WORKING PAPER

MACHINING FMS:
TENDENCIES OF DEVELOPMENT

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IIASA
International Institute
for Applied Systems Analysis

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FOREWORD

One of Saint-Exupery's heros said: "We are forecasting the past". This is why, in order to predict the future FMS diffusion as well as its development, the author had to analyze historical tendencies of the changes of the indicators, collected in the FMS World Data Bank. The current version of the Bank includes more than 30 indicators for about 800 FMS installed in the world industry.

Approximately 750 systems give information on the year of installation. This is why a clustering of the data by years of installation allows to compare the average indicators for each FMS generation and to retrieve some temporal tendencies.

The paper focuses on the general development tendencies for the systems used in machining and manufacturing processes, as well as on the East-West comparison of the tendencies. It presents statistically reliable results, which could be extremely useful for the prediction of FMS development and diffusion.

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1. Introduction

The 3.2 version of the FMS World Data Bank [2], developed in IIASA's CIM project, consists now of about 800 cases from 26 countries. It covers more than 30 indicators, describing technical, operational and economic FMS features, including cost-benefit figures and relative FMS advantages. For some indicators their total number does not exceed 70, but for the majority of them there are more than 100 FMS, where such data are available.

From the statistical viewpoint this information is sufficient, not only for a general data analysis, but for clustered subsets investigation. For example, there are more than 750 FMS in the Bank with data on their years of installation. This allows to cluster the whole FMS set into several samples (generations) by the year of installation, and to analyze some temporal tendencies in changes of average figures. Thus, the analysis will be based on the comparison of average figures for each generation. This could be interesting for the assessment of FMS diffusion processes, as well as for the better understanding of their development.

The general FMS distribution by the years of installation, shown in Figure 1, confirms that the real FMS penetration into the industry began in the 1980's, though the first implementations were reported before 1970. Some stabilization of the annual FMS installations, observable in the Figure after 1984, could be explained by a growing number of missed systems installed during the last years. According to indirect information, the average annual growth rate of the world FMS population was approximately 15% at that time.

The FMS diffusion through the industries and areas of application, illustrated in Figures 2 and 3, shows that in spite of growing shares of electronics and instruments industries (IND2), as well as non-traditional areas of application (metal-forming - APP3, welding and assembling - APP4+5), the significant majority of FMS is used in machinery and transportation equipment industries (IND1) for machining and manufacturing (APP2 and APP1, respectively).

One can notice some important differences between the average characteristics of FMS used in machining, assembling or metal-forming. For example, the average number of robots in assembling FMS is 9 times higher than in machining systems. Metal-forming FMS produce 10 times more product variants than machining FMS and 25 times more than assembling systems. The lead time and unit cost reduction is the highest for metal-forming FMS, but the highest record in personnel reduction is observed in manufacturing systems.

In order to avoid mixing different types of FMS in the analysis of dynamic tendencies described below, we have chosen machining systems and manufacturing FMS, where machining processes dominate, as a background sample. Totally there are 694 such systems in the Bank with information on installation years.

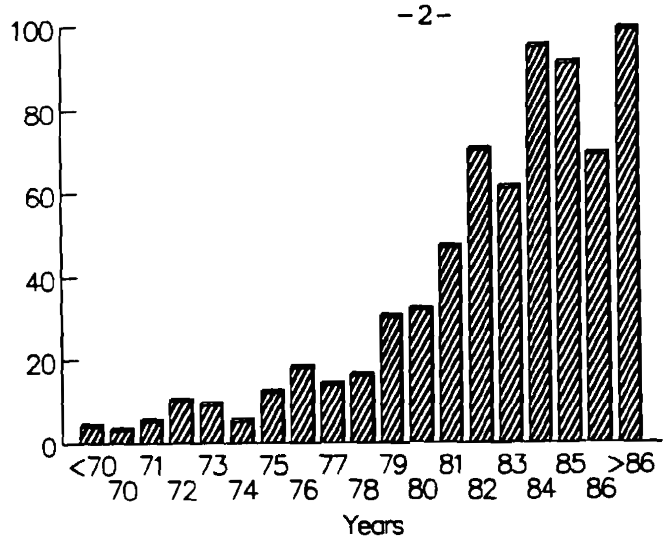

Figure 1. Number of FMS by years of installation.

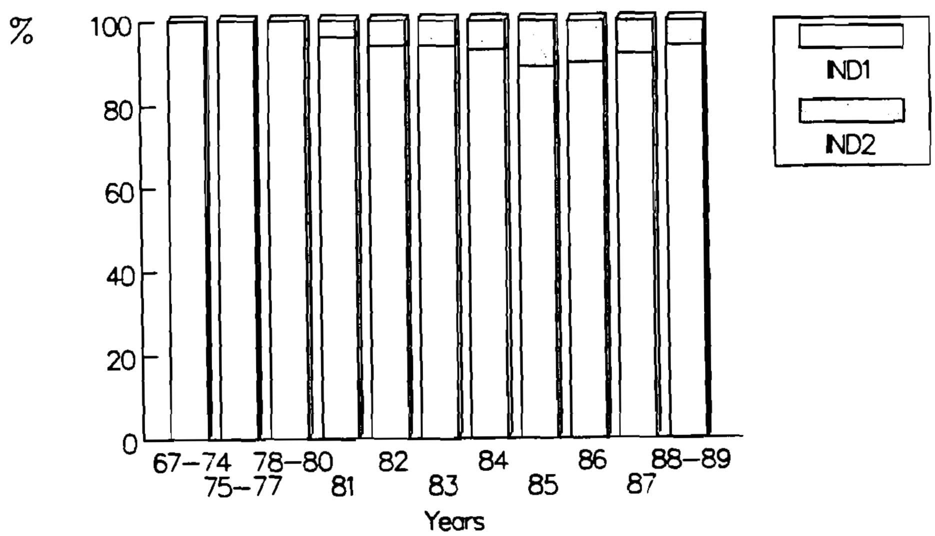

Figure 2. FMS distribution by industries (IND).

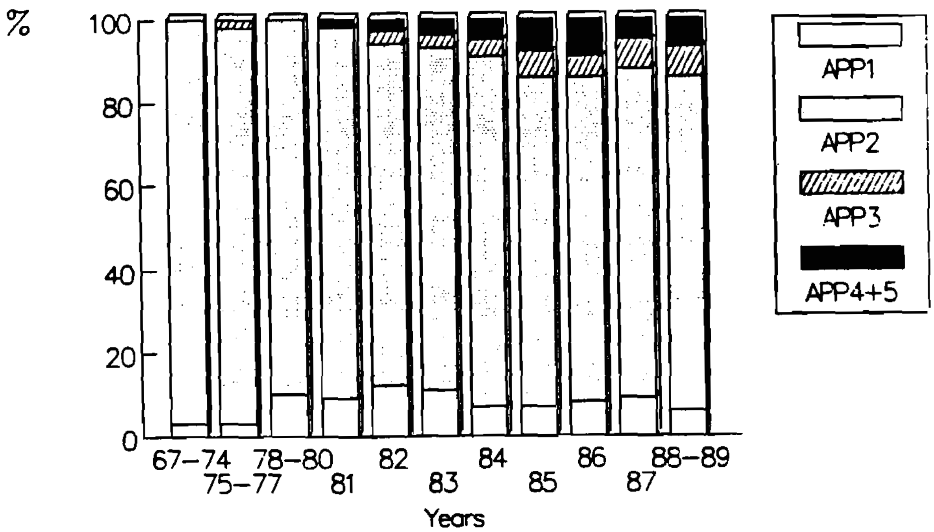

Figure 3. FMS distribution by areas of application (APP).

Table 1. Average FMS indicators by areas of application (APP1 - manufacturing, APP2 - machining, APP3 - metalforming, APP4+5 - welding and assembling).

	NCMT	ROB	TC	OPR	PV	BS	INV	PBT	LTR	PER	UCR
APP1	11.5	6.8	6.2	2.4	83	844	6.0	3.0	4.6	6.2	1.48
APP2	6.8	3.1	4.3	2.6	166	184	5.8	4.0	4.9	3.6	1.69
APP3	4.2	1.4	2.2	2.1	1628	74	5.1	4.6	21.7	1.7	2.35
APP4+5	20.2	26.1	9.2	2.0	66	449	6.2	3.0	5.2	3.8	1.95

Here and below:

NCMT - number of NC machine tools, ROB - number of robots, TC - technical complexity index, OPR - operation rate (number of shifts a day), PV - number of product variants, BS - average batch size (units), INV - investments (million US$), PBT - pay-back time (years), LTR - lead time reduction, PER - personnel reduction, UCR - unit cost reduction (all three - by a factor of).

2. Development Tendencies of Machining FMS

As described in [4], the FMS technical complexity was measured as a weighted function of the number of machining centers, the number of the other NC-machines, the number of industrial robots and the type of transportation system (TRT = 2 for a sophisticated flexible system, like AGV, and 1 for the other types).

The changes of TC (for abbreviations see Table 1) over time are shown in Figure 4. We had to aggregate the first time interval to obtain statistically more representative estimates of the average data. One can observe a growing tendency of the average technical complexity up to 4.75 in 1986 and a certain decline afterwards. This result confirms the information, published in some Japanese and international sources, that today the main FMS vendors simplify FMS in order to standardize them and make them marketable and attractive for new adopters.

The same tendencies are demonstrated in Figure 5 for the US and Japanese cases. The former passed a technical complexity peak in 1986, while the latter ones had passed it in 1983.

In order to understand the factors behind such a tendency in TC changes, we had to analyze the behavior of the TC components over time. In spite of some fluctuations in the number of average machining centers (MC) (see Figure 6), this indicator could be considered as stable, with an implicitly expressed tendency of growth up to 1982, followed by a decline.

The general tendency in the number of total NC-machines per FMS (NCMT) is definitely negative, which is shown in Figure 7. But within this general tendency one can notice a growing average NCMT tendency till 1981 and a decline afterwards.

The strong growth of the average number of robots per system (ROB) for 209 FMS, where the use of robots was reported (see Figure 8), is significantly influenced by the increasing share of assembling systems. The lower curve in the Figure, estimated for machining FMS only (172 cases), demonstrates a much more moderate rate of ROB growth.

One can observe a certain saturation tendency in the average index of transportation systems TRT. As TRT is a dual index equal to 1 or 2, the saturation level of 1.6 means that approximately 60% of the FMS installed in the middle of the 1980's were equipped by AGV or other sophisticated flexible transportation systems. A definite tendency of growth in changes of the average index of storage systems (STO) is shown in Figure 10. The analogous figure for the inspection system index (INS) demonstrates an extremely strong growth up to 1.6 in 1982, followed by a definite decline down to 1.35. This means that 60% of the FMS installed in 1982 had sophisticated systems of quality and process control and only 35% of the FMS installed in 1987-1989 were equipped with such systems.

From the figures it is possible to derive the following conclusion. In the 1980's the tendency towards a higher technical

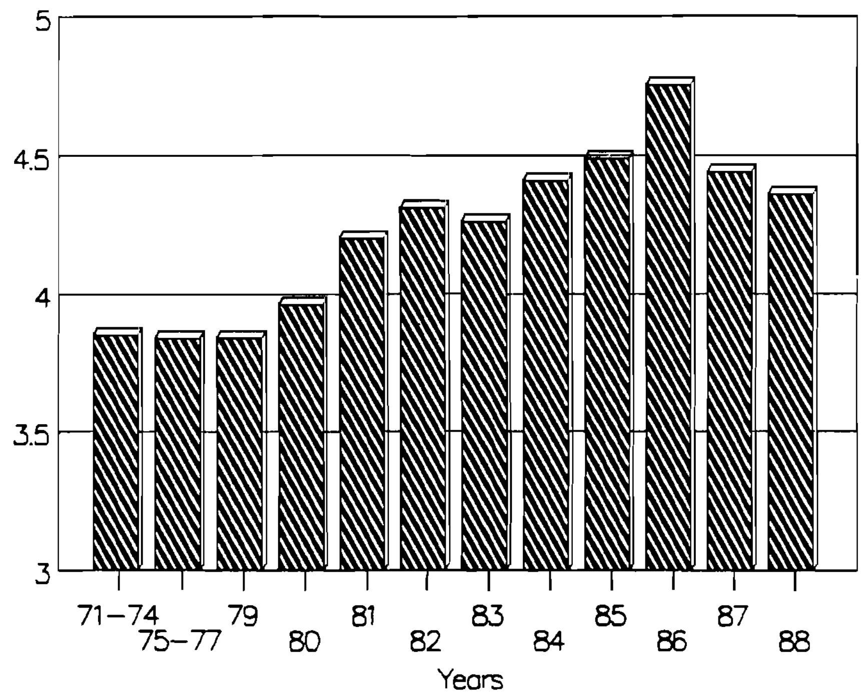

Figure 4. FMS technical complexity (TC) tendency.

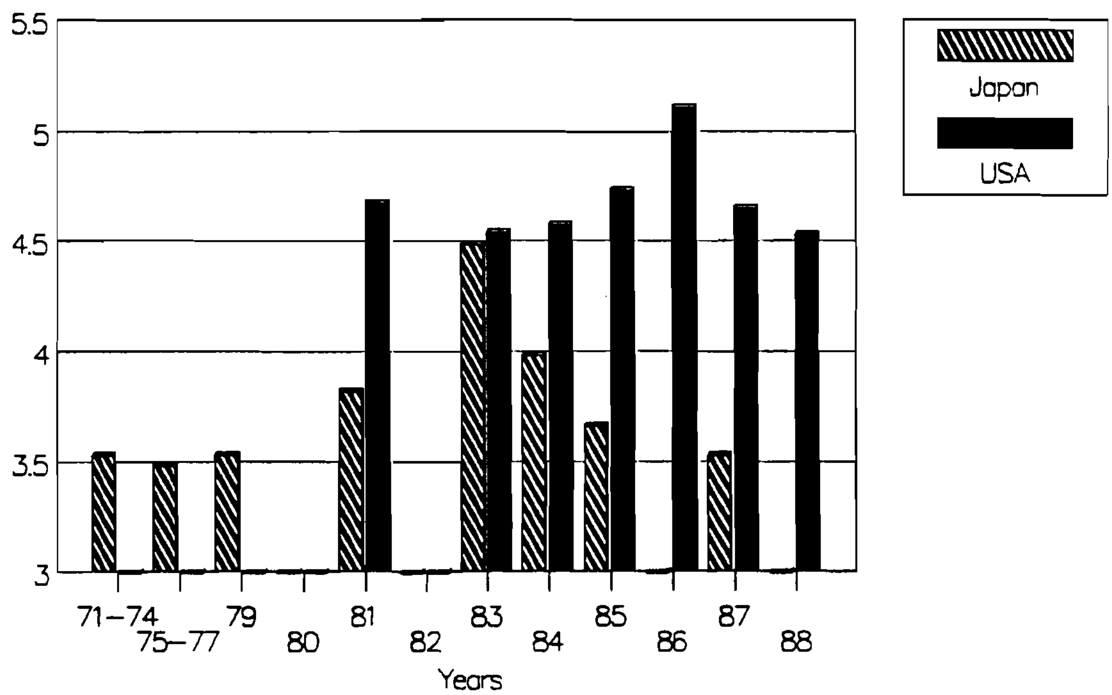

Figure 5. FMS technical complexity (TC) tendencies in Japan and in the USA.

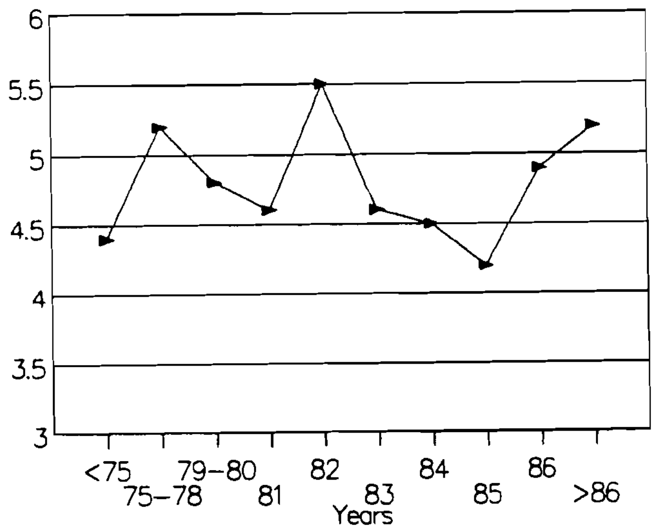

Figure 6. Average number of machining centers (MC) per FMS by years.

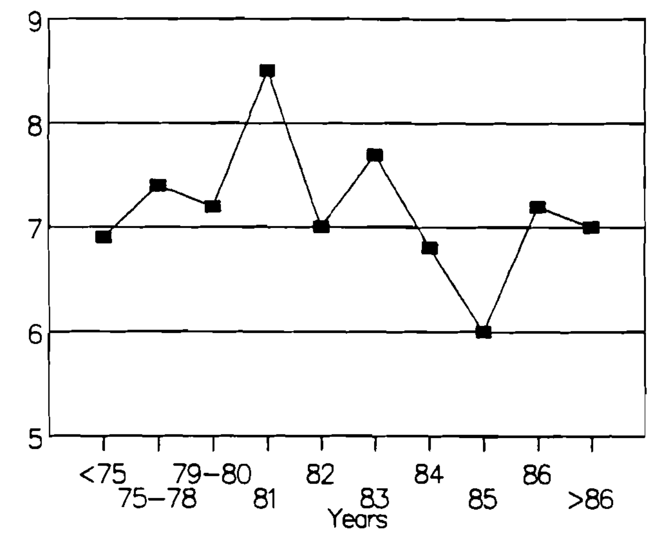

Figure 7. Average number of NC machine tools (NCMT) per FMS by years.

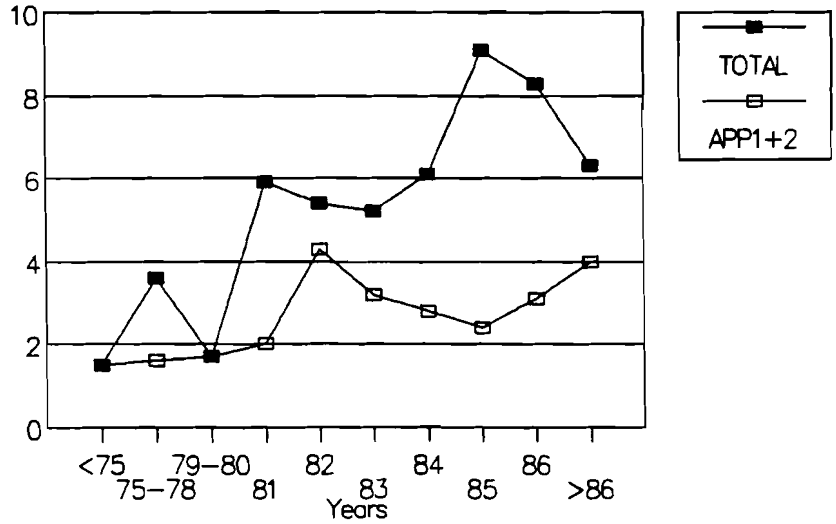

Figure 8. Average number of robots (ROB) per FMS by years.

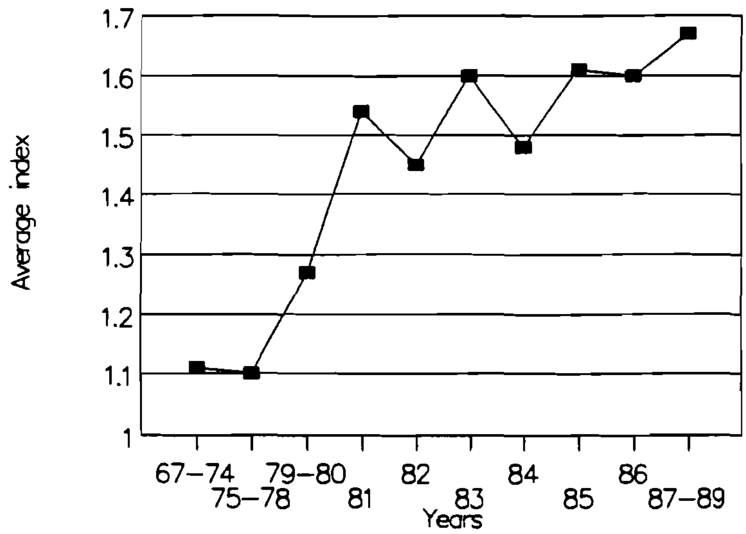

Figure 9. Average TRT index by years.

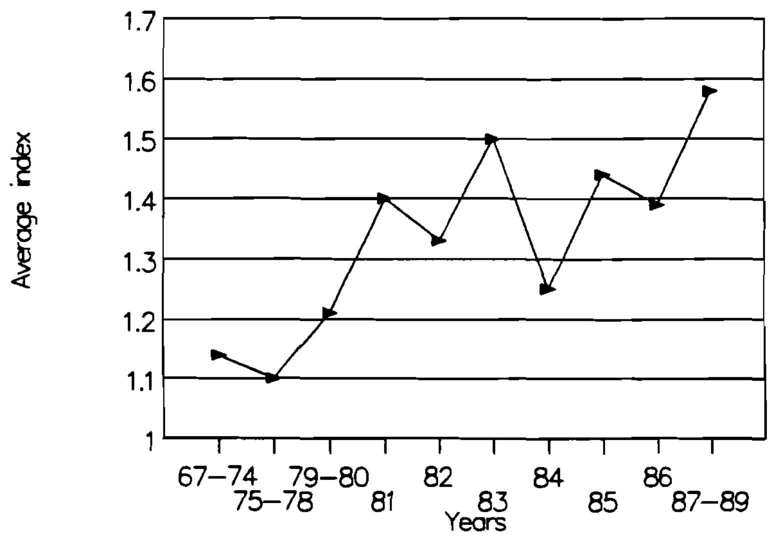

Figure 10. Average STO index by years.

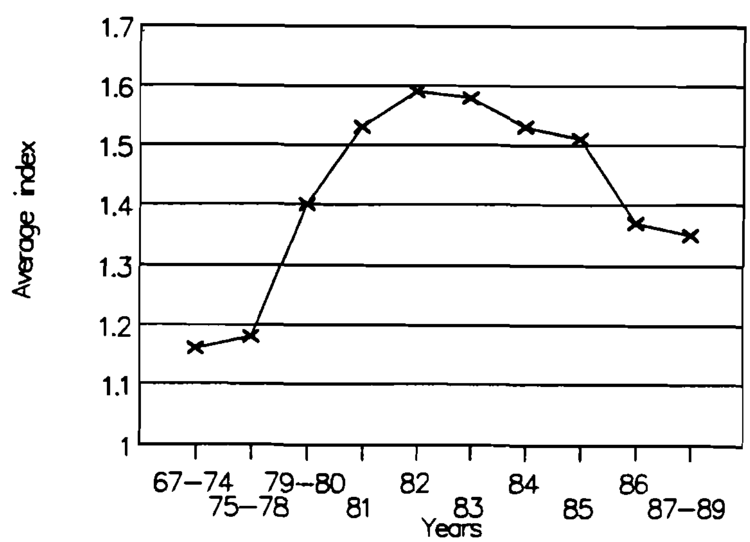

Figure 11. Average INS index by years.

complexity met some obstacles. First of all, the experience in FMS use indicated that from the economic viewpoint some expensive subsystems were not reasonable and increased the pay-back time. Secondly, certain limits to the growth of the number of machines are connected with hyperbolically increasing software costs when the number of pieces under computerized control is increasing. The third reason for TC stabilization -- or even decrease -- is the growth of the FMS world market. Highly sophisticated FMS could be invested and managed by big companies sufficiently experienced in high-tech use. But in the 1980's a lot of new FMS adopters came on the market, and some of them were relatively small companies, subsidized by governmental bodies. Having no experience in FMS use, they demanded relatively simple and inexpensive systems.

FMS flexibility, measured in the number of product variants (PV) and the average batch size (BS), looks rather stable on the long-term horizon (see Figures 12 and 13, respectively). In order to avoid disturbances caused by several cases, where, as we suspect, the maximal (but not average) values of PV and BS were reported, these values were restricted by 1000. The role of such disturbances is not so important when we estimate average figures for the whole data set with hundreds of cases, but in smaller annual samples they lead to serious shifts.

After these changes we got some PV fluctuations in time, but around a horizontal axis at a level of 120 product variants (see Figure 12). The axis of BS fluctuations looks like a curve (see Figure 13) with a growing tendency till 1982 and a declining one after it. One can observe in the Figures that peaks in PV usually coincide with troughs in BS and vice versa. This means a rather stable value of PV*BS. The main conclusion is as follows. The average FMS flexibility increases somewhat in time due to a decrease of the average batch size. This tendency is true for the period after 1982.

The relative FMS advantages were reported in a minority of the cases in the Bank. This is why we had to aggregate the time intervals to obtain more than 10 figures for each sub-period. The results for the selected indicator are shown in Figures 14 - 17.

The really strong growth in lead time reduction (LTR), when FMS substituted for conventional technologies, is obvious in Figure 14 at the beginning of the 1980's. Before this time an FMS implementation led to 50% LTR, while in the 1980's it reached more than 80%. Stabilization of the indicator at this level means a certain saturation and reaching the upper limit for the current FMS generation after passing through a learning curve. Naturally, there are several exclusive cases in the Bank, where more than 95% lead time reduction was reported.

The comparison of the three sub-periods of changes of logistic indicators (see Figure 15) disclose a continuing growth of the inventory and work-in-progress reduction (INR and WIP, respectively). Of course, the INR figure for 1986-1989 is somewhat overestimated, which is due to several cases, where zero inventories were reported after the FMS implementation. But in

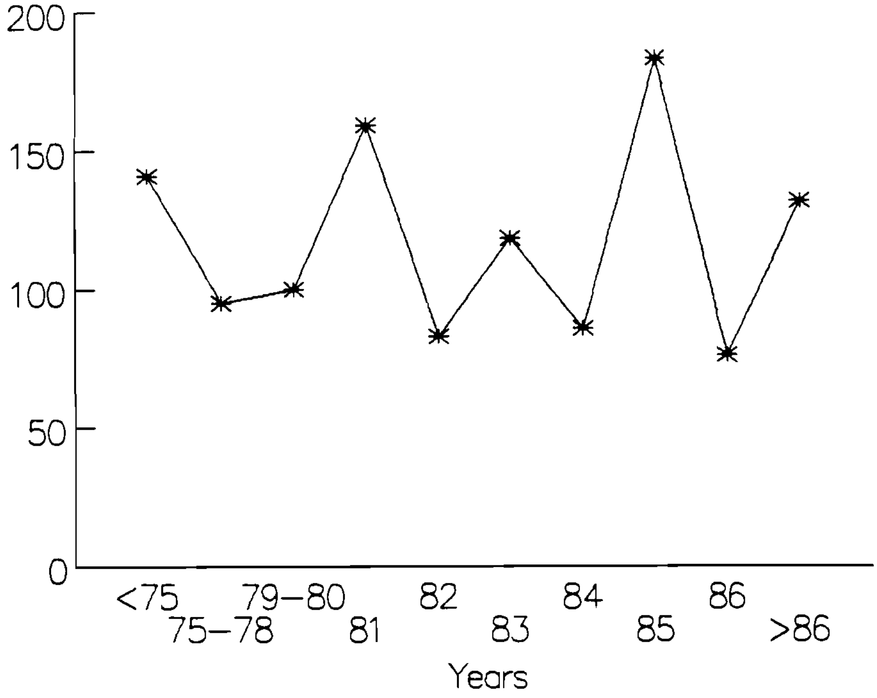

Figure 12. Average number of product variants (PV) by years.

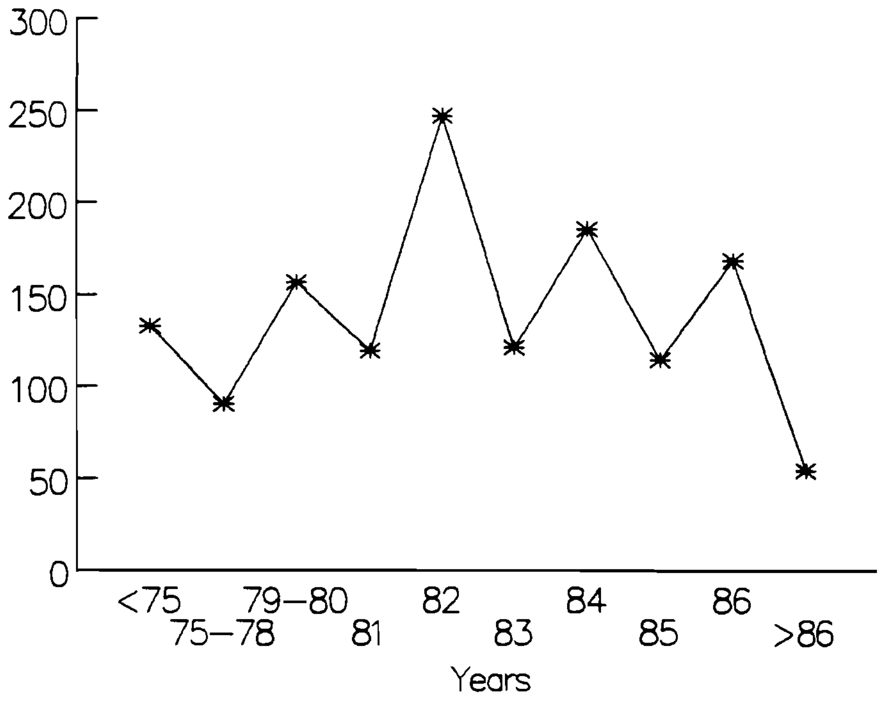

Figure 13. Average batch sizes (BS) by years.

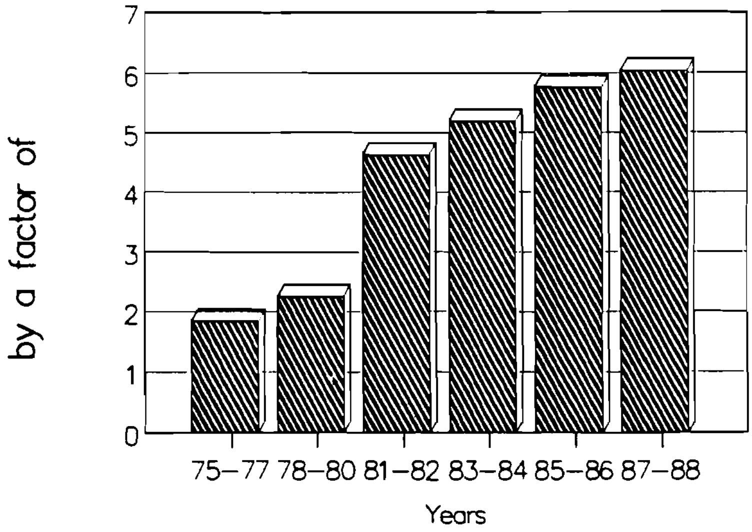

Figure 14. Lead time reduction (LTR) tendency.

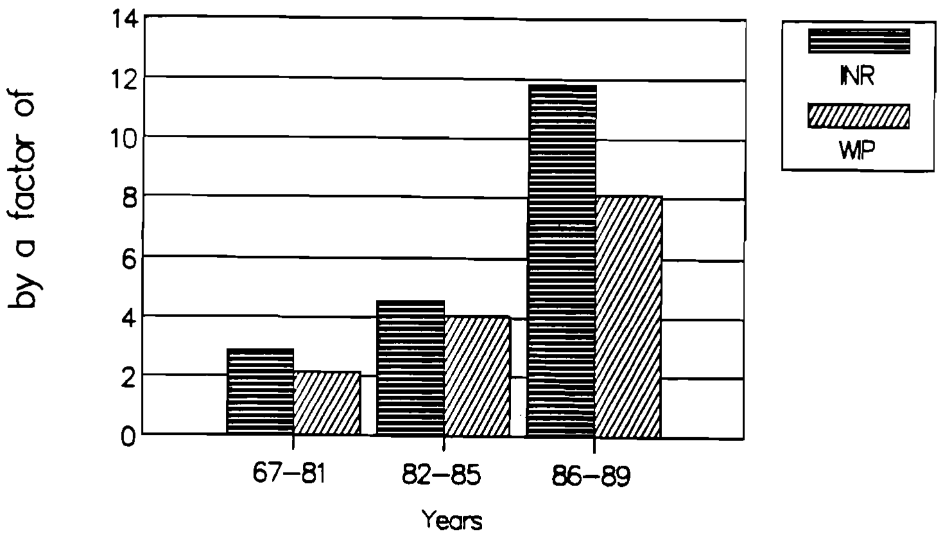

Figure 15. Inventories (INV) and work-in-progress (WIP) reduction tendencies.

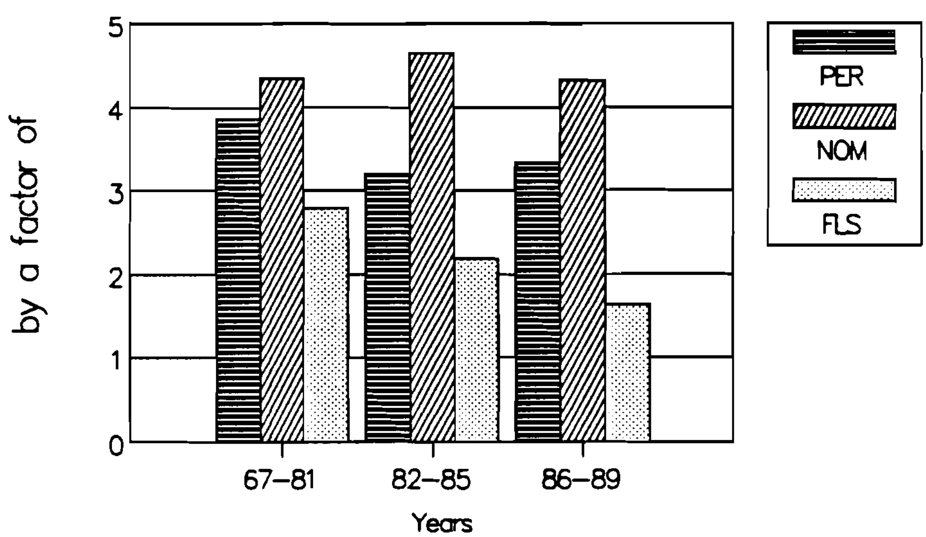

Figure 16. Personnel (PER), number of machines (NOM), and floor space (FLS) reduction tendencies.

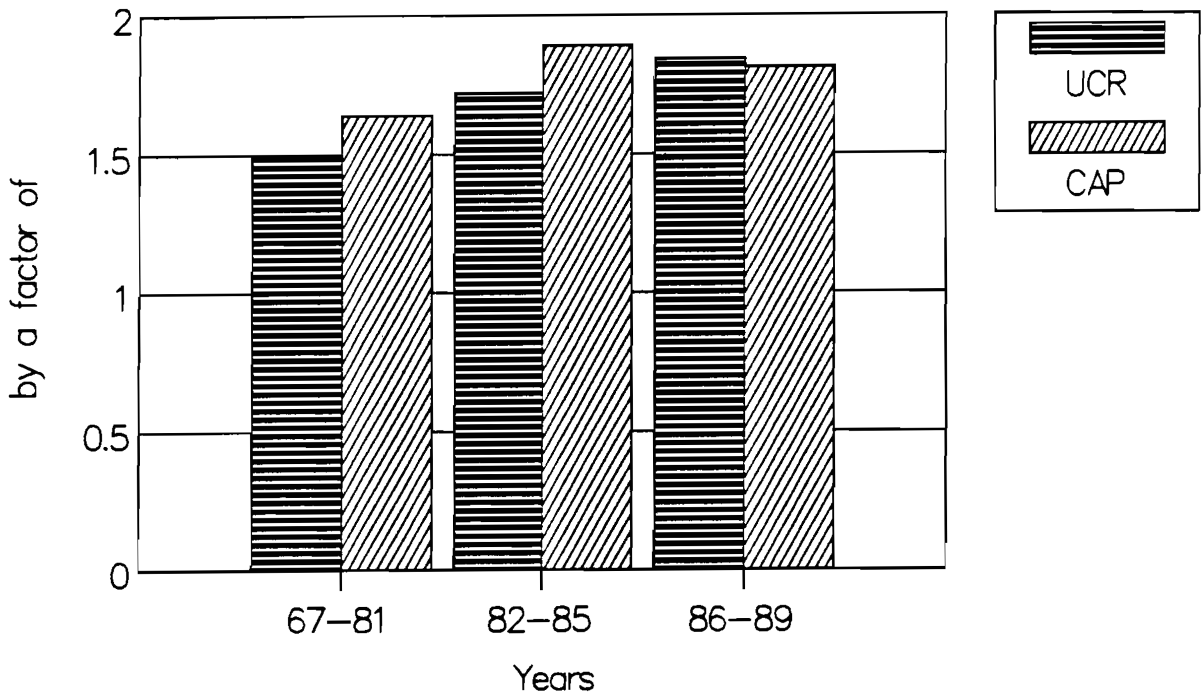

Figure 17. Unit cost reduction (UCR) and capacity utilization increase (CAP) tendencies.

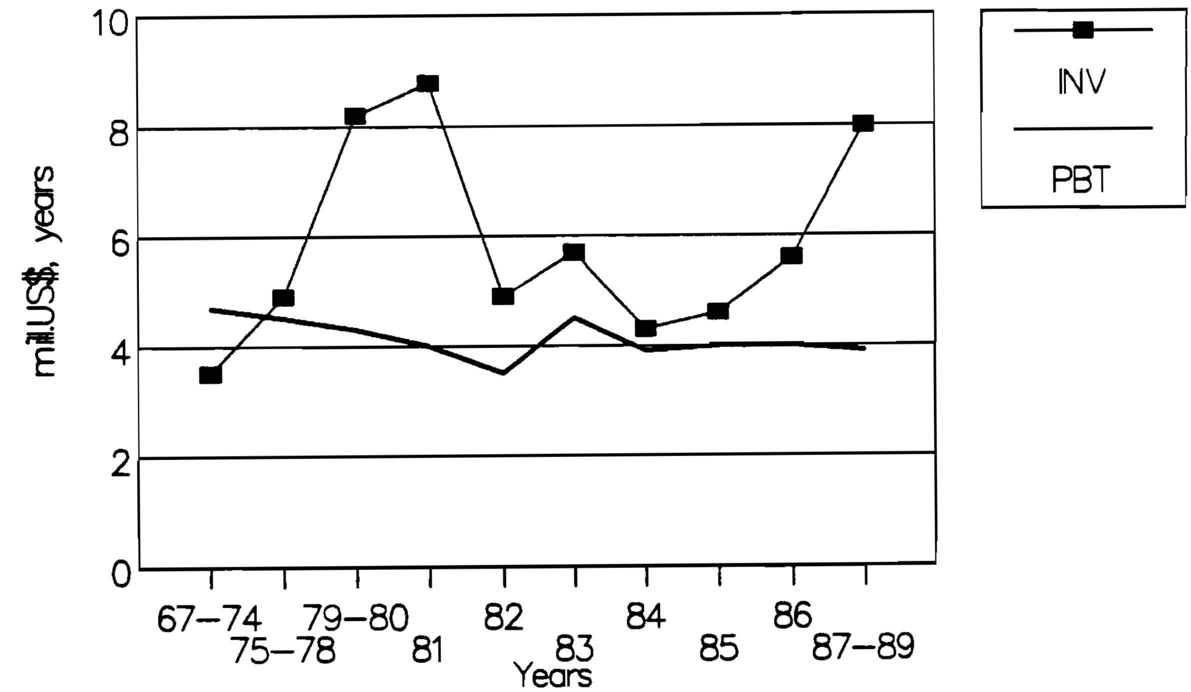

Figure 18. Investment (INV) and pay-back time (PBT) tendencies.

any case, the strong tendency of growth is clear and this fact confirms the high importance of these FMS advantages.

The analogous figures for the personnel, number of machines and floor space reduction (PER, NOM and FLS, respectively -- see Figure 16) do not show any increase of the indicators in time. Moreover, FLS is decreasing over time. Two other indicators look rather stable, independent of time. The results stress a relatively low importance of floor space saving in the total cost reduction. The further increase of PER and NOM beyond the attained levels (66 and 77%, respectively) could meet with some economic obstacles, making the incremental growth unprofitable from the viewpoint of a total cost reduction.

The capacity utilization increase (CAP) and the unit cost reduction (UCR) are more moderate by nature than the above-mentioned advantage indicators (see Figure 17). In these cases a slight tendency towards growth is observable. CAP increased from 65% in the 1970's up to 80% in the second half of the 1980's. This means that in the first period FMS had 65% higher capacity utilization than their predecessors, and 80% higher capacity in the second period. In the 1970's the cost of a unit produced by an FMS was two thirds of the cost of the same unit produced by a conventional technology. This ratio dropped to about half.

The dynamics of the average FMS investment cost (INV) looks rather contradictory, while the average pay-back time (PBT) was permanently going down during the 20 years of the FMS history (see Figure 18). The latter fact probably reflects the learning curve effect, but the investment behavior needs a more detailed explanation.

The strong INV growth took place in FMS generations installed in 1967-1981. The average FMS cost increased at that time from 3.5 million US$ to 8-9 million. This process could be explained by the growth of FMS technical complexity, when more sophisticated NC-machines, as well as more complex supplementary systems (for parts transportation, storaging and inspection) appeared. It was especially obvious for the systems installed in 1979-1981. The next period -- from 1982 to 1984-1985 -- was the period of an average FMS cost decline to approximately 4-4.5 million $ per system. This was due to the system passing through the learning curve, to NC-machines and a computer hardware price decrease. But in the second half of the 1980's one can see a certain increase of the FMS investment cost. This could be explained by the installation of several super-expensive systems, like LTV and GM FMS (both in the USA), which were installed in 1988 and 1987 and amounted to more than 50 mill.$ each, or Ferrari Auto (Italy), Austin Rover (UK) and McDonnel Douglas (USA) FMS, which amounted to around 20 mill.$.

3. A Comparison of East-West Tendencies

There are some specific features of FMS implementation in different countries [3], but a lack of data does not allow us to cluster the Bank by years of installation and by countries simultaneously. That is why we shall analyze development tendencies for the two main aggregates - Eastern and Western countries. In order to increase a statistical reliability of the estimates, we divided the whole sample into 5 and sometimes into 4 temporal intervals.

Dealing with the technical complexity indicators we found some differences between the Eastern and Western patterns. The strong growth of the average number of machining centers per FMS is observable for the Eastern cases in Figure 19A, while the slight decline of the indicator is obvious in the Western sample. The same, but much weaker tendencies for the total number of NC-machines are shown in Figure 19B. The different weights of the Eastern and Western cases in the general sample provide an approximate stability of the first and the decline of the second indicator in general (see Figures 6 and 7). The average NCMT was higher for the Eastern FMS in all the sub-periods, while they had more MC than the Western systems only after the middle of the 1980's.

There are similar tendencies in the development of transportation and storage systems in both samples (see Figures 20A and 20B). But while the Eastern systems started at a much higher level, then flattening off till 1982-1983 and growing again later, the Western systems had the indicators permanently increasing. Finally they have reached almost the same levels. In the case of the inspection systems (see Figure 20C) both groups of FMS started from the equally low levels, but in the 80's the Western FMS went ahead, while the Eastern ones improved very slowly. As a result, in spite of a drop of the Western indicator at the final stage, 40% of the Western FMS had -- after 1985 -- sophisticated inspection systems and the share in the Eastern cases reached 25%.

One can see a strong declining tendency in the changes of number of product variants in the Eastern sample, as well as an extremely weak tendency of growth of this indicator in the Western sample, see Figure 21A (again we fixed the maximal PV and BS values equal to 1000). The first tendency could be explained by the growing share of FMS substituting for conventional transfer lines in the Eastern countries (a detailed explanation is given in [1]). There are some declining tendencies in the average batch size changes in both samples (after 1979 in the Western sample and after 1982 in the Eastern one -- see Figure 21B). As a result the average values of PV and BS for the modern FMS generation are practically equal in the both samples.

The relative FMS advantage indicators are the poorest from the viewpoint of statistical data availability. This is why we have aggregated the time intervals and fixed the maximal FMS advantages at the level of change by no more than a factor of 20 in comparison with conventional technologies.

The FMS of both origins demonstrate a growing efficiency in terms of set-up time reduction (see Figure 22A), but the Western curve lies significantly higher than the Eastern one. The Western FMS, installed after 1985, reduced set-up time by a factor of 7 in comparison with their predecessors. The Eastern systems of the

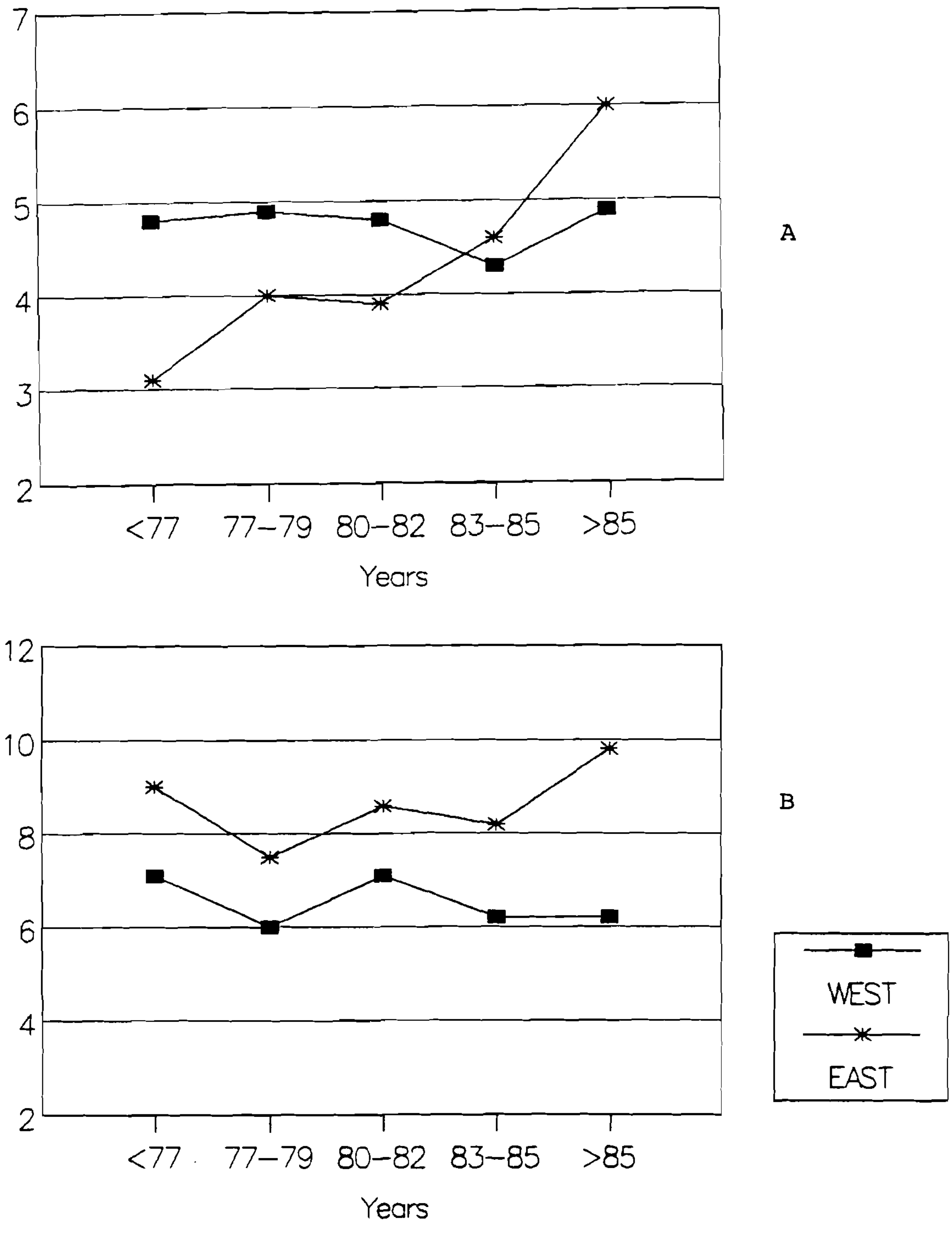

Figure 19. Average numbers of MC (A) and NCMT (B) by years, units per FMS.

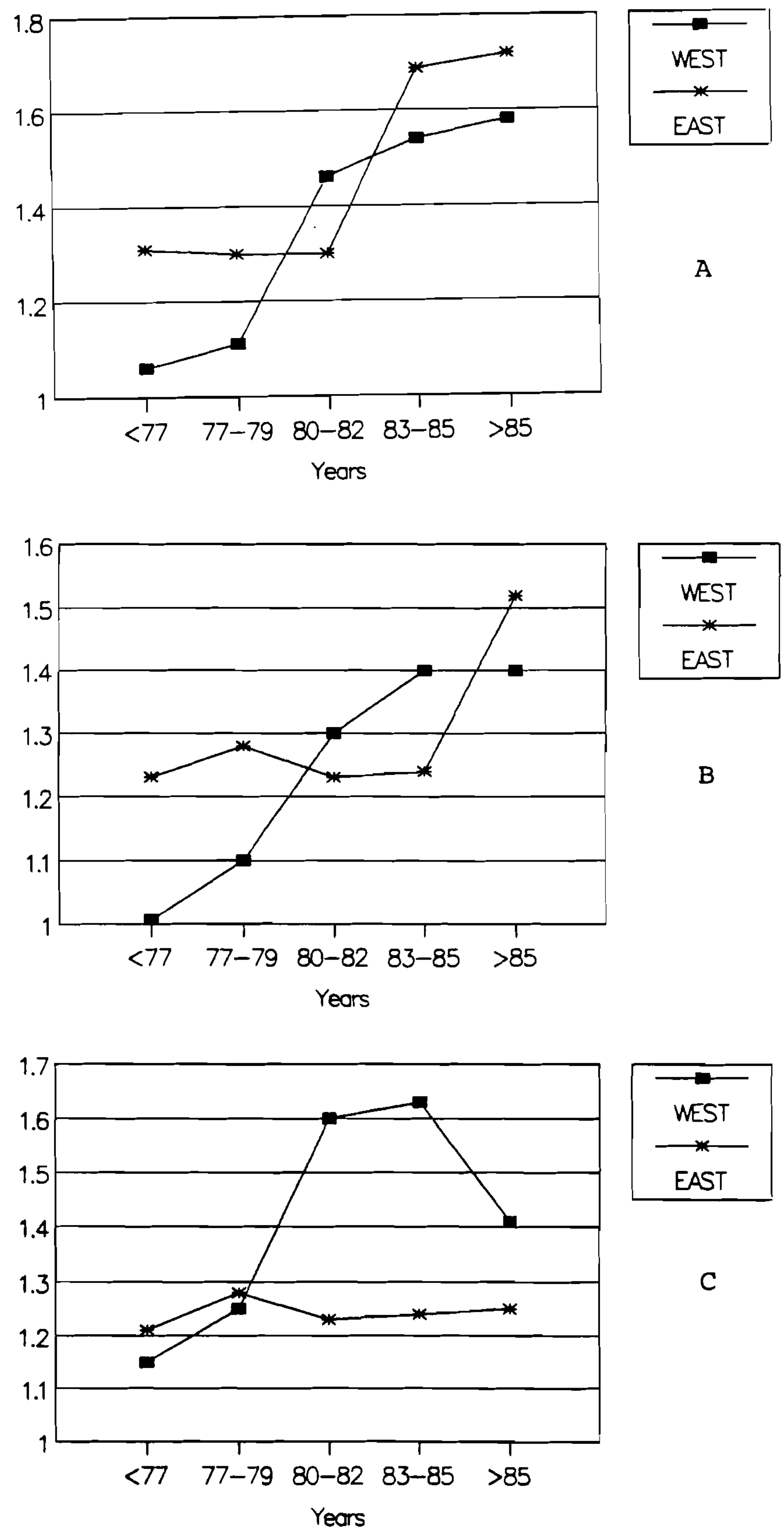

Figure 20. Average TRT (A), STO (B) and INS (C) indices by years.

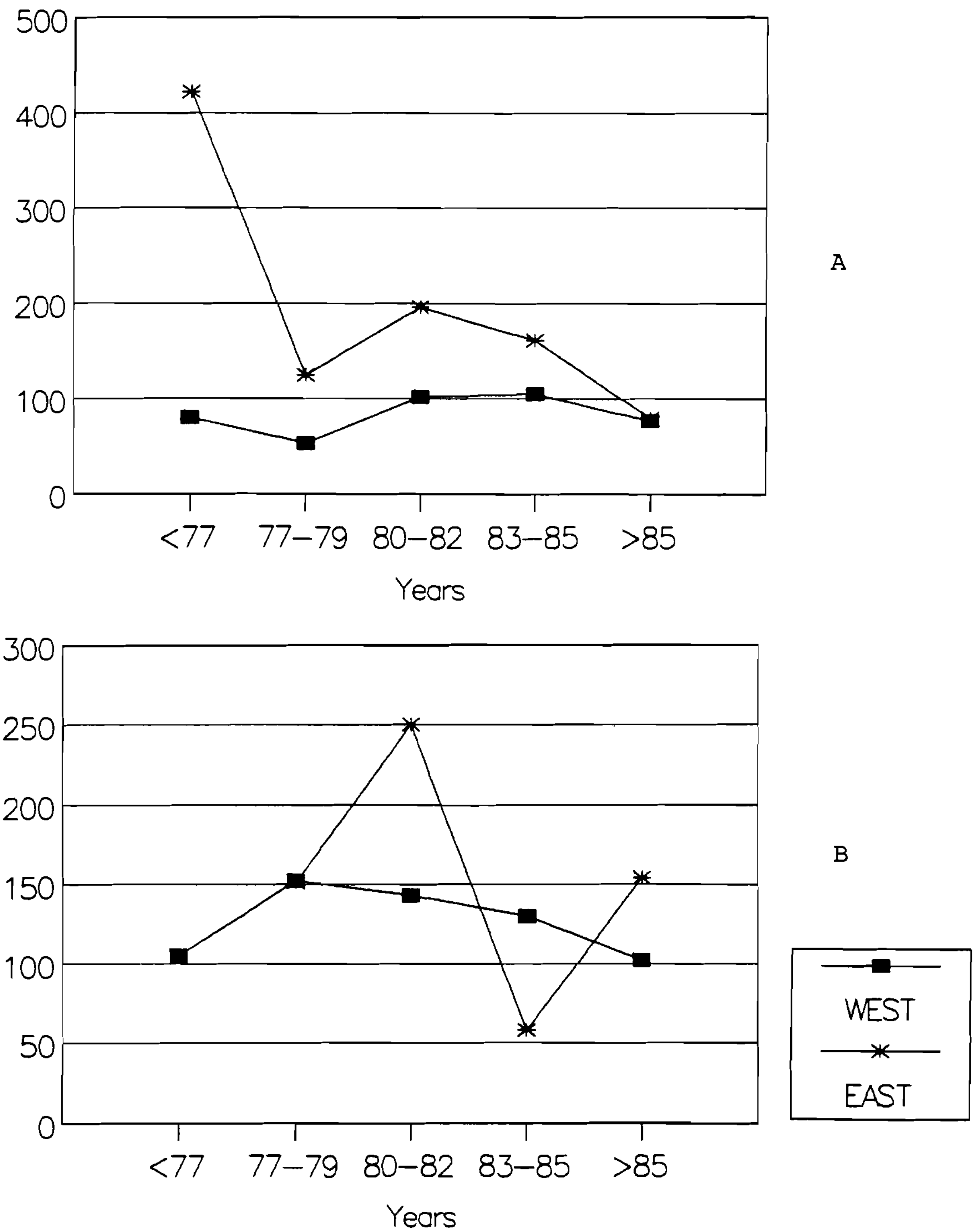

Figure 21. Average PV (A) and BS (B) tendencies, units.

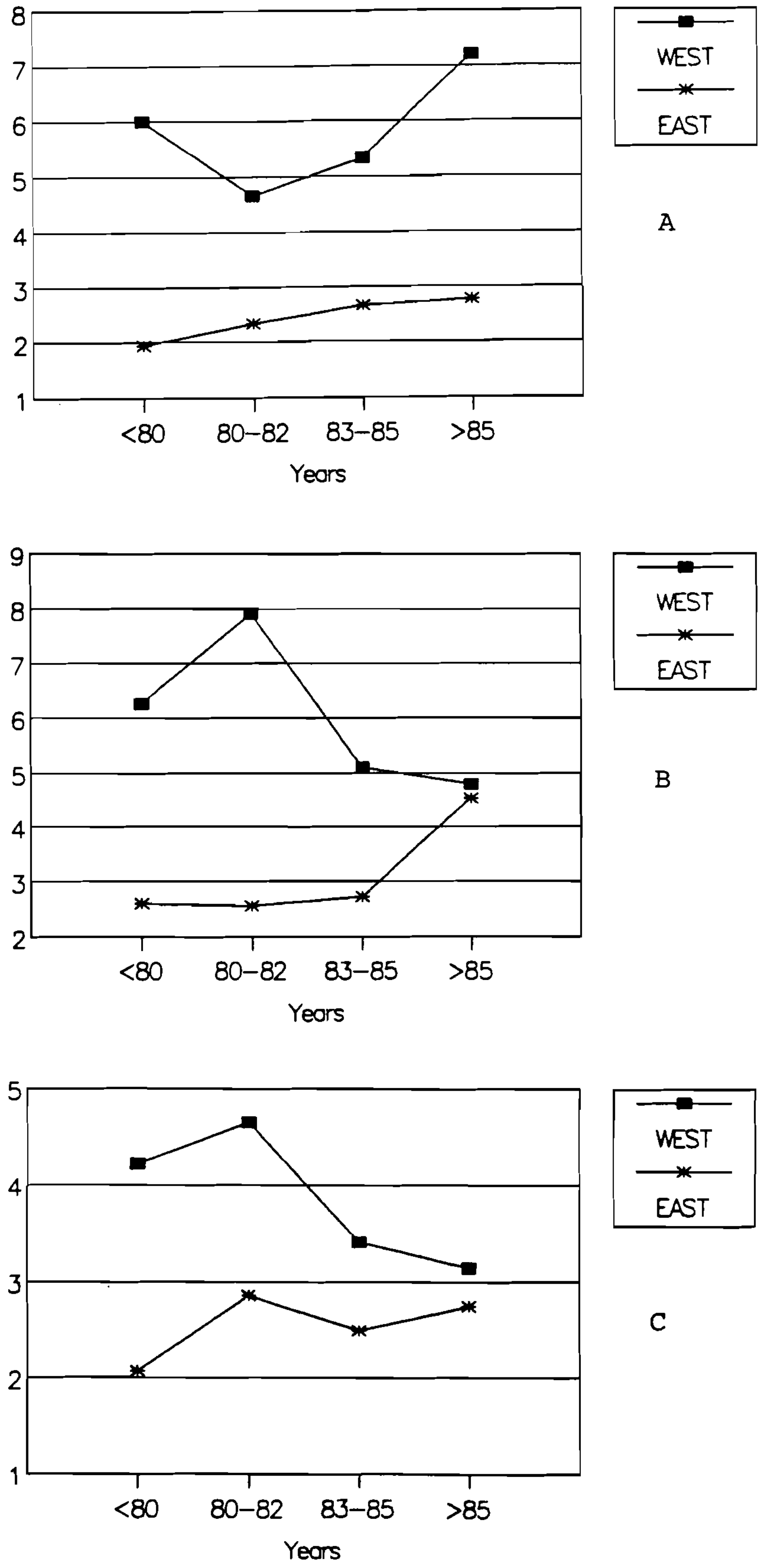

Figure 22. Set-up time (A), in-process time (B) and personnel reduction (C) tendencies, by a factor of.

same generation reduced it by a factor of 3. The likely reason for this could be connected with organizational or managerial factors.

On the other hand, one can observe converging tendencies in two other advantage indicators -- in-process time and personnel reductions (see Figures 22B and 22C). In both cases an efficiency decline takes place for the different generations of the Western FMS in contrast to the growing efficiency of the Eastern systems. As a result the indicator values are very close to each other for the youngest FMS generations in the both samples.

The average Western FMS costs fluctuate in time around the 6 million dollar level, while the Eastern FMS costs were decreasing from 5 to 3.5 million $ before the 1980's and were rather stable afterwards (see Figure 23A). Again, one could see certain converging tendencies in the pay-back time dynamics (see Figure 23B). Unfortunately we had no PBT data for the Western FMS installed before 1982, but after that time an average PBT decrease is clearly shown for the Eastern sample in contrast to a PBT growth for the Western systems. We suppose, that the first tendency could be explained by the efficiency growing from one FMS generation to another (see, for example, Figure 22). The second tendency for the Western cases is probably connected with the growing share of FMS equipped with more sophisticated supplementary (transportation, storaging and inspection) systems (see Figure 20). As was reported by different sources, the implementation of such systems increases the FMS pay-back time.

4. Findings and Conclusions

The FMS diffusion is expanding rapidly in the 1980's and new industries (electronics, instruments) as well nontraditional areas of application (assembling, welding, EDM, plating, etc.) become new niches for FMS implementation. Nevertheless, the majority of the current FMS population is installed for the traditional machining of prismatic case-type or rotational parts in non-electrical and electrical machinery, as well as in transportation equipment production. For these traditional FMS the following conclusions could be drawn.

Each new FMS generation had a higher technical complexity than its predecessor, due to more NC-machines, machining centers, and robots included in the new FMS generation, which is supplemented by more intelligent transportation, storaging and inspection systems. This was a natural way of technological development until the middle of the 1980's. The peak was reached in 1982-1986, depending on the respective indicator and country.

After the peak a certain decline or stabilization is observable. We find that one of the main reasons of such a turn is the following. At that time FMS left the embryonic phase of their introduction when the main focus was concentrated on technical problems. The first adopters have passed through the learning curve and FMS appeared on the market. The FMS users club became wider and wider.

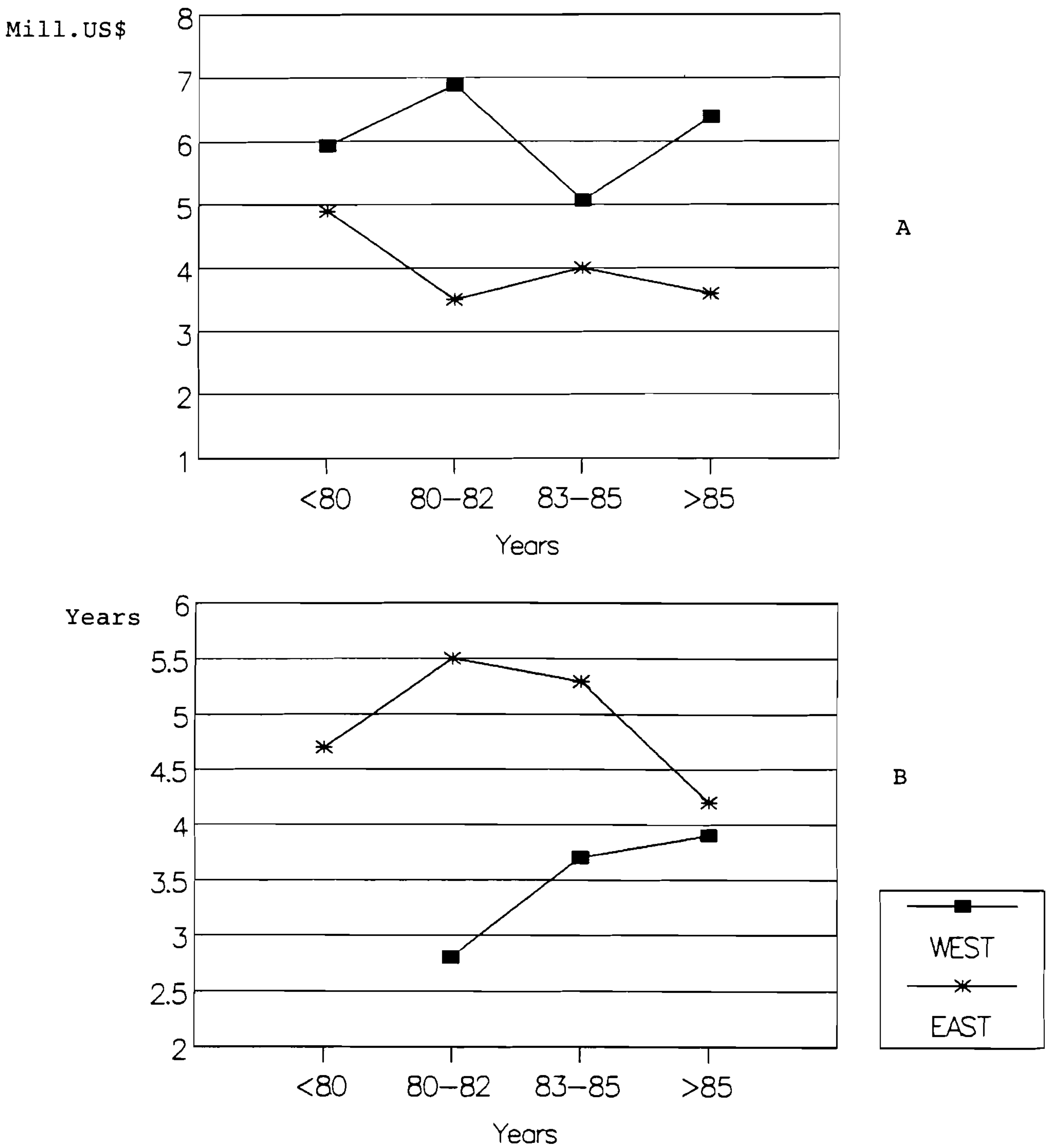

Figure 23. Average investment cost (A) and pay-back time (B) by years.

In this situation economic, managerial, and social factors began to play a much more important role in the success or failure of FMS than technical factors. This was why FMS flexibility was increasing due to a smaller batch size, and some other indicators, which were important from the viewpoint of the economic success of FMS (inventories, work-in-progress, lead time and unit cost reduction), were also increasing. Those indicators which play, as we know, a less important role in the economic success of FMS (personnel, floor space or number of machines reduction), or have reached a certain economically reasonable ceiling, did not grow in time and sometimes even decreased.

The strategies and results of FMS implementation look similar in the Eastern and Western countries, but some differences do exist. The average number of machining centers in an FMS is increasing in Eastern companies, while this indicator is stable in Western companies. Some indicators improved faster in the Eastern countries and reached average levels which are typical of the Western FMS. This is true for in-process time and personnel reduction, and average pay-back time.

REFERENCES

[1] Ranta, J., Tchijov, I. Economics and Success Factors of Flexible Manufacturing Systems: The Classical Theory Revisited. In: Ranta, J. (ed.): Trends and Impacts of Computer Integrated Manufacturing. IIASA WP-89-1, p.311-353.

[2] Tchijov, I. FMS World Data Bank. IIASA WP-89-33.

[3] Tchijov, I. FMS in Use: An International Comparative Study. IIASA WP, forthcoming.

[4] Tchijov, I., Alabian, A. Flexible Manufacturing Systems (FMS): Main Economic Features. Part 2. IIASA WP-88-83.