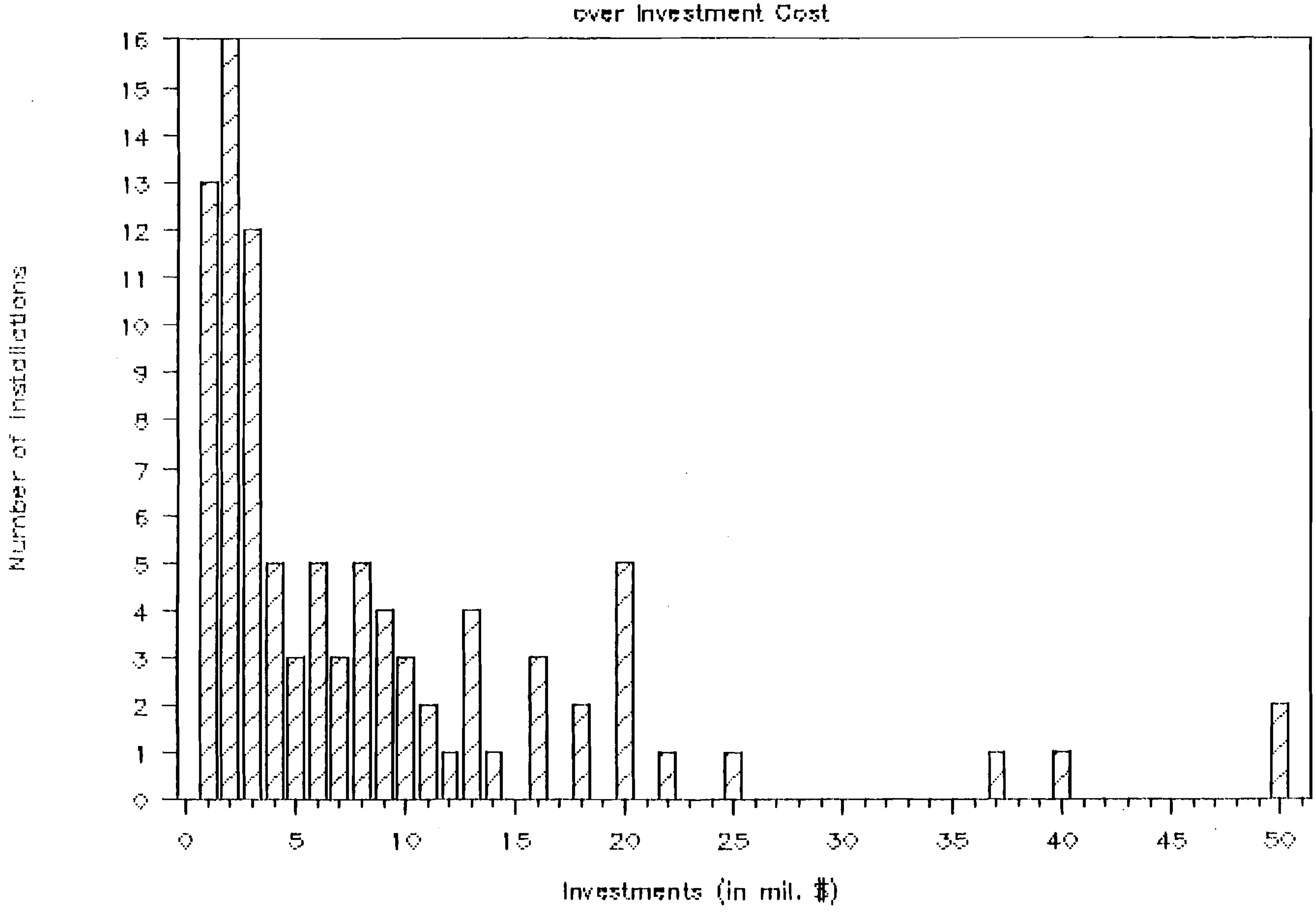


Figure 4. Distribution of Installations



50 million dollars. It shows that at least three clusters of FMS installations do exist with investment cost ranges up to 5 million dollars, up to 12 or 15 million dollars and others. A formal cluster analysis procedure could be used to locate the bounds of clusters more accurately. We would like only to stress one methodological point, namely that in some cases it could be necessary to consider each FMS cluster separately. The reason for doing this is that data regularities, which we are looking for, may differ from cluster to cluster.

D. Distribution by technical complexity

Let us consider such an aspect or a dimension of FMS installations as technical complexity. We suppose that such parameters as a total number of machine tools and a number of robots reflect this complexity. One can refer to Figure 5 to see the distribution of FMS installations over the total number of machine tools - MT (including machining center - MC). As can be seen, FMS, most frequently used, have four MTs. At the same time the variability of this parameter is rather high.

With regard to the above mentioned hypothesis, the FMS of the lowest level have 2-5 NC-machines, the intermediate group has approximately 7-10 machines and only the experimental sophisticated FMS have more than 16 machines. The exotic case (FIAT) mentioned includes 17 robots and 72 machining centers.

Figure 6 shows the distribution of FMS installations over the number of general-purpose robots. It can be drawn from this graph that most of the FMS installations include less than five robots. Namely, 26 installations of 39 belong to this group. But it is necessary to take into account that special and material-handling robots are out of consideration. Only multifunctional programmable robots are put into the data base.

E. FMS flexibiltiy

Flexibility is one of the most important features of FMS, its main advantage. From the statistical point of view the flexibility may be estimated as a number of products produced by using one FMS. But it is necessary to distinguish real and potential numbers. The latter are estimated with rounded figures by producers and they are much higher than the real ones.

To get acquainted with the relevant distribution of FMS

Figure 5. Distribution of Installations

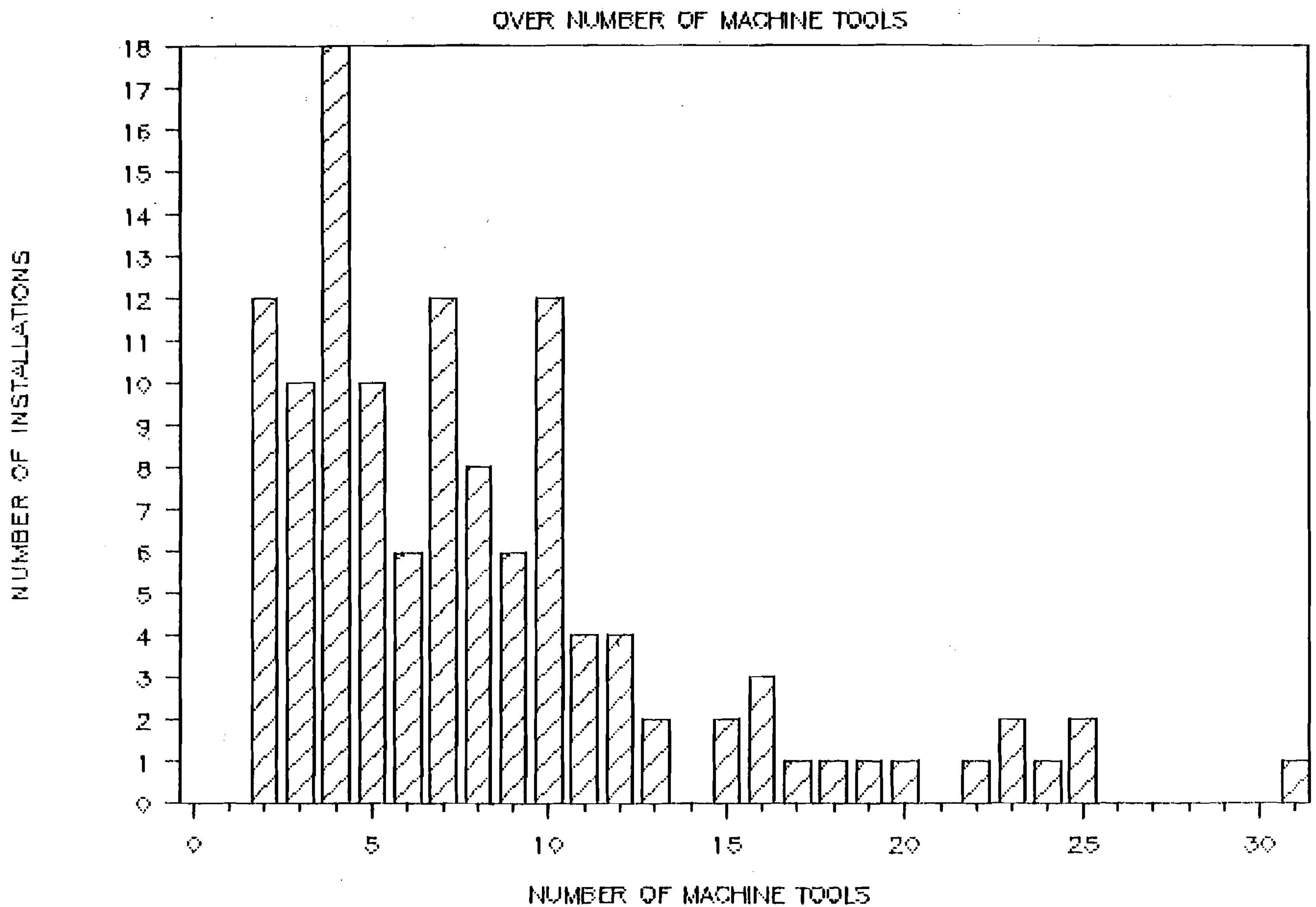
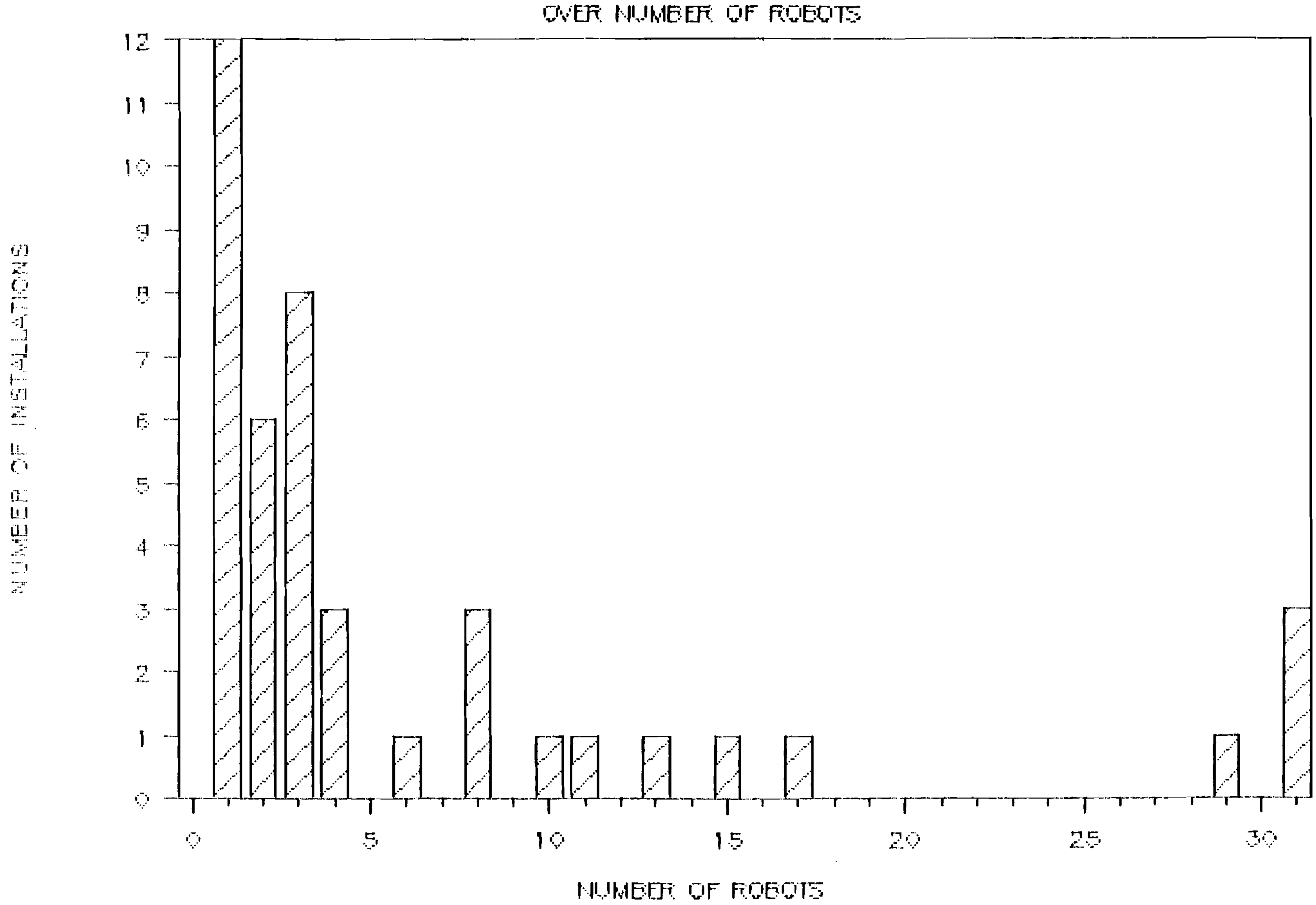


Figure 6. Distribution of Installations



installation over values of this variable one can refer to Figure 7. It can be seen that 32% of all installations are really not very flexible, because they were designed to produce no more than ten variants of products. Two thirds of all installations are able to produce up to 60 variants of products and only 20% of them can produce more than 100 variants of products.

To consider the question whether any trend of the number of product variants exists, we will refer to Figure 8, which represents a scatter diagram of the latter versus time. Only FMS which are able to produce 100 product variants and less (80% of the whole set) are represented in this graph. As one can see, there is a tendency of increasing the number of product variants over time. Thus, as FMS technology develops, installations in general become more flexible.

In Figure 8 it is possible to split the space into two areas - A and B. Area A consists of the data belonging to more sophisticated and expensive FMS and inside a tendency to growing flexibility is obvious. Area B describes a great amount of rather simple FMS, which are now recognized by a lot of consumers. The flexibility in these cases increases too, but not so fast. This means that the major diffusion of FMS is based now on copying rather simple, but profitable FMS which are acceptable for a lot of different consumers in various metalworking industries.

In order to check this preposition, we estimated the dynamics of maximum and average flexibilities for the cases mentioned above (see Figure 9).

The dynamics of the maximum flexibility for moderate flexible FMS reflects a strong growth of this important feature. But the average flexibility is growing moderately. It refelcts two processes in the FMS diffusion: rapid growth of flexibility of sophisticated experimental FMS and high stability of rather low flexibility for the main number of FMS accepted by industries.

Of course, the most exotic cases were out of consideration. For instance, among 20% of the total list of cases missed, there are such systems as two Toshiba FMS (3000 and 4000 product variants - the first was installed in 1983), one Murata FMS, installed in 1981 (1500 variants), etc.

Moreover, we found that in most cases rounded figures for

Figure 7. Distribution of Installations over

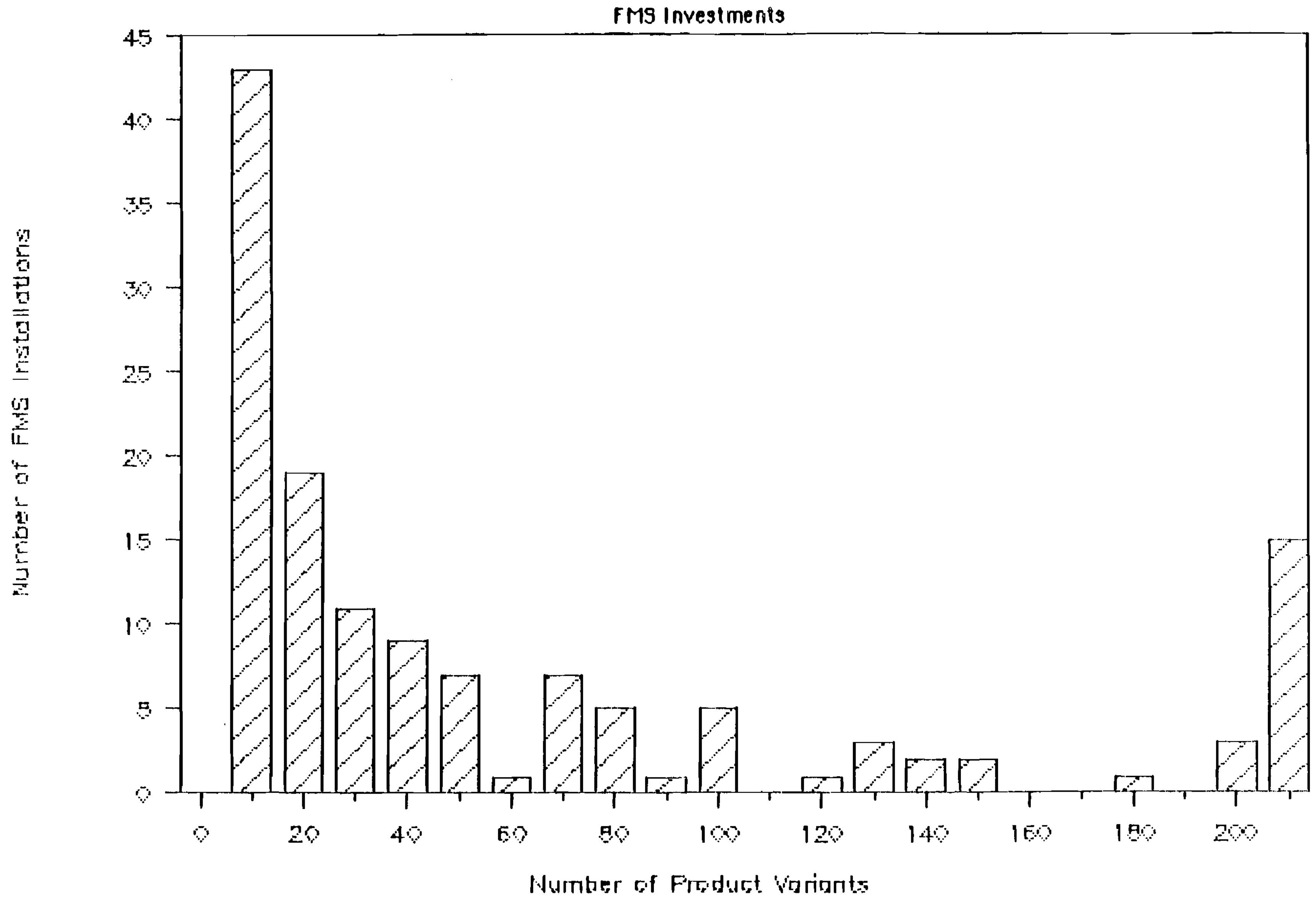


Figure 8. Product Variants versus Time

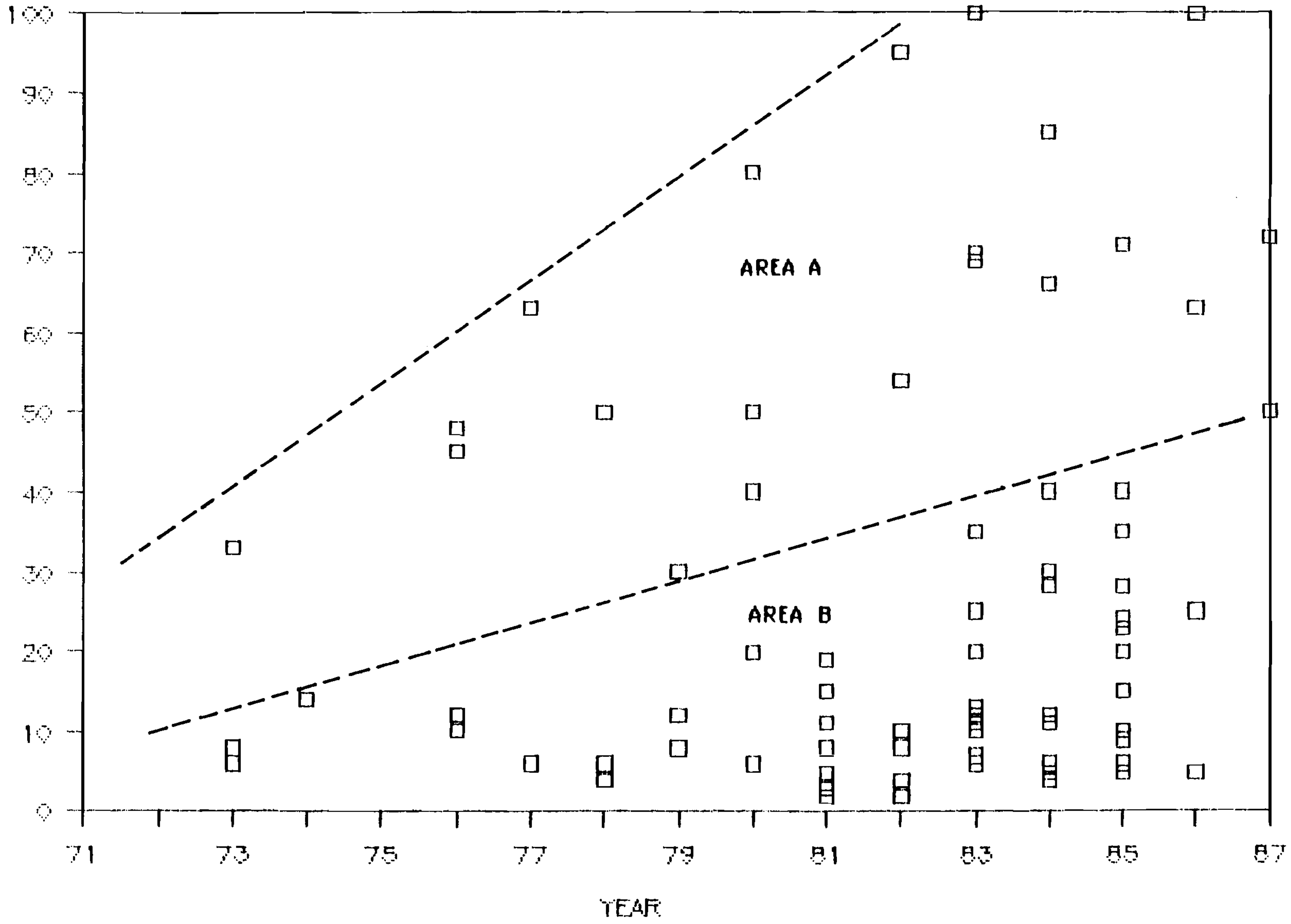
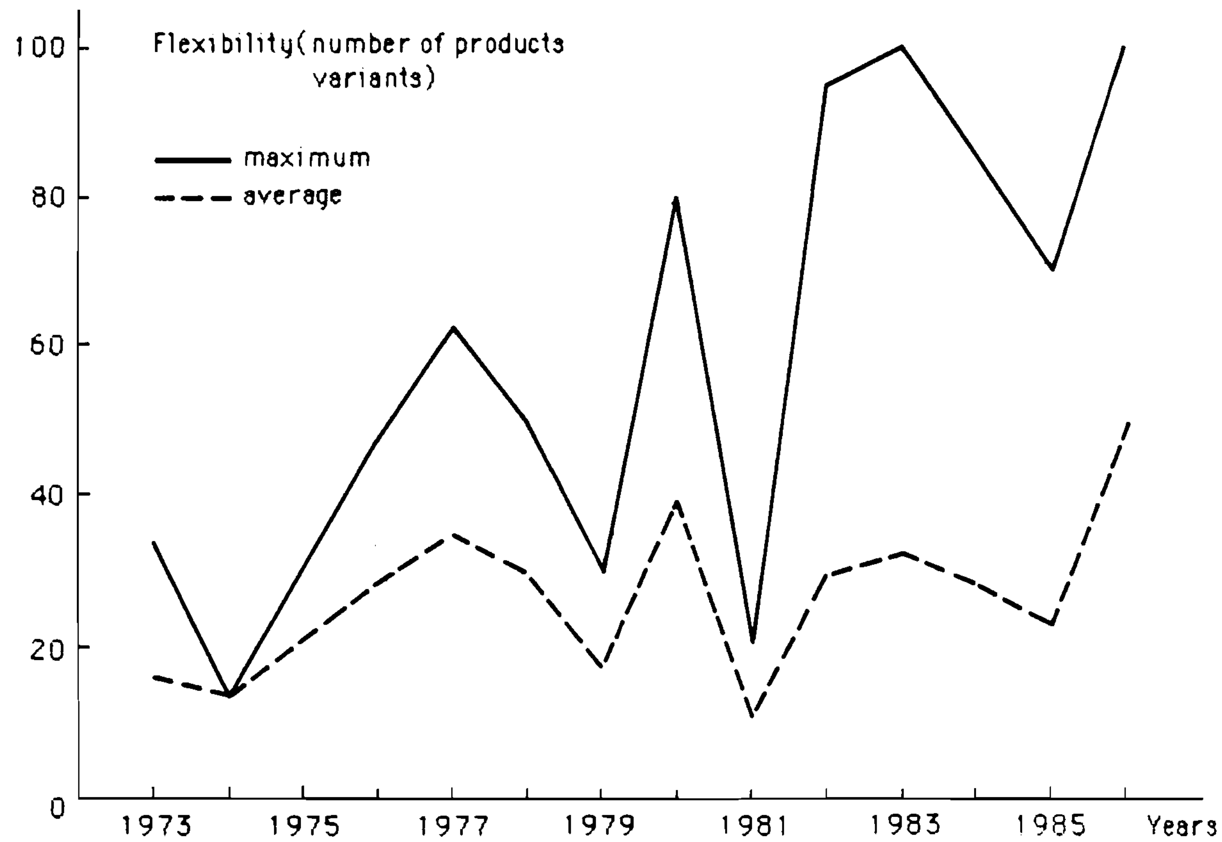


Figure 9. Dynamics of FMS Flexibility (based on data from Figure 8)



the product variants were reported if the number of variants exceeded 50. This might mean that we deal with real flexibility when a moderate number of variants is reported and with hypothetical potential flexibility when the reported number is high.

F. Miscellaneous data

The shortage of long enough series of some data gives no possibility to analyze the average features of FMS. Now it refers to the reduction of, for example, set-up time, in-process time, machining time, floor space and production cost. Several contradictory figures for them are reported only in few cases.

Later we hope to fill in the blank space in the table and analyze the data, which are not available now. But for some variables we have collected enough information to make some estimates and conclusions.

Table 2. Types of transportation systems for FMS

Type	Number observed	Percentage
1. Conveyors	37	25.9
2. Automated guided vehicles	104	72.7
3. Computer controlled carts	2	1.4
Total	143	100

It is obvious that the main type of transportation in FMS is automated, guided vehicles and the most sophisticated type-computer controlled carts - is very seldom used.

There are two types of inspection equipment identified for FMS: an automated measuring and inspection system or an automated maintenance and monitoring system. With regard to the information we have got, 81% of 21 cases belong to the first type of inspection equipment.

There is a similar situation in warehousing systems. Among 31 cases reported, 84% used the automated storage and retrieval system and, respectively, 16% used the computer controlled warehousing system.

These results indicate that now only few FMS use adequate computerized subsystems of transportation, control and storage. Most FMS are based on the use of automated systems with low flexibility.

The increase of an operation rate (or a number of shifts per day) is one of the most important advantages of FMS. If the conventional metalworking equipment is used during 1.3-1.6 shifts a working day, the reported 79 cases for FMS show an average operation rate equal to 2.6. Three FMS are used during 1 shift a day, one FMS during 1.5 shifts, eighteen are used during 2 shifts, eight between 2 and 3 shifts, and 49 FMS are in operation during 3 shifts a day.

The average number of shifts in unmanned regime reported for 24 FMS was much less than the total operation rate - 1 shift a day. And there is only one case - "Niigata International FMS"- where over 2 shifts were reported. It can work with unmanned operations during 2.6 shifts a day.

We have collected a lot of information for FMS personnel reduction - 42 cases. The average reduction was by 6.3 times. But if we exclude two exotic cases - 100 for "AB SKF" and 20 for "Mori Seiki" - the average personnel will be reduced only by 3.6 times, which looks more reliable and reasonable. The distribution of the reduction is shown in Figure 10.

The saving of the other production components was estimated for lead-time and inventory reduction, but when using a rather limited number of cases. The lead time for 9 cases was reduced by 7 times on average. But if we exclude one exotic case ("Westinghouse-85" - by 32 times) from the sample, we get an average reduction by 4.3 times.

Inventory reduction for 6 cases was by 7.9 times on average. But the exclusion of one exotic case (Westinghouse-85" - by 30 times) decreased this figure to 3.5.

We are sure that only successful firms have reported the information about pay-back time. We have found 18 such cases with the values of PBT from 1 to 5 years. The average pay-back time was estimated as 2.75 years and the distribution of the data is shown in Figure 11.

There were few firms which reported the estimates of such an important figure as an increase of productivity when FMS is used. We have collected only 7 cases with the range of estimates from 1.6 up to 6.3. The average value of the increase was 2.9.

Figure 10. Distribution of Personnel Reduction

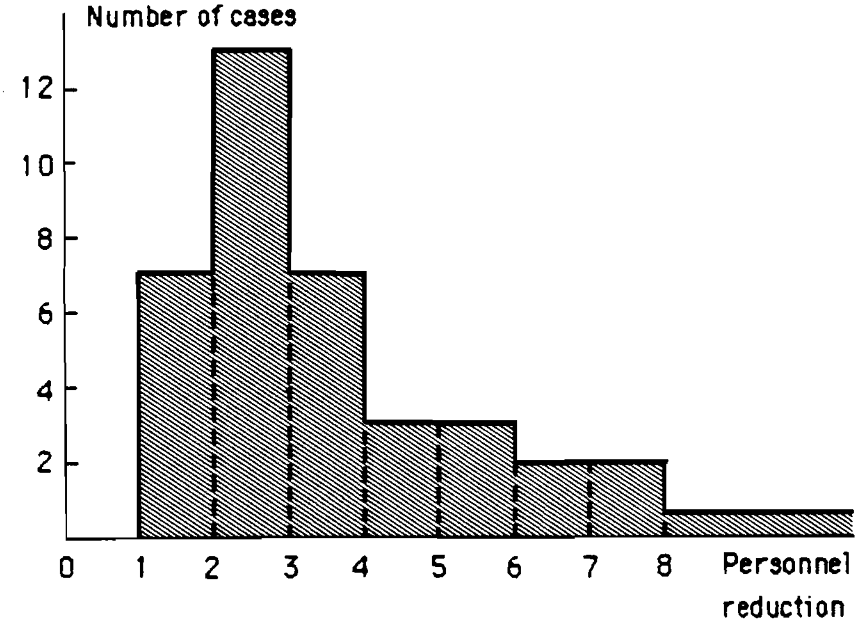
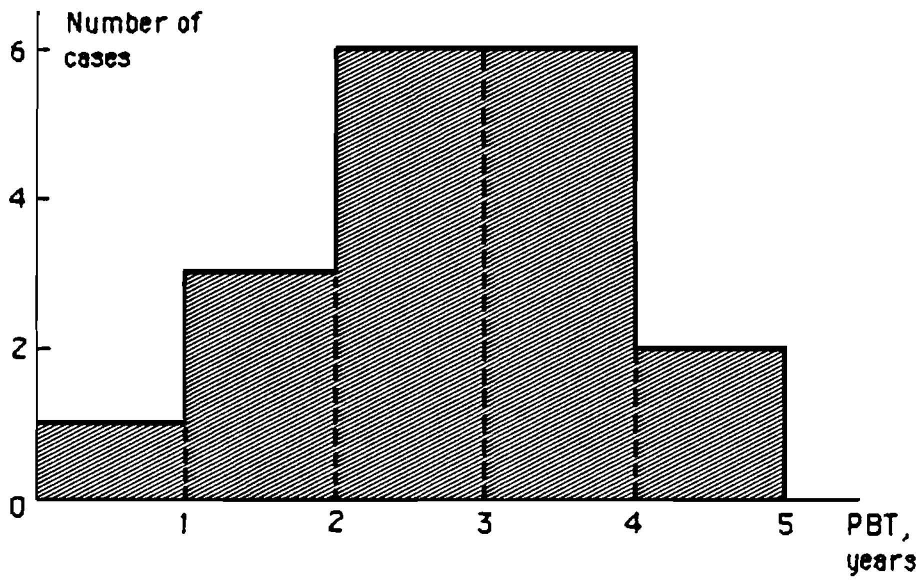


Figure 11. Distribution of Pay-back Time



Of course, reliability of the estimates and conclusions should be increased by adding the missing relevant data to the bank and by checking the methods of their collection.

5. ANALYSIS OF INTERRELATIONSHIPS

Up to now three important dimensions of FMS, namely scale, technological complexity and flexibiltiy, have been introduced. We have also described some scales or variables which could be used to measure properties of FMS installations on these dimensions. Naturally a question arises whether it is possible or not to find out any interrelations between the above-mentioned dimensions.

First of all, we will introduce two more variables or parameters which will be used in the further analysis. These are: a ratio of investment cost to the number of machining centers and a ratio of the former to the total number of machine tools. The meaning of these parameters is the follwoing.

Each of them is characterized, in some sense, by how expensive one unit of technical complexity scale is in a particular installation. This allows us to study and compare FMS installations of different scale.

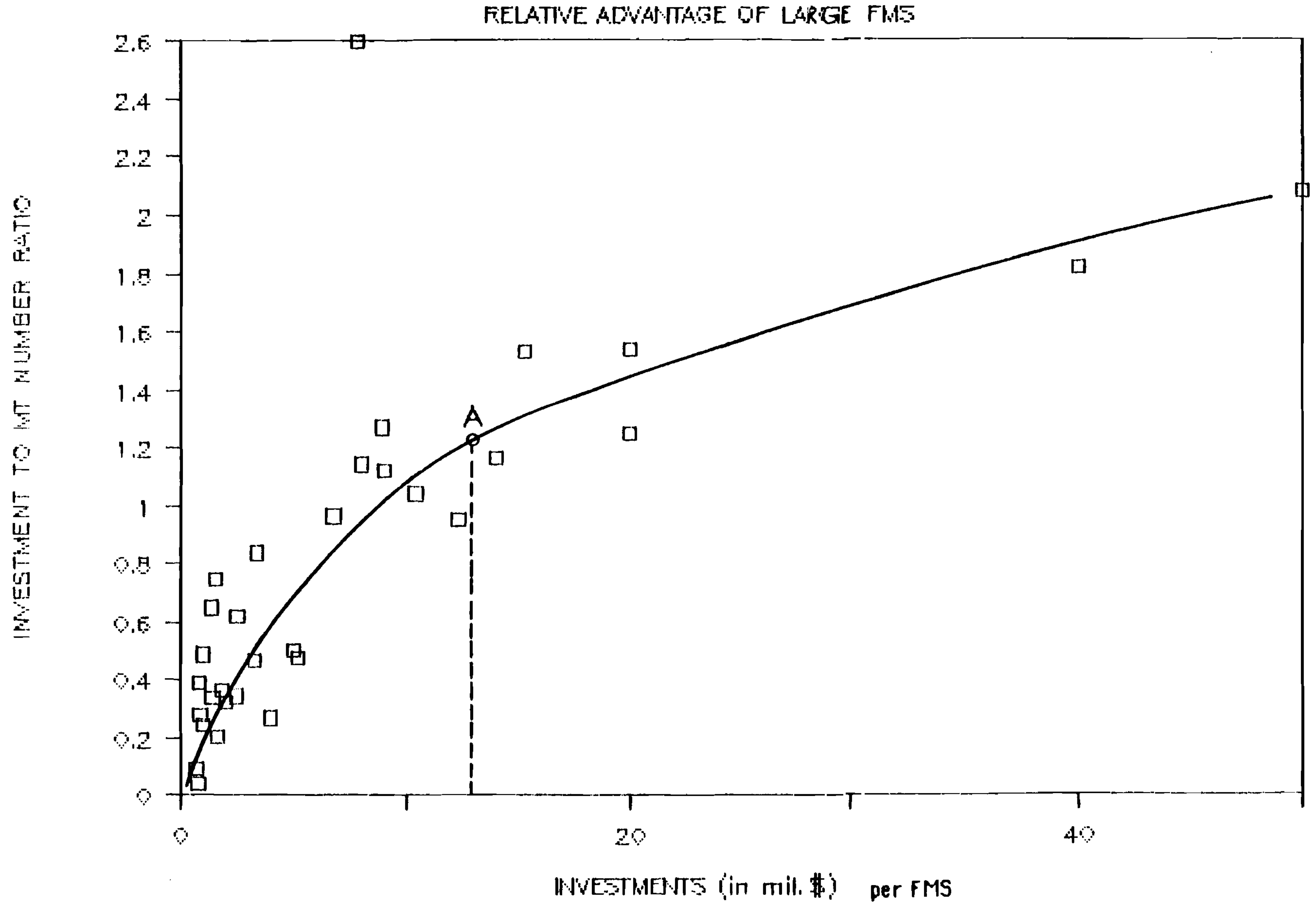
Let us consider Figure 12 which represents a scatter diagram of investment cost per one machine tool over investment cost. In other words, it shows how expensive one unit of technical complexity for FMS of different scale is.

We did not use the nonlinear regression to explain analytically the scatter diagram but tried to draw a fitting curve by hand. As one can see, it is some kind of nonlinear dependence with a derivative decreasing, while investment cost increases. The interpretation of this dependence is the following. Large-scale FMS are preferable in a sense that a unit of technical complexity scale is cheaper for such FMS in comparison with relatively small FMS. We believe that this fact is an illustration of one of the consequences of the well-known scale effect.

As one can see, critical point A, when the rate of investment per MT growth becomes much lower, corresponds to 12 million dollars of FMS cost.

A similar pattern shows the investment per one machining

Figure 12. Investments per one MT:



center versus the FMS investment cost scatter diagram (Figure 13). FMS consisting of only machining centers were taken into consideration while drawing this diagram. Thus the ratio of investment cost to the number of machining centers is meaningful and is correct from a methodological point of view in this case.

Here again, we drew a nonlinear fitting curve "by hand" and got even a more impressive result than in Figure 12. That is to say, it is possible to locate the point corresponding to maximum investment cost per one machining center. The "threshold" level of investments is again approximately equal to 12 million dollars, so the scale effect proves to occur in this case too.

Another interesting point connected with figures of investment per MC or MT is the trend of these parameters over time. The methodology used to obtain these trends was the following.

First, we divided all FMS installations into a few groups or clusters according to investment cost. Second, within each cluster for each available point of time, the average value of the above-mentioned parameters was obtained. After that, the dependencies of average values of these parameters over time were plotted. A very important point here is how to obtain in some formal way the decomposition of FMS installations to clusters in such a way that installations within each cluster are similar in the sense that investment cost and trends of investment per MT or MC over time are meaningful. One can find the description of the relevant procedure in [13].

Figure 14 shows trends in the average value of investment per one machining center over time for two subsets of FMS installations: those with investment costs of no more than 5 million dollars and those between 5 and 15 million dollars for one FMS. Similar trends were obtained for both clusters, namely, the trend of increasing "unit" investments up the the middle of the 1980s and decreasing the latter after this point. It should be noted that information related to 1987 is, of course, only projected data and too few relevant information entries are available now, so this conclusion is to be verified in the future.

Figure 15 demonstrates different patterns connected with trends of investment per one machine tool. Four clusters of FMS installations were obtained with "threshold" values of investment

Figure 13. Investment per one MC over

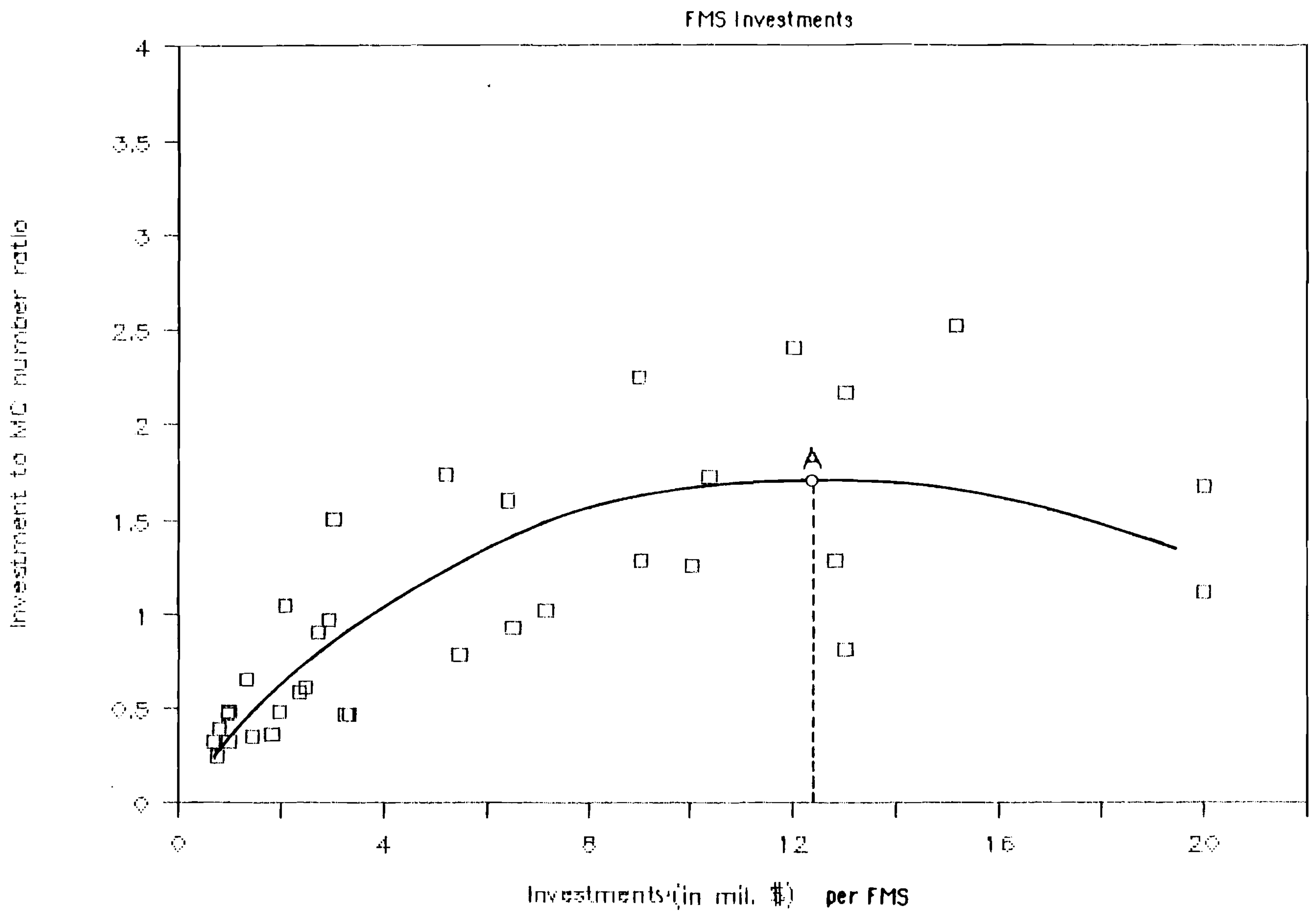


Figure 14. FMS with Different Investment Costs:

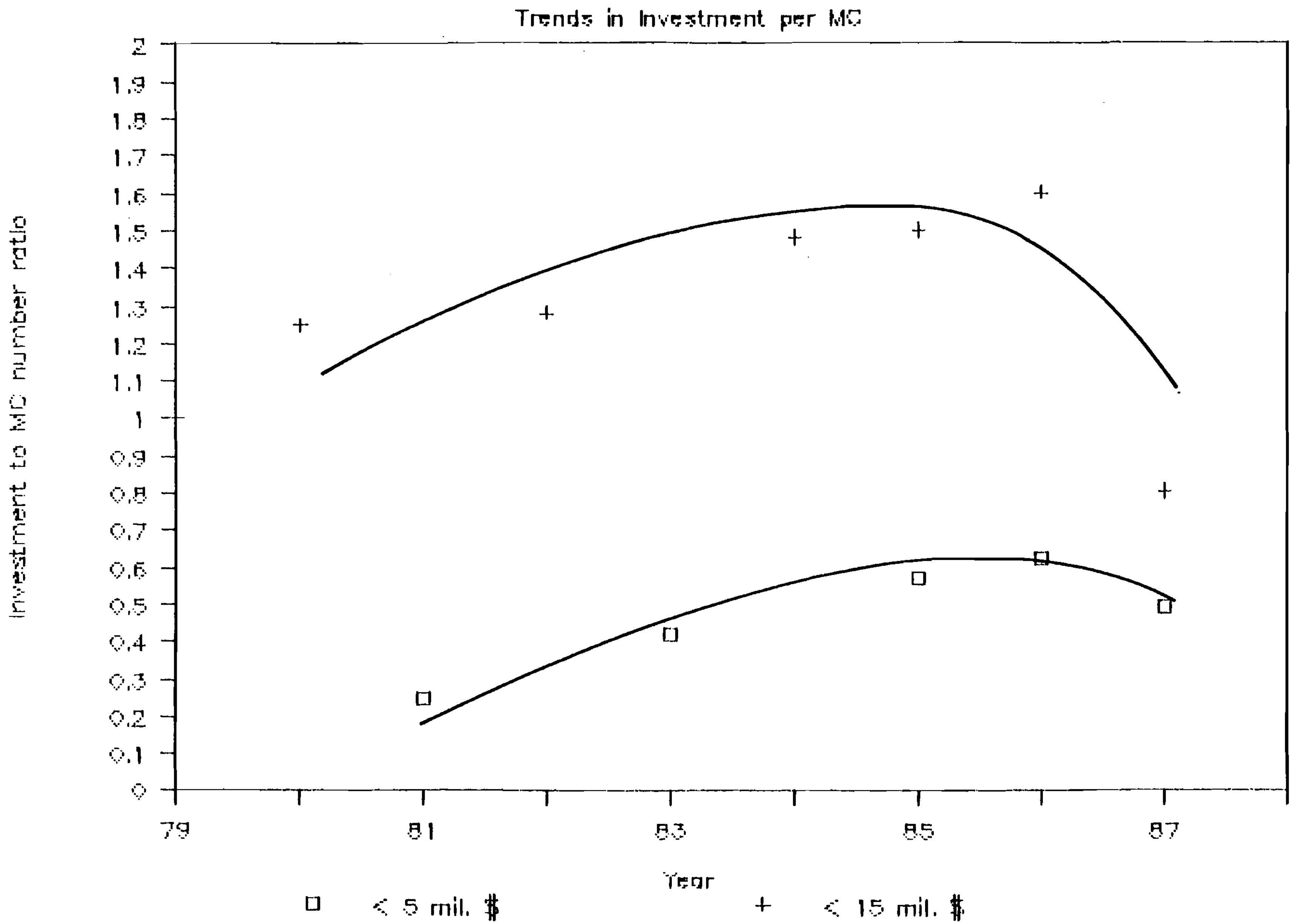
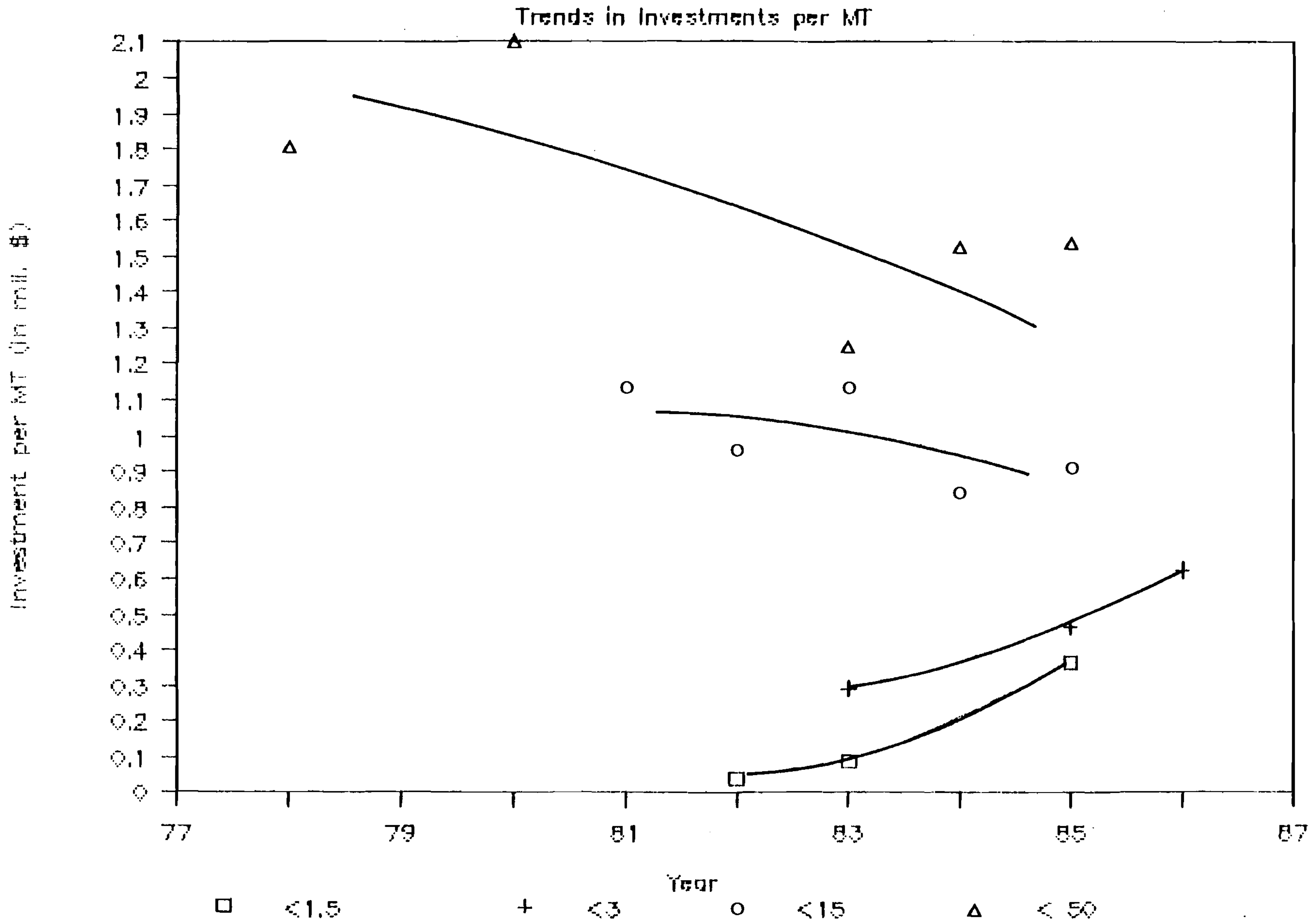


Figure 15. FMS of Different Scale:



costs accordingly equal to 1.5, 3, 15 and 50 million dollars per FMS.

For the first two subsets of FMS installations there is a tendency of increasing investment per one MT, while for large-scale FMS there is an opposite tendency.

The increase of relative MT cost for small FMS may be explained through the growth of supplementary costs (i.e. transportation, control costs), which have a relatively big share in the total investment per MT. The declining MT cost for big FMS reflects the cost reduction process which usually follows technological progress.

It seems reasonable to suppose that the distinction of trends in MC and MT can be explained in the following way.

Machining centers are relatively new technological equipment, which are now at the embryonic stage of development. This equipment becomes more and more sophisticated and accordingly more expensive. Economy of scale does not affect MC.

On the other hand, numerically controlled machine tools (and MT data mainly consists of this euqipment) have been produced for many years. They are now at the expansion stage of development. That is why the scale effect demonstrates itself.

There are two investigations made for the FMS flexibility analysis: batch size and bay-back time versus flexibility.

Unfortunately, we could not verify the well-known theoretical graph, mentioned by Cross and Trecker, Spur and Martins and the others - "productivity versus flexibility" (see Figure 16) - because of the lack of information on the "yearly production of each variant".

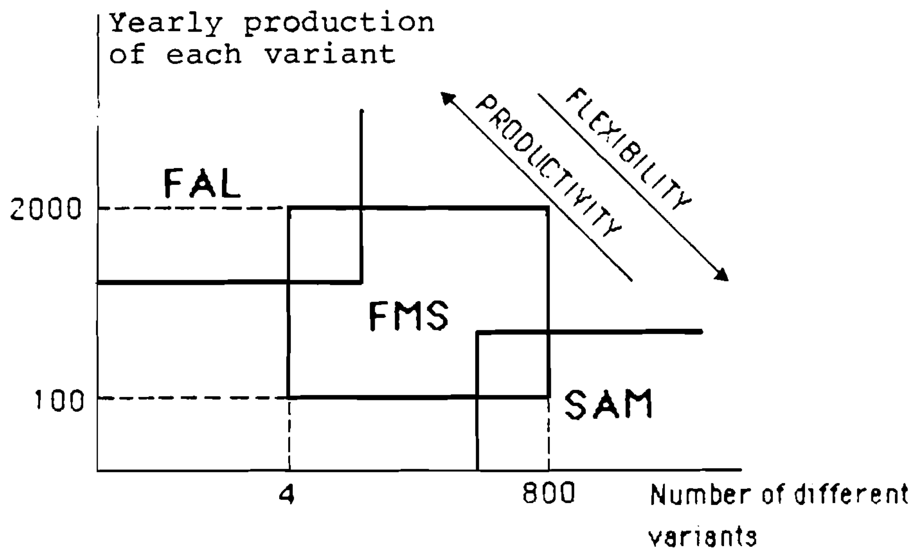
But we tried to find the relationship between a batch size and flexibility. For the more reliable part of the data (number of product variants less than 100 and batch size less than 500) we got a rather reasonable, hyperbolic type curve (see Figure 17).

For the most exotic Japanese FMS with the variant numbers 1500, 3000, 4000 the batch size was 20, 20 and 20, respectively. And vice versa, the maximum batch size (5000) corresponded to variant number 40.

The last issue to consider is the interrelation between flexiblity of FMS and pay-back time.

Figure 18 is relevant to this point. As one can see, there

Figure 16. Flexibility versus Productivity



FAL - fully automated lines

FMS - flexible manufacturing systems

SAM - stand-alone machines

Figure 17. FMS - Batch Size versus Flexibility

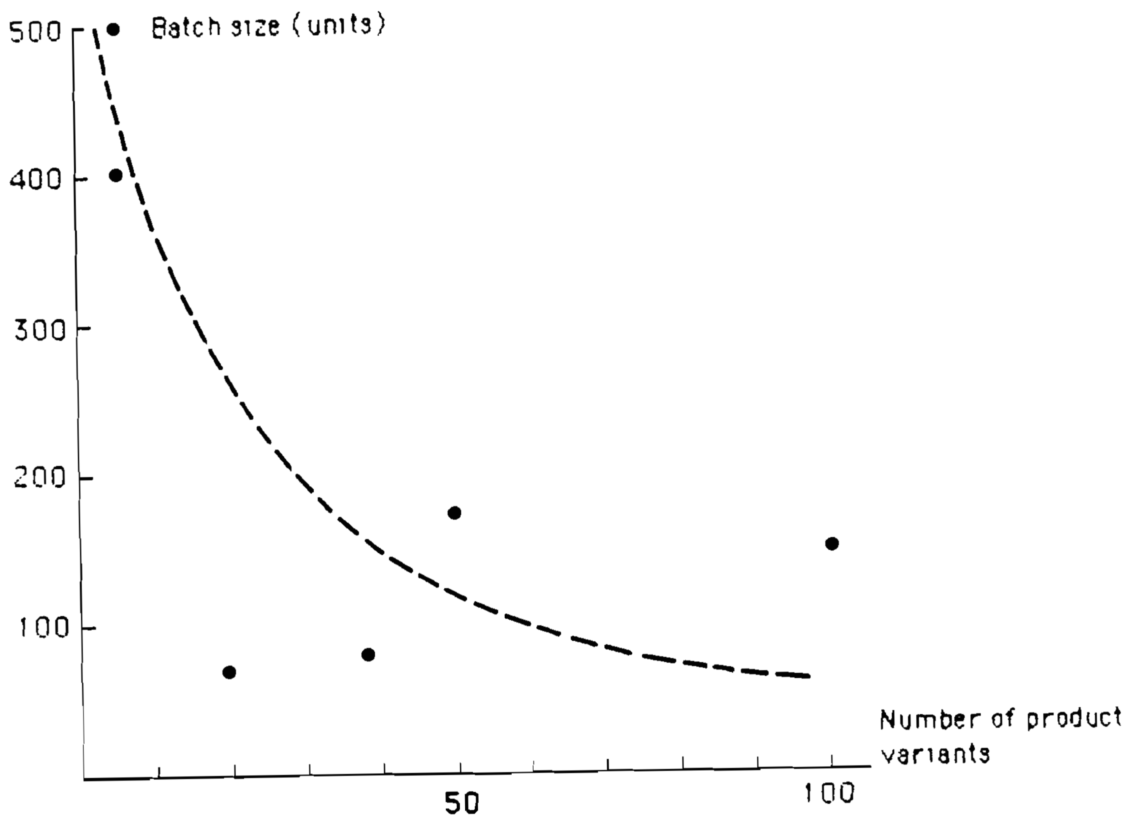
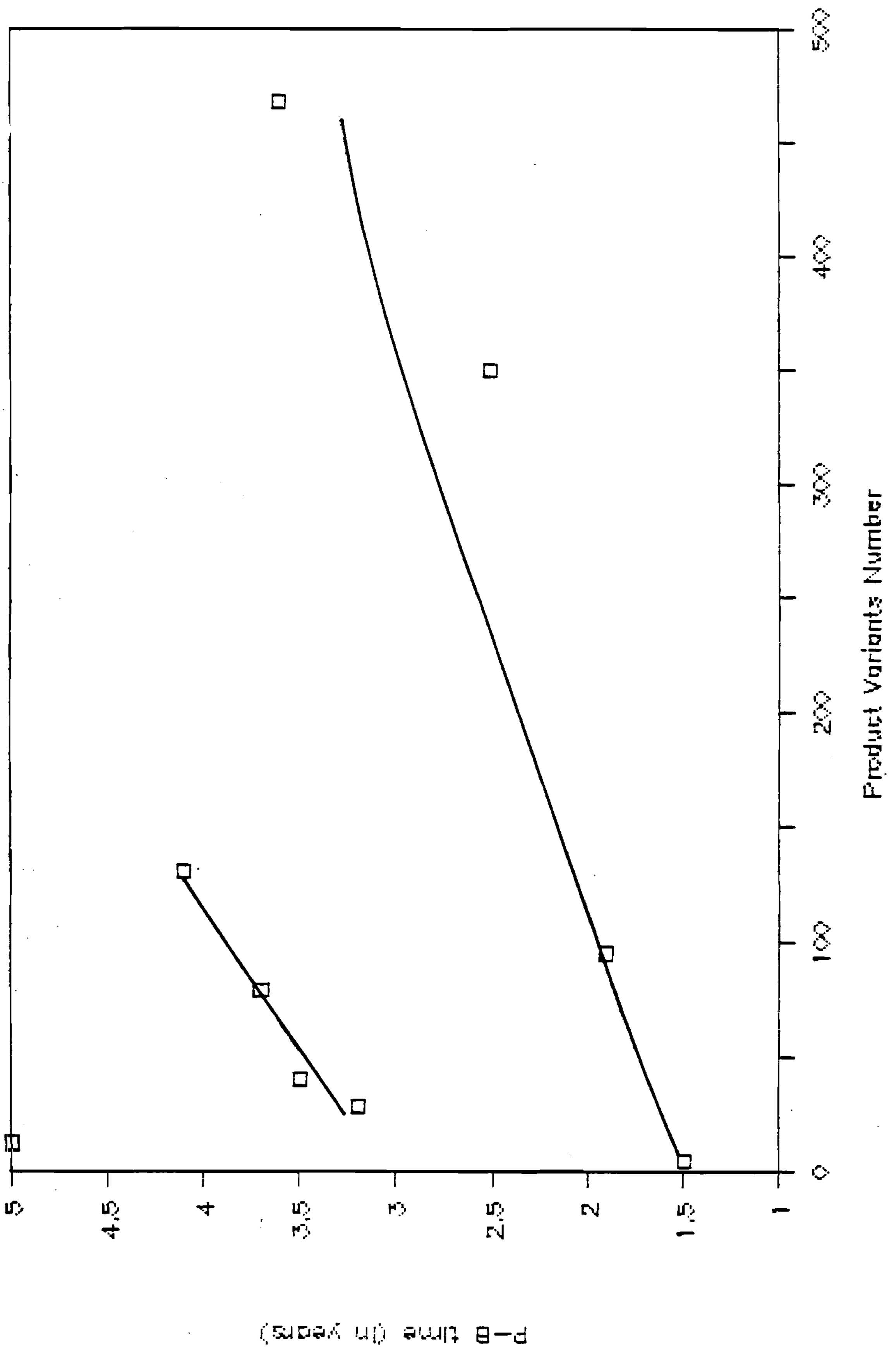


Figure 18. P–B time versus Product Variants Number



are two dependencies between analyzed variables with one exclusion point for PBT = 5. Both dependencies show that pay-back time increases as flexibility increases. The proposed explanation is the following.

The growth of flexibility is connected with the increase of FMS cost. If the latter grows more rapidly than the value of products, the pay-back period will increase. This is correct for cases of embryonic type technologies which FMS belong to.

LITERATURE

[1] Baranson J. Automated Manufacturing: The Key to International Competitiveness - and Why the United States is Falling Behind. Washington, D.C.: Developing World Industry and Technology, Inc., 1983.

[2] Flexible Manufacturing Systems Handbook Volume I-IV. Charles Stark Draper Laboratory, Cambridge, Mass., February 1983.

[3] Flexible Manufacturing Systems - State of the Art and Trends in Their Diffusion. Draft Study, Economic Commission for Europe. Working Party on Engineering Industries and Automation, July 1984.

[4] Proceedings of the First International Conference on Flexible Manufacturing Systems, Bedford, England: IFS (publications) Ltd., October 1982.

[5] Clifford Y., Airey J. Economic Justification for FMS: Counting Strategic Benefits. Arthur D. Little, Inc. 21.

[6] Darrow W.P. A Survey of Flexible Manufacturing Systems Implementations. U.S. Department of Commerce, NBC, July 1986.

[7] A Competitive Assessment of the U.S. Flexible Manufacturing Systems Industry. U.S. Department of Commerce, International Trade Administration: Washington, D.C., July 1985.

[8] The Past and the Present of FMS. Metal-working Engineering and Marketing, March 1986, pp. 29-59.

[9] Computerized Manufacturing Automation. Office of Technology Assessment: Washington, D.C., April 1984.

[10] The FMS Report. John Mortimer, ed. IFS (publications) Ltd., Bedford, England, 1982.

[11] Recent Trends in Flexible Manufacturing. U.N.: N.Y., 1986.

[12] Ayres, R. et al. A Rough Draft of an Inventory of Computer-Integrated Manufacturing Systems. Carnegie-Mellon University, 1983.

[13] The Problems of Organizations Functioning Analysis. Sheinin R.L., ed., Moscow, VNIISI, 1986 (in Russian).

[14] Tchijov, I. The Cyclical Dynamics of Diffusion Rates. IIASA Working Paper, 1986.

[15] Edquist C., Jacobsson S. The Diffusion of Electronics Technology in the Capital Goods Sector in the Industrialized Countries. UNCTAD/TT/65, 11 Sept. 1985.

APPENDIX 1

List of Data Used in Statistical Data Basa

TYPE	NO.	NAME	DESCRIPTION
Identification	0	Country	Name of the countery where FMS is allocated.
	1	Company	Name of user
	2	Vendor	Name of main producer
	3	Year	Year of installation
	4	Applic	Application area 1) machining 2) assembling 3) manufacturing 4) metalforming 5)welding
System Features	5	MC	Number of machining centers
	6	NCMT	Total number of numerically controlled machine tools
	7	Robots	Number of robots (excluding transportation robots and manipulators).
	8	Transport	Type of transportation system: 1 conveyor, 2 automated guided vehicles, 3 computer controlled carts
	9	Storage	Type of storage system: 1 automated storage and retrieval systems, 2 computer controlled warehousing systems
	10	Inspec	Type of inspection: 1 automated measuring and inspection systems, 2 automated maintenance and monitoring systems
Economic and operation data	11	Op. Rate	Operation rate (number of shifts a day
	12	Unman. op.	Number of shifes of unmanned operations
	13	B. Size	Batch size (maximum/average)
	14	Prod. Var.	Product variation (number of products produced by FMS)
	15	Invest	Investment cost in local currency
	16	$ Invest	Investment cost in US $
	17	P-B Time	Pay-back time (years)

			REDUCTION OF:
Relative Advantages	18	Lead time	Lead time
	19	S-U-T	Set-up time
	20	I-P-T	In-process time
	21	W-I-P	Work-in-progress
	22	Mach. Time	Machining time
	23	Inventory	Inventory
	24	Personnel	Personnel
	25	Floor SP.	Floor space
	26	PCR %	Production cost, %
			INCREASE IN:
	27	Product	Productivity
	28	Prod. Cap.	Production capacity
	29	Source	Name of Information Source