WORKING PAPER

FMS IN USE:
AN INTERNATIONAL COMPARATIVE STUDY

Iouri Tchijov

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IIASA
International Institute
for Applied Systems Analysis

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FOREWORD

The present paper is the second one in a set of papers presenting the results and conclusions of the third version of the IIASA FMS database. This version of the database includes 799 systems from 26 countries. The accuracy and completeness of the data has improved since the second version.

This paper focuses on international comparisons. First, it presents the features and characteristics of the systems in the five main Western user countries. Secondly, it makes an East-West comparison indicating regular patterns and differences between countries. The paper gives a deep insight into adaptation patterns of FM-systems.

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Computer Integrated Manufacturing

1. Introduction

International peculiarities, such as production planning systems, social interrelationships, industrial traditions, greatly influence the indicators of FMS use. This is why the clustering of FMS databases by countries, as well as international comparisons of FMS applications, could help to purify some general tendencies from specific national trends.

There are few publications in which attempts of such a comparison were made. In [2, 7, 9] the comparison was developed for several concrete FMS cases from different countries. The bilateral studies analyzing average figures for two countries (Sweden versus the UK, or the USA versus Japan) are described in [4, 5]. The multinational study for several countries (the main FMS users) is published in [1], and the attempts to make East-West comparisons are reported in [6] for some economic indicators and in [3] for the technical features. However, all these studies were based on relatively small samples of national data, and the statistical reliability of the figures was not very high.

Below we shall demonstrate the results of the international comparative study, based on our FMS World Data Bank, which was compiled at IIASA during the last three years. The detailed description of the Bank and its development are available in [10, 11, 12].

The third version of the Bank (3.1) was finalized in 1989 [12]. It contains 765 FMS cases from 26 countries. However, in this paper the latest version (3.2) is used. There are 664 cases from 19 Western countries and 135 cases from 7 Eastern countries, see Table 1.

Among the countries it is possible to choose the main FMS users -- France, the FRG, Japan, the UK and the USA. Their share in the total FMS population is about 70% and the total number of FMS population reported ranges from 67 (France) up to 167 (Japan). This amount is sufficient to make some statistical conclusions even in view of the limited information for some indicators.

The study consists of two parts. The first one is based on the data from the above five countries, i.e. main FMS users. The second one is made in the context of the East-West comparison.

The analysis is made on the basis of 33 indicators, collected for the FMS cases and described in detail in [12], but the countries/regions and indicators were chosen to have a high enough number of observations for a statistical reliability of the results.

2. Cross-Country Analysis for the Main Users

The growth of the world FMS population was considerable in the 1980's. This statement applies to the USA and several other countries, in Japan, however, the process started earlier -- in

Table 1. Distribution of FMS installations by countries, FMS World Data Bank, version 3.2.

Country	Number of FMS installed	Share, %
1 Austria	6	0.8
2 Belgium	6	0.8
3 Canada	3	0.4
4 Finland	12	1.5
5 France	67	8.4
6 FRG	74	9.3
7 Ireland	1	0.1
8 Israel	1	0.1
9 Italy	37	4.6
10 Japan	167	20.9
11 Netherlands	8	1.0
12 Norway	1	0.1
13 S. Korea	2	0.3
14 Spain	2	0.3
15 Sweden	36	4.5
16 Switzerland	6	0.8
17 Taiwan	5	0.6
18 UK	93	11.6
19 USA	137	17.1
Total Western Countries	664	83.1
20 Bulgaria	15	1.9
21 CSSR	23	2.9
22 GDR	28	3.5
23 Hungary	7	0.9
24 Poland	5	0.6
25 Rumania	1	0.1
26 USSR	56	7.0
Total Eastern Countries	135	16.9
TOTAL	799	100.0

the first part of the 1970's. Now a certain decrease of the FMS growth rate is observable (see Figure 1).

Among 167 Japanese FMS registered in the Bank approximately one third was installed in 1980-1982. This result is partly influenced by the lack of information on the latest installations, but a tendency towards a stable, high amount of annual increment is obvious.

On the other hand, more than 60% of 137 FMS installed in the US industry appeared after 1982. The share of this generation in the world, amounting to 57%, is also relatively high. The comparison shows that in the pioneering country, Japan, a certain growth deceleration takes place in the 1980's, that might be connected with a first adopter saturation. In the other countries the 1980's were a period of wide FMS introduction.

One of the main technical indicators of an FMS is its technical complexity, which was measured as follows (for details, see [10]):

$$TC = 0.7\ MC + 0.35\ NC + 0.3\ ROB + 0.3\ TRT$$

where

MC	–	number of machining centers;
NC	–	number of other NC-machines;
ROB	–	number of industrial robots in the system;
TRT	–	1 or 2 -- type of transportation system.

The difference between the average FMS technical complexity in the leading Western countries is not very high, see Figure 2. The lowest level of the indicator is found in the British industry (3.6), and the highest one in the USA (5.5). But there are more differences of the individual countries behind the similar average levels.

The distribution of this weighted indicator (TC) is demonstrated in Figure 3 for the national FMS samples. The share of the simplest FMS, including usually from 2 to 4 NC-machines or 2 machining centers, with a TC = 1-2, is relatively moderate (16%) in the USA and the FRG. In Japan it is slightly higher (22%), and in the UK and France it reaches around 32%.

The next group, TC = 2-4, has the highest share in all five countries, ranging from 33% to 41%. Then the shares go down. The super-complex FMS with TC > 20 are installed only in the USA and in Japan, but their share does not exceed 5% of the FMS populations in these countries.

The most similar distribution curves belong to the USA and the FRG. The share of simple FMS (TC = 1-4) is the highest in the UK. The share of the systems with a medium complexity (TC = 4-10) is the highest in the FRG, but also the US and Japanese companies dominate in the sample of highly complex systems (TC > 10).

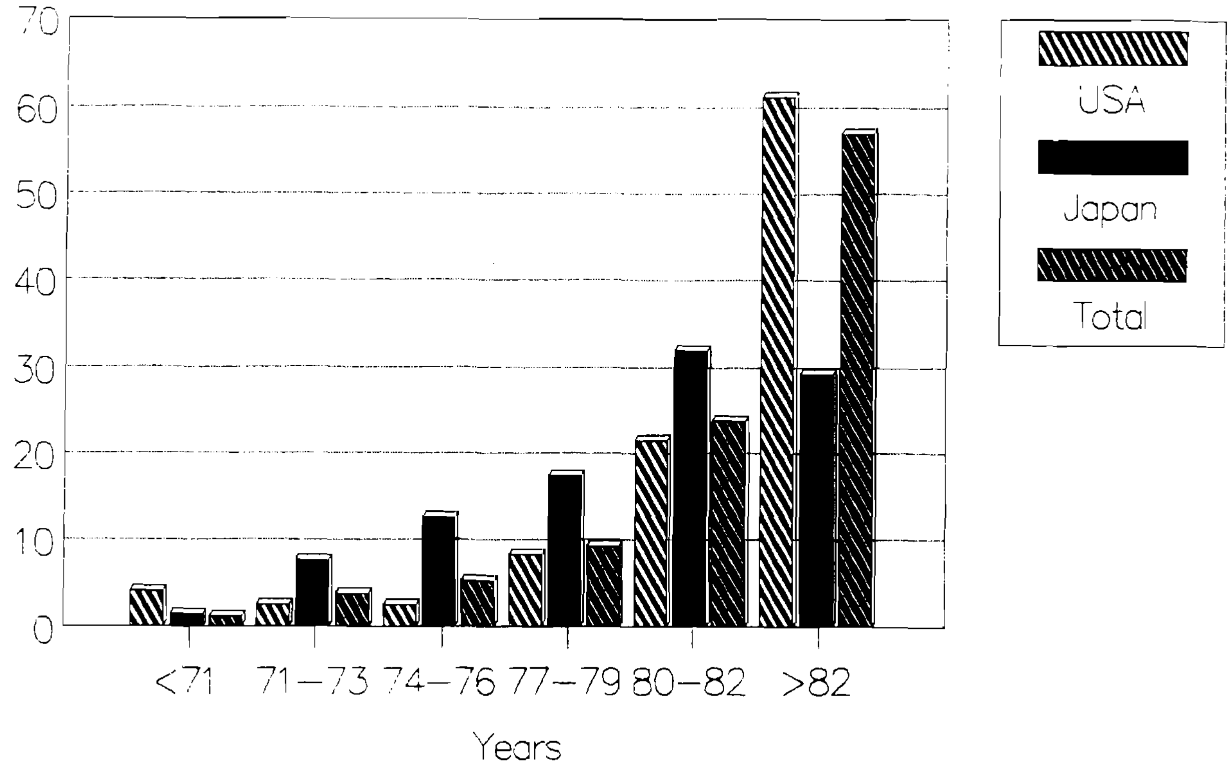


Figure 1. Age structure (years of installation), %.

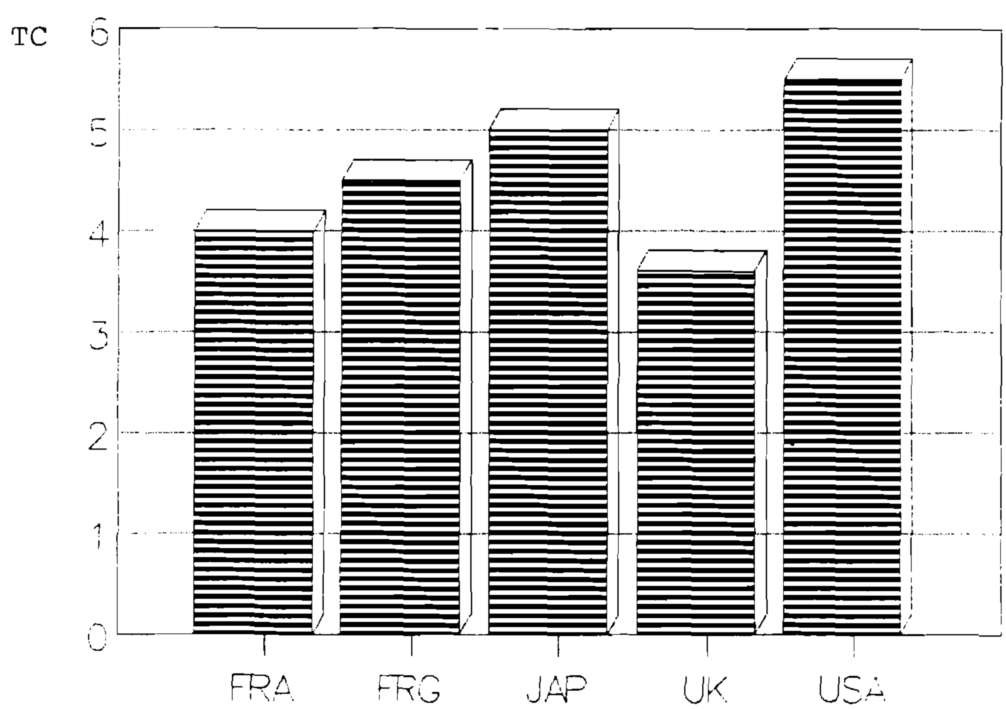
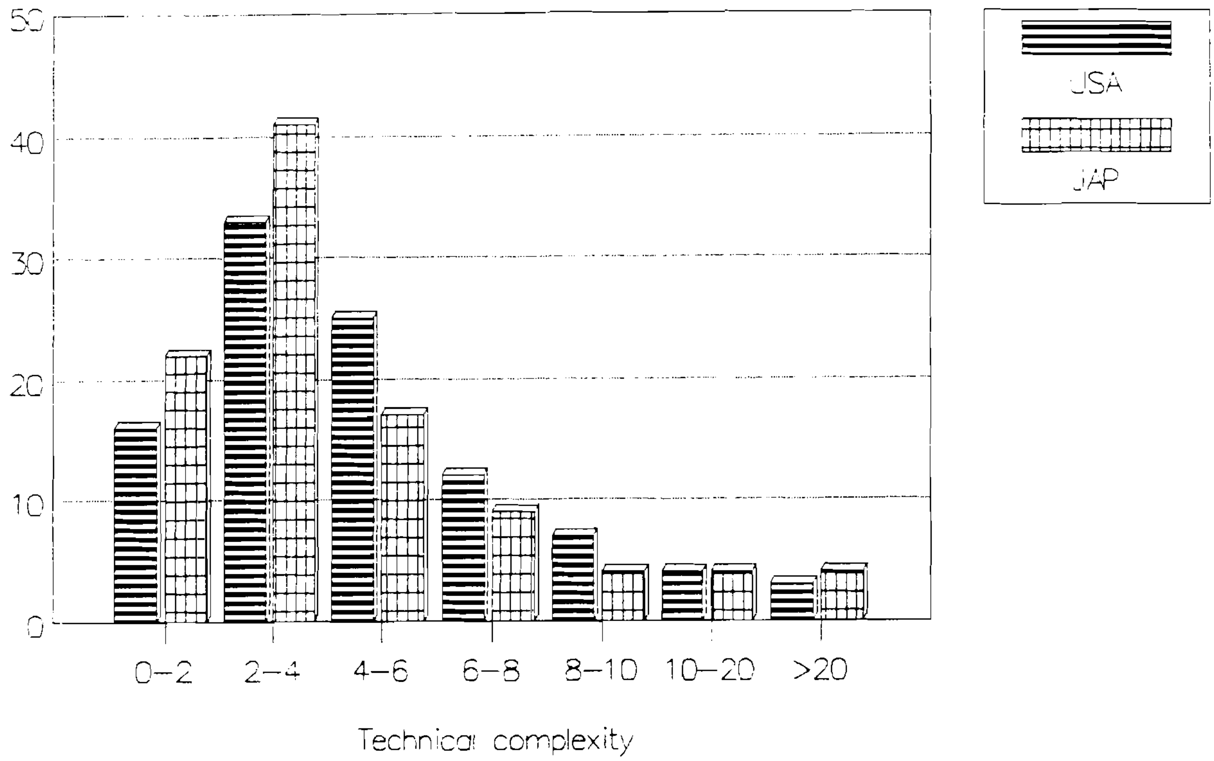


Figure 2. Average FMS technical complexity by countries.



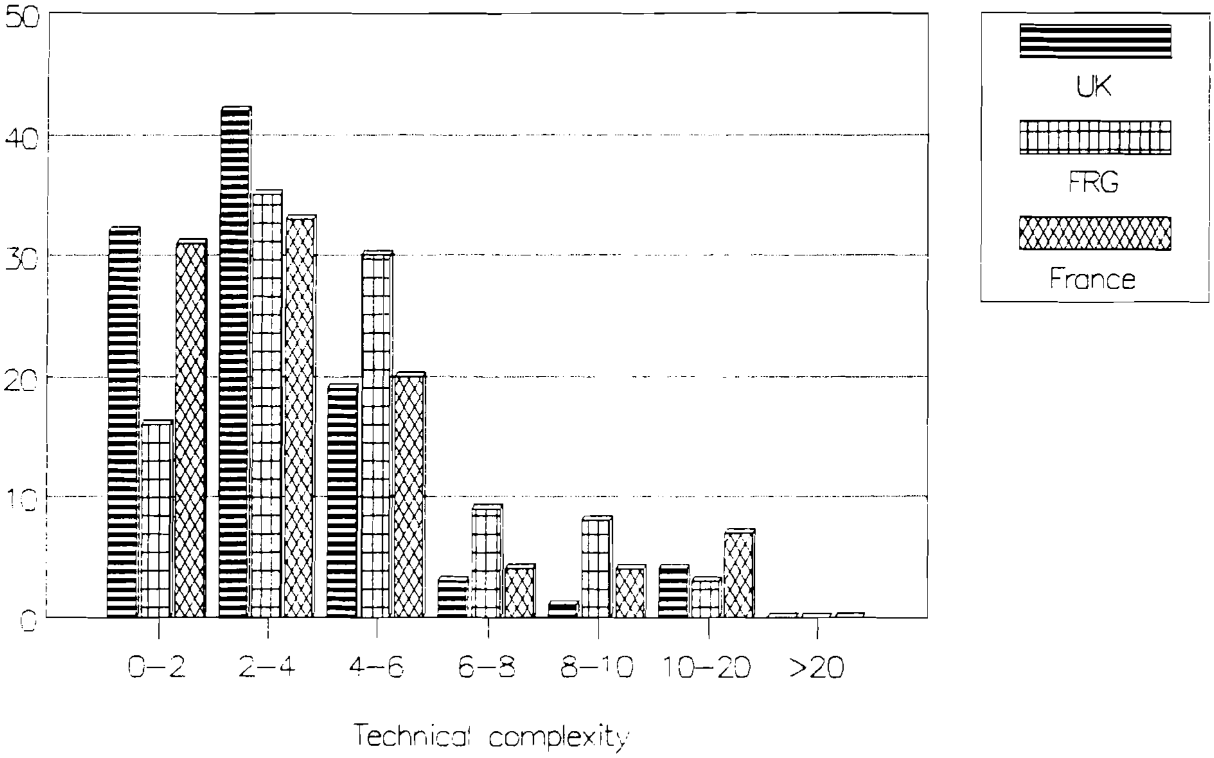


Figure 3. Technical complexity distribution by countries, %.

The relatively high share of the simplest FMS in the British and French industries could be explained by the late application of FMS by their companies. 60 of 62 French FMS, as well as all 51 British FMS, for which the year of installation was reported, were installed after 1980. It is natural that these companies have to pass the learning curve first, using simple systems. At the same time the most advanced Japanese companies use a lot of relatively simple FMS, and moreover, the share of FMS with a TC = 2-4 is growing in the youngest generations of the Japanese systems.

The latest statistical observation confirms the occasional information, published in some articles, that the main Japanese FMS producers are returning from the production of sophisticated to relatively simple systems. They simplify supporting subsystems (tools and parts delivery, storage) and usually base an FMS on 3-4 machining centers.

The most expensive FMS (11.7 million US $ on the average) are installed in the USA. The average costs of Japanese and German systems are 7.0 and 6.5 million $, respectively, see Figure 4. In France and in the UK this figure is two times less, i.e. 3.5-3.6 million $. The cost distribution reflects a lagging behind of the two latter countries in average FMS technical complexity. The investment/technical complexity ratio is extremely high in the USA. There it reaches 2.1, but for all the other four countries it lies between 0.9 (France) and 1.4 (FRG).

To analyze the ratio in detail we have estimated regressions between investment cost (INV) and technical complexity (TC) by countries, limiting INV $\leq$ 20 million $ and TC $\leq$ 10, i.e. excluding the most sophisticated and expensive systems from the estimation. The results are shown in Figure 6.

In Japan and the UK the simple FMS (TC = 1-4) cost from 1 to 3 million $, independent of their complexity. In general one can observe a rather strong proportionality between these two indicators, but the interpolating straight lines are different (see Figure 6F).

The slopes of the lines are the highest for the USA (1.82) and the UK (1.47), but the British line is significantly lower than the US line. The lines for Japan and the FRG are parallel, but the Japanese is 1.5 million $ lower than the line for the FRG. The lowest slope is observed for French cases (0.665).

The figures could be interpreted in the following way:

The US FMS are much more expensive than other FMS of the same technical complexity. This could be explained by higher costs of FMS elements in the USA, different methods of the cost calculation and the lack of some important components in the TC calculations.

Historically the first FMS implementations in the USA took place in the high-tech aerospace industry, and now the share of super-sophisticated systems used in this industry is relatively

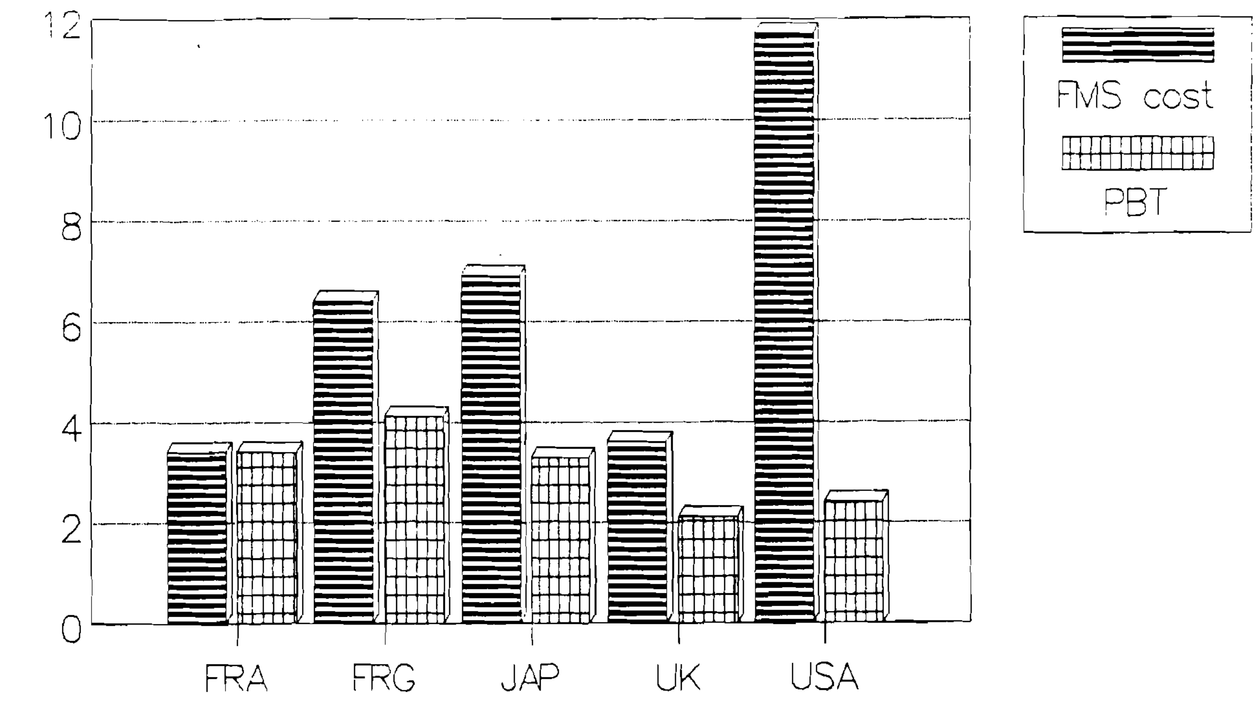


Figure 4. Average FMS cost (million US$) and pay-back time (PBT, years) by countries.

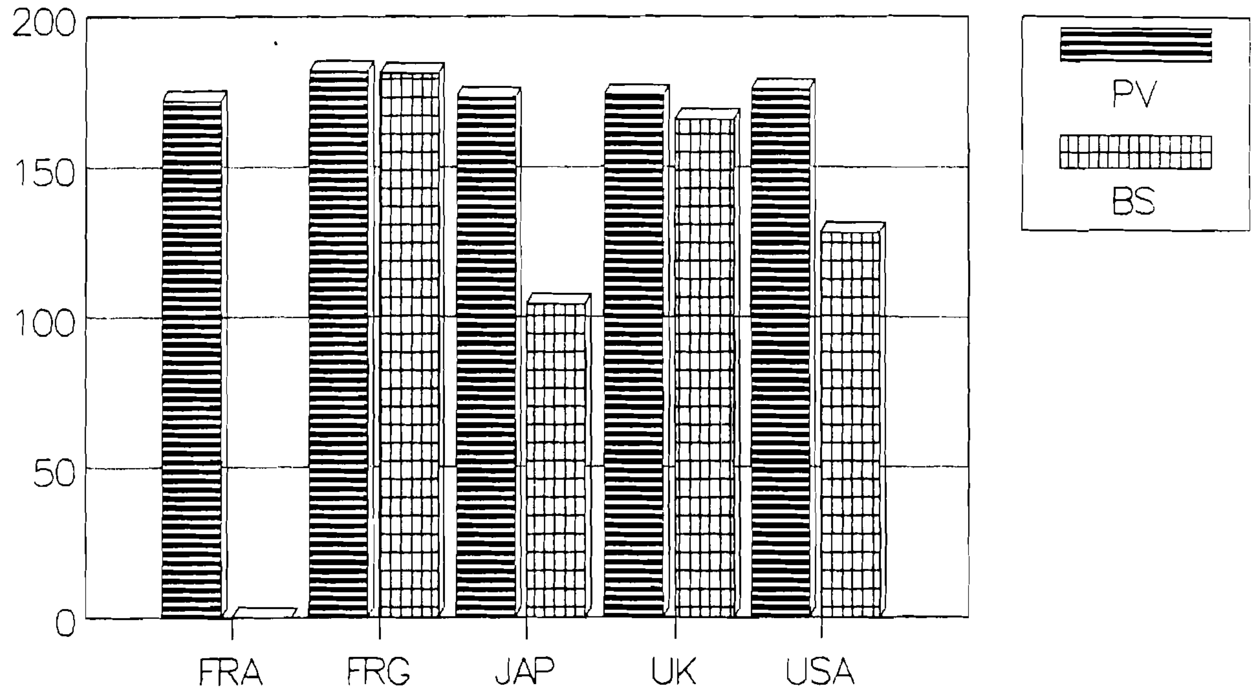


Figure 5. Average number of product variants (PV) and batch size (BS) by countries, units.

high. Their costs are extremely high too, because they are unique and have been developed for very sophisticated production. The leading companies of this industry have enough investment resources to cover the costs of such FMS.

Some systems in the USA have an extremely high accuracy and the share of an inspection subsystem is more than 50% of the total investment. For example the IBM FMS, producing hard discs, is based on two turning NC-machines and a very expensive inspection system, amounting to 90% of the total costs.

The US users usually buy "turn-key" FMS, and many machine-building companies using the systems in Europe and in Japan develop some FMS elements (including software) themselves.

The higher slope of the British line could be explained by a high share of aerospace companies in the sample.

The list of "leaders" in the use of expensive FMS in the two countries is headed by the American companies LTV, General Dynamics, Lockheed, McDonnel Douglas, and British companies British Aerospace and Rolls-Royce.

The FMS flexibility comparison is shown in Figure 5. All the countries have almost the same average number of products. This indicators varies from 172 in France to 182 in the FRG and is not influenced by a different average technical complexity or cost, different structures by areas of application etc. Moreover, the standard deviation of this indicator was very similar for the countries investigated.

On the other hand, the average batch size varies from country to country. The most flexible (in terms of batch size) are the Japanese systems with an average indicator of 104. In the American companies it reaches 128, in the UK 166, and in the German industry 181.

The higher average batch size might not only mean less flexibility, but also a higher share of FMS substituting for several transfer lines in a sample.

Among the relative FMS advantages the lead time reduction plays one of the most important roles in the context of flexibility. The average figures for this indicator, shown in Figure 7, display the highest flexibility for the cases of Japanese FMS. LTR was cut by a factor of 6.8. The lowest record among the four countries was registered in the British industry (4.4), but even this figure might be regarded as a considerable advantage.

The results confirm the fact that one of the main driving forces of FMS implementation is the higher flexibility and, consequently, the lower lead time.

The relationship between the average national values of the two indicators of flexibility -- LTR versus BV/BS -- ratio is shown in Figure 8. The higher flexibility, measured as the ratio of a number of product variants to the average batch size,

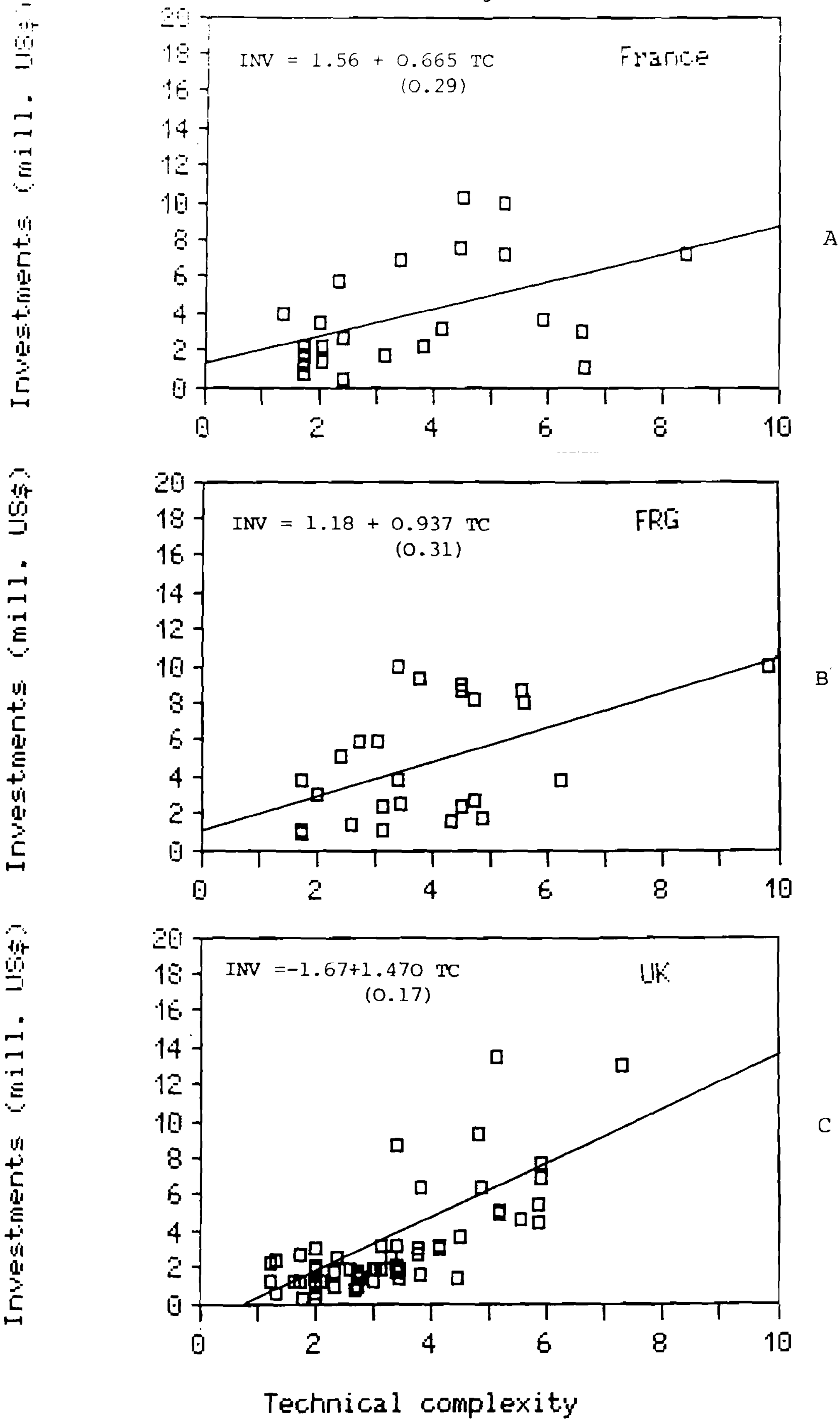
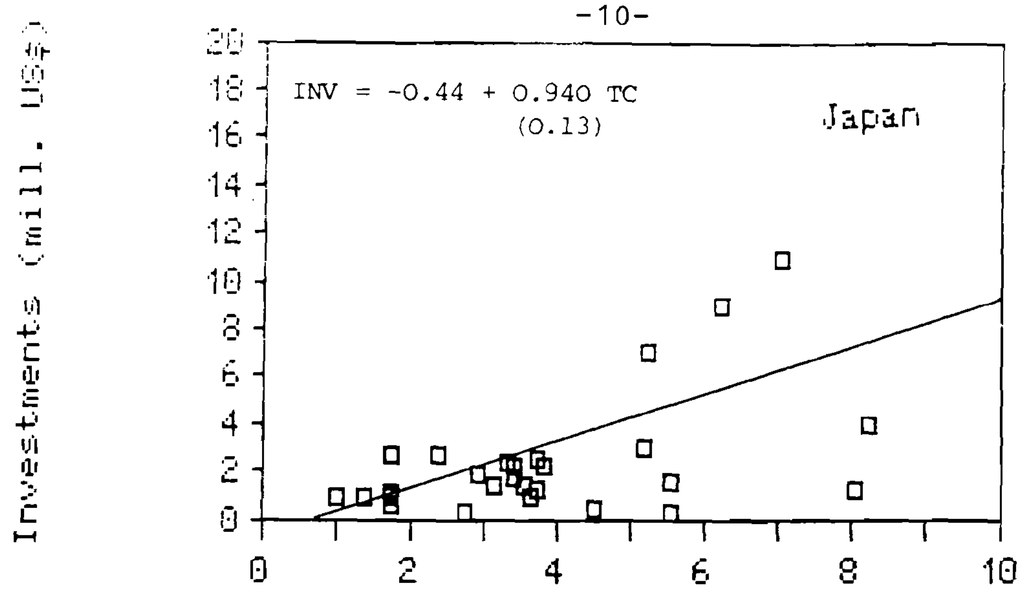


Figure 6. Investment regressions on technical complexity by countries (standard error of the coefficient is in brackets), to be continued.



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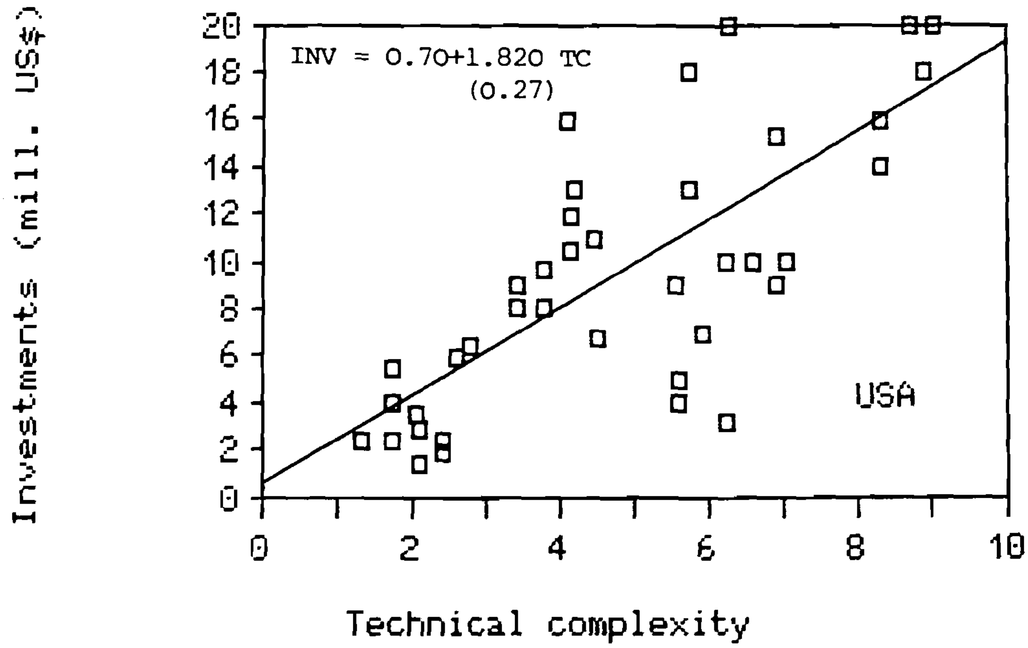

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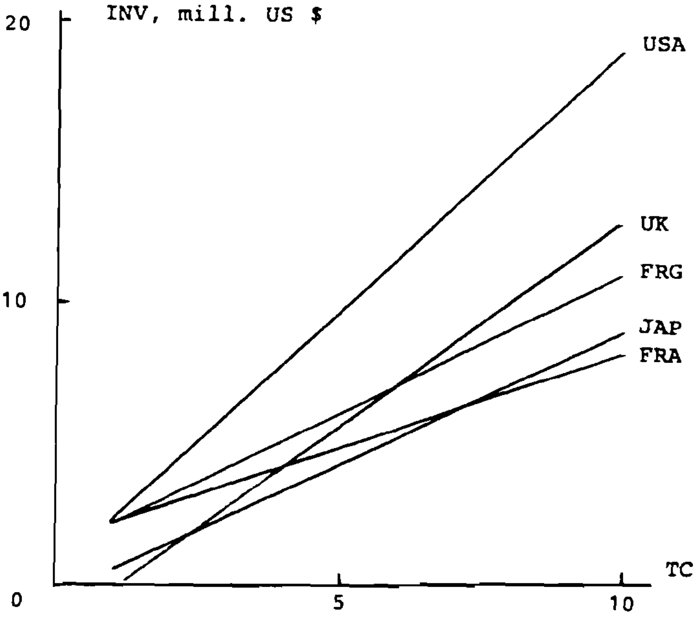

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Figure 6. (continued).

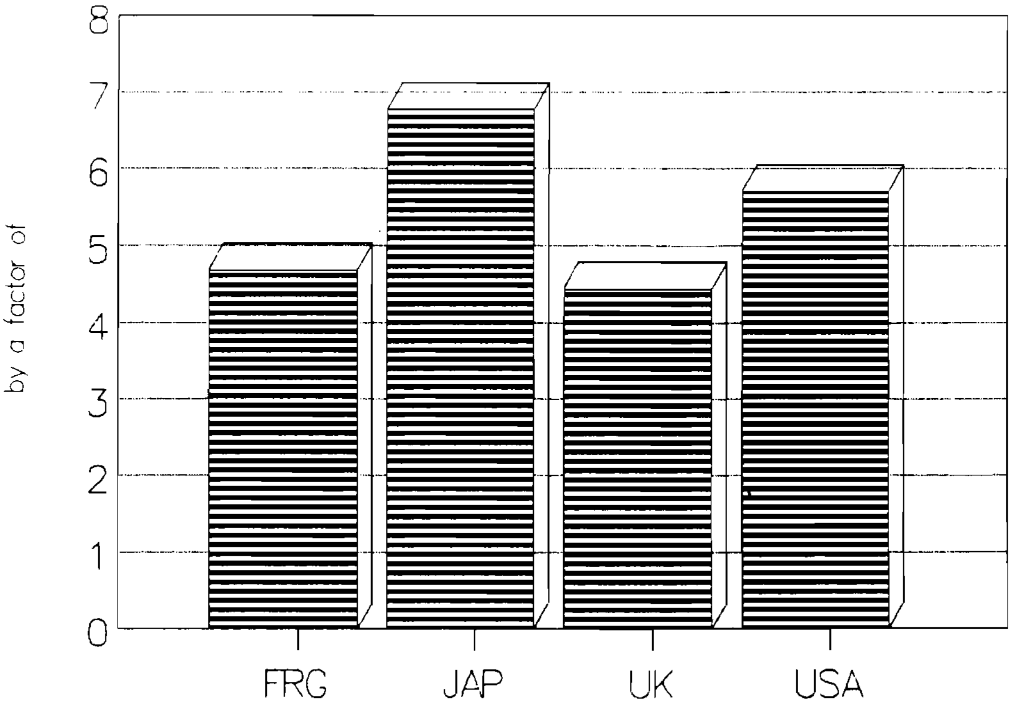

Figure 7. Average lead time reduction by countries.

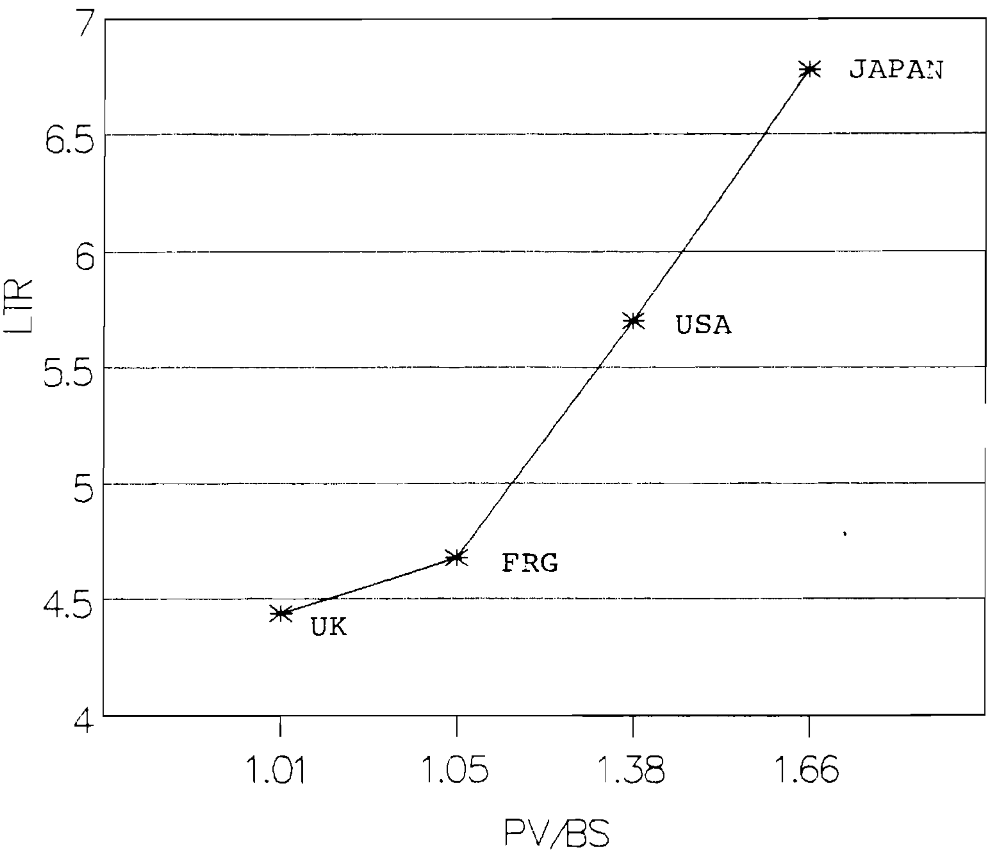

Figure 8. Average lead time reduction (LTR) versus PV/BS ratio by countries.

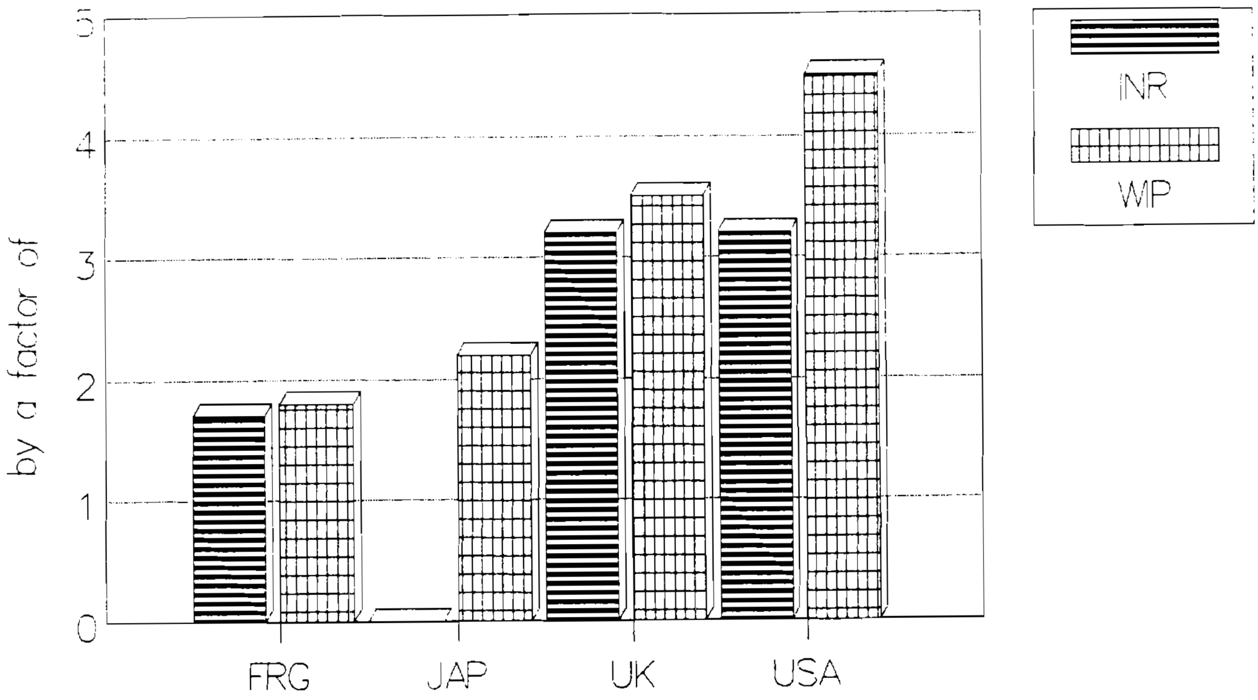

Figure 9. Average inventory and work-in-progress reduction (INR and WIP) by countries.

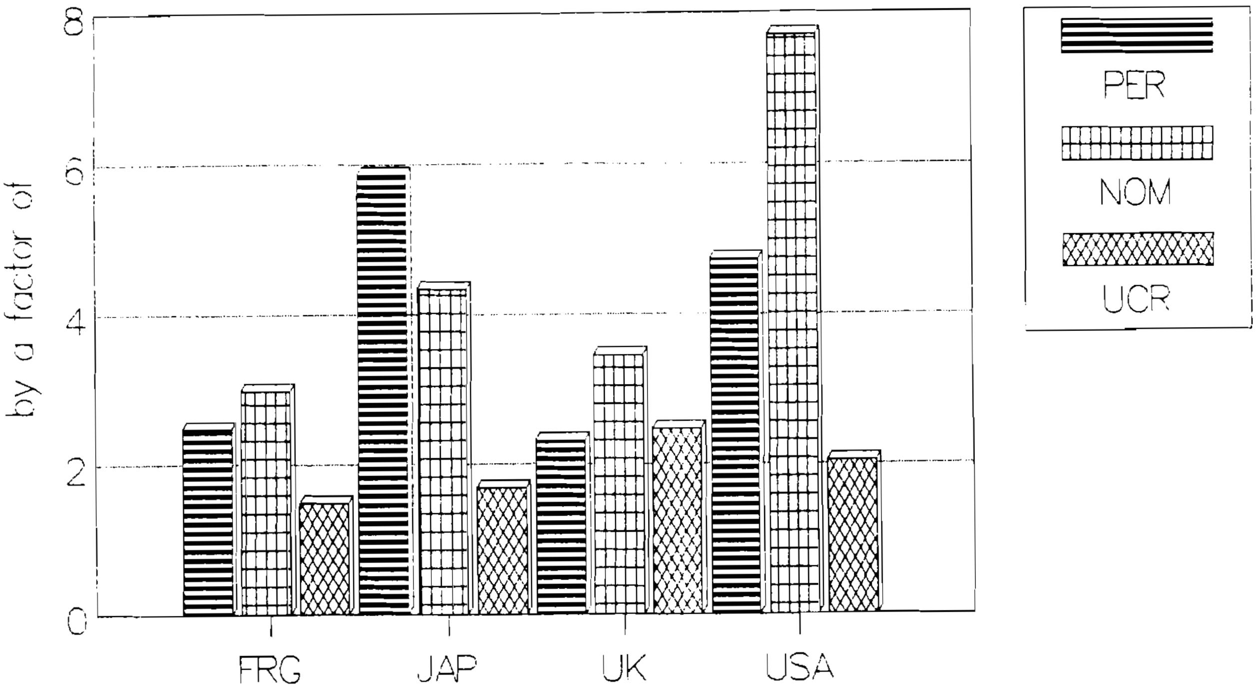

Figure 10. Average personnel, number of machines and unit cost reduction (PER, NOM and UCR, respectively) by countries.

corresponds to a higher average lead time reduction. One can observe that the flexibility leader is Japan, and the USA takes the second place. The FRG and the UK are in the third and fourth places, respectively.

The logistic FMS advantages, namely inventory and work-in-progress reduction, are shown in Figure 9. Unfortunately there are not enough data on INR in Japan and on both indicators in France to estimate a statistically reliable average. The higher advantages are found in the US FMS (by a factor of 4.5 and 3.2, respectively). The same WIP reduction can be observed for the UK, though the INR is only 3.5. The reduction of the logistic components of the production costs is more moderate in Japan and in the FRG.

The highest record in labor saving is demonstrated by Japanese companies, see Figure 10. They reduced personnel by a factor of 6, while US companies reached only 4.7, and British and German companies reached 2.3 - 2.5. On the other hand, the reduction of the number of machines is the highest in the USA (see Figure 10), i.e. by approximately a factor of 8, while its main competitors, Japan, the UK and the FRG, decreased the number of machines only by a factor of 3-4.

If we use NOM as an indicator for fixed capital saving, PER for labor saving, and INR/WIP for current expenditures saving, the dominating way of unit cost reduction in the USA is the first one, and in Japan it is the second (labor saving). Capital and labor saving is much higher in the Japanese and American cases than in the UK and the FRG, while the "leaders" of current expenditures saving are the USA and the UK.

The integrated cost reduction indicator is the unit (or part) cost reduction (UCR) and its average values for the four countries are shown in Figure 10. Due to a relatively small number of the national cases, where the UCR value was reported, the cross-country comparison is not reliable enough. The average reduction lies between 1.5 in the FRG (for 11 cases) and 2.5 in the UK (for 4 cases only).

3. East-West FMS Comparison

As was shown in Table 1, there are 664 Western FMS cases and 135 Eastern FMS cases in the Bank. The lack of some indicators in one or another sample did not allow their comparison. The availability of the data and their average values are demonstrated for Eastern and Western countries in Table 2.

In the technical complexity block (indicators 1-4) there is a certain advantage of the Eastern FMS, measured in a greater average number of machining centers and total number of NC-machines. The lower number of robots reflects a smaller share of assembling systems in the Eastern sample. Totally, the technical complexity index is slightly higher in the Eastern countries, but the difference is negligible and much less than between the main Western users (see Figure 2).

Table 2. East-West Data Comparison

Indicators	East: N of cases	East: Average	West: N of cases	West: Average
1 Number of machining centers (MC)	71	5.3	441	4.6
2 Total number of NC-machines (NCMT)	116	8.5	576	7.2
3 Number of robots (ROB)	39	5.0	170	6.4
4 Technical complexity (TC)	120	4.9	595	4.6
5 Operation rate (OPR), shifts	66	2.4	207	2.6
6 Number of unmanned shifts (UNM)	13	0.9	112	1.0
7 Number of product variants (PV)	87	348.0	380	157.0
8 Average batch size (BS)	66	354.0	178	170.0
9 Investments (INV), mill. US$	30*	4.2	263	5.9
10 Pay-back time (PBT), years	29*	4.8	61	3.5
Reduction by a factor of:				
11 Lead time (LTR)	20*	2.0	82	6.3
12 In-process time (IPT)	31	3.6	44	7.0
13 Work-in-progress (WIP)	17	3.3	54	3.4
14 Personnel (PER)	60	2.5	111	4.5
15 Number of machines (NOM)	11	2.4	76	4.3
16 Floor space (FLS)	38	2.3	20	2.3
17 Unit cost (UCR)	14	1.6	48	1.7
Increase by a factor of:				
18 Productivity (PROD)	44	2.8	34	3.3
19 Capability utilization (CAP)	20	1.8	59	1.9

*Mainly the CSSR cases

The operation rate and number of unmanned shifts almost coincide in both samples, but with regard to the flexibility indicators (7 and 8) there is a big difference between the samples.

In the Western cases the average number of product variants is 2.2 times less than in the Eastern cases, and also the average batch size is 2.1 times less.[1] The latter fact could be interpreted in the following way.

There are two possible areas for the replacement of conventional technologies by FMS (for more detail, see [8]).

The first one is a small batch production of a large number of different products. The second one is a big batch production, where several production lines are substituted by an FMS.

In the second case the average batch size is much higher, usually amounting to several thousands. The share of the second type of the substitution is much higher in the Eastern countries.

Generally, the Eastern FMS are more flexible than the Western FMS in terms of a higher number of product variants, but less flexible in terms of bigger batches.

The average costs of the Eastern FMS are lower than in the Western countries, but almost all the Eastern cases giving investment data came from the CSSR. In spite of lower average costs the Eastern FMS demonstrate a longer pay-back time -- about 5 years versus 3.5 years for the Western systems. This could first be explained by differences of pay-back time calculation in Eastern and Western systems and, secondly, by a lower efficiency of the FMS in Eastern countries.

The second conclusion is confirmed by the relative advantage indicators for FMS (11-19). The average lead time and in-process-time reductions are 2-3 times lower for the Eastern countries, which reflects a certain organizational lag behind the Western countries, taking place at a shop-floor level.

Labor and fixed capital savings (indicators 14, 15, 16) are lower for the Eastern industry. At the same time there is an almost equal floor space, work-in-progress, and unit cost reduction, as well as a fairly equal capacity utilization increase.

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[1]When we excluded 4 Eastern cases with PV > 2000 (one of them was a metal-forming FMS) and 7 Western cases (four of them belonged to this area of application), the average PV dropped to 178 units for the Eastern sample and to 98 for the Western sample. The exclusion of the cases with BS > 2000 (two Eastern and one Western case) led to a decrease of the average figure to 248 units for the Eastern FMS and to 143 units for the Western systems.

The above-mentioned differences are partly due to different FMS allocations by industries, areas of application, etc. The East-West comparison of ranked indicators is shown in Table 3.

The share of electronic and instrument industries, as FMS users, is relatively small in both samples, but 8% of FMS are installed in these specific industries in the Western countries and only 3% in the Eastern countries. Machining (metal cutting) FMS dominate in the both samples, but the shares of manufacturing FMS (based either on alternative methods of surface development or on a combination of metal cutting and assembling) and of assembling FMS are higher in the Western sample.

It can be observed that the share of more sophisticated inspection systems is slightly higher for the Western FMS, but the shares of more sophisticated transportation and storaging systems are almost the same in the both samples. The higher share of the quality control systems in Western cases could partly explain their higher investment costs.

We furthermore analyzed the distributions of several indicators for Eastern and Western cases. We found that there are some differences in the distributions behind the almost equal average figures of the technical complexity, see Figure 11. The number of the investigated cases is shown in the legend windows.

The share of simple FMS (with a TC = 1-4) is the same in the both samples and is equal to 60%. In the Eastern countries the systems with a TC = 3-4 dominate in this group (21%), while the Western systems with a TC = 1-2 have the highest share (22%).

The share of an intermediate group (TC = 4-5) is higher in the Western countries, but the share of the systems with a TC = 6-7 in these countries is lower than in the Eastern countries. However, the main reason for a higher average TC in the Eastern sample is its higher share of the systems with a TC = 10-20 (7.5% versus 4.2% in the Western sample).

As can be retrieved from Figure 12, the longer pay-back time for Eastern FMS is due to the absence of cases with a PBT of less than two years and to the extremely high share of the systems with a PBT of more than 5 years (all of the latter ones belong to Czechoslovak cases).

The above mentioned flexibility difference between the Eastern and Western samples can be explained through the analysis of the FMS distribution over a number of product variants (PV) and batch sizes (BS), see Figures 13 and 14, respectively.

Approximately 64% of the Western FMS produce up to 50 product variants. The analogous share of the Eastern cases is only about 44%. The shares in the next range (PV = 50-100) are similar, but the share of the Eastern systems producing more than 100 product variants is above 56%, as compared to 36% in the Western sample. The average figures are sensitive to the difference between the shares of FMS producing more than 1000 product variants (7% of the Eastern cases versus 3% of the Western cases).

Table 3. East-West comparison of the ranked indicators, % of total

Indicators	East	West
1 Industry of application		
1 final metal products, machinery, transportation equipment	97	92
2 electronics, instruments	3	8
2 Area of application		
1 manufacturing	3	10
2 machining (metal-forming)	91	79
3 metal-forming	4	5
4,5 welding and assembling	2	6
3 Type of transportation system		
1 conventional conveyors or cranes	50	55
2 AGV or computer-controlled carts	50	45
4 Type of storage system		
1 conventional	67	66
2 computer-controlled warehousing system, automated storage and retrieval system	33	34
5 Type of inspection system		
1 manual inspection	74	52
2 automated maintenance and monitoring system	26	48

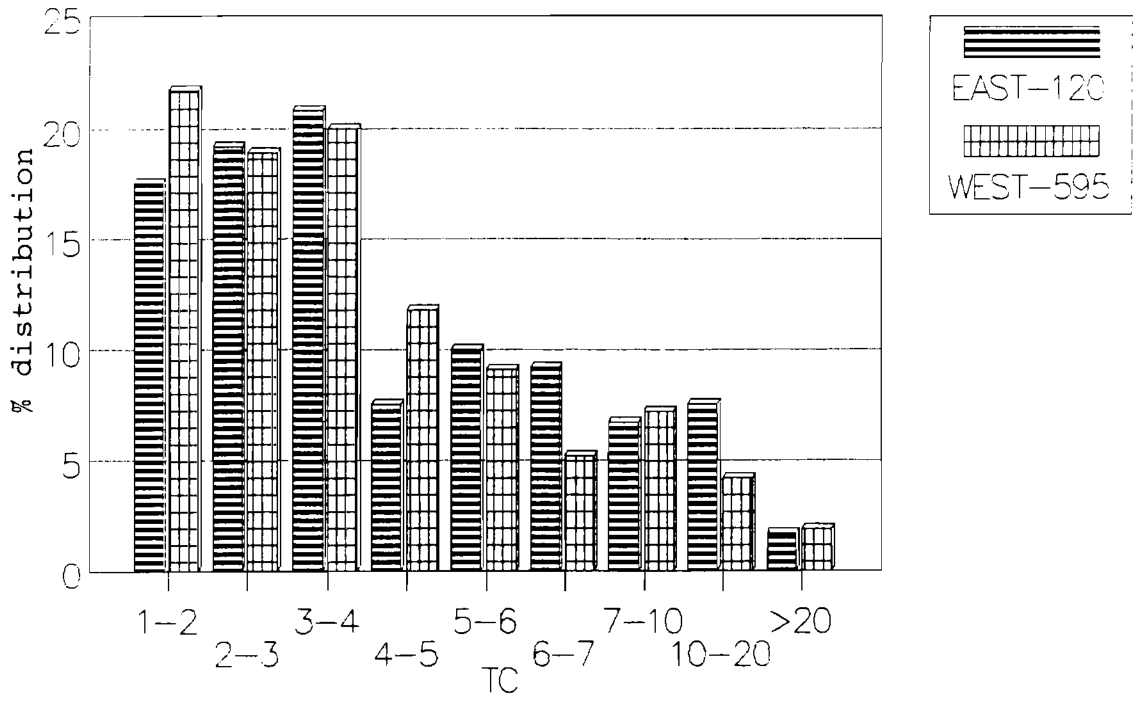

Figure 11. East-West comparison of FMS distribution over technical complexity (TC), %.

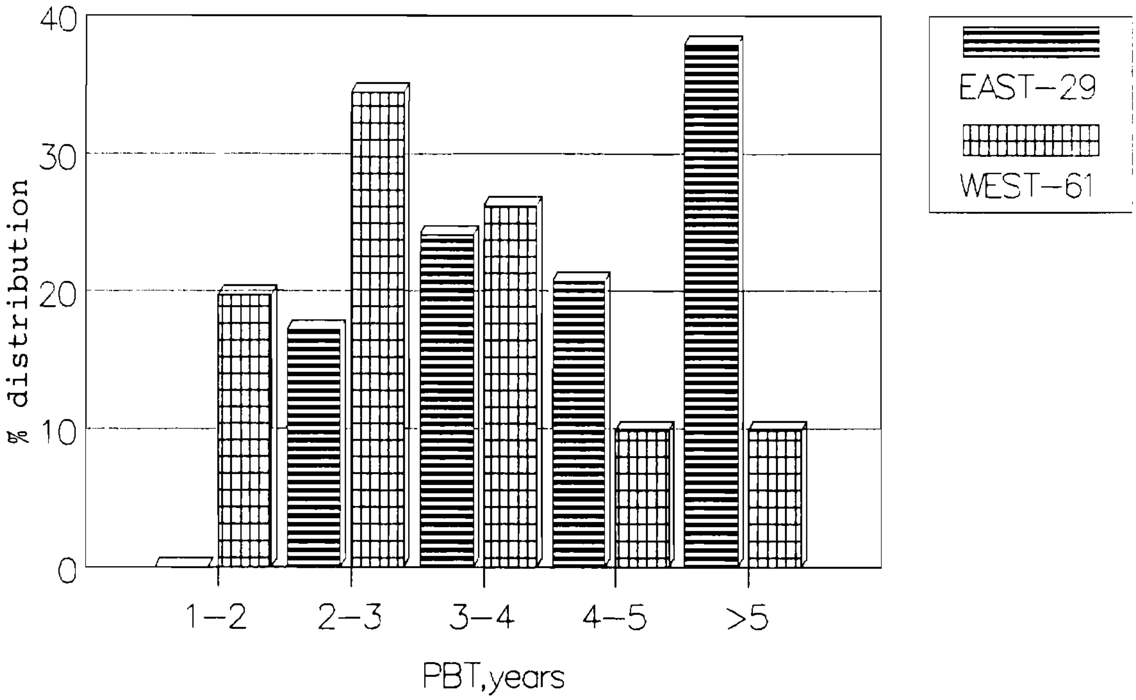

Figure 12. East-West comparison of FMS distribution over pay-back time (PBT), %.

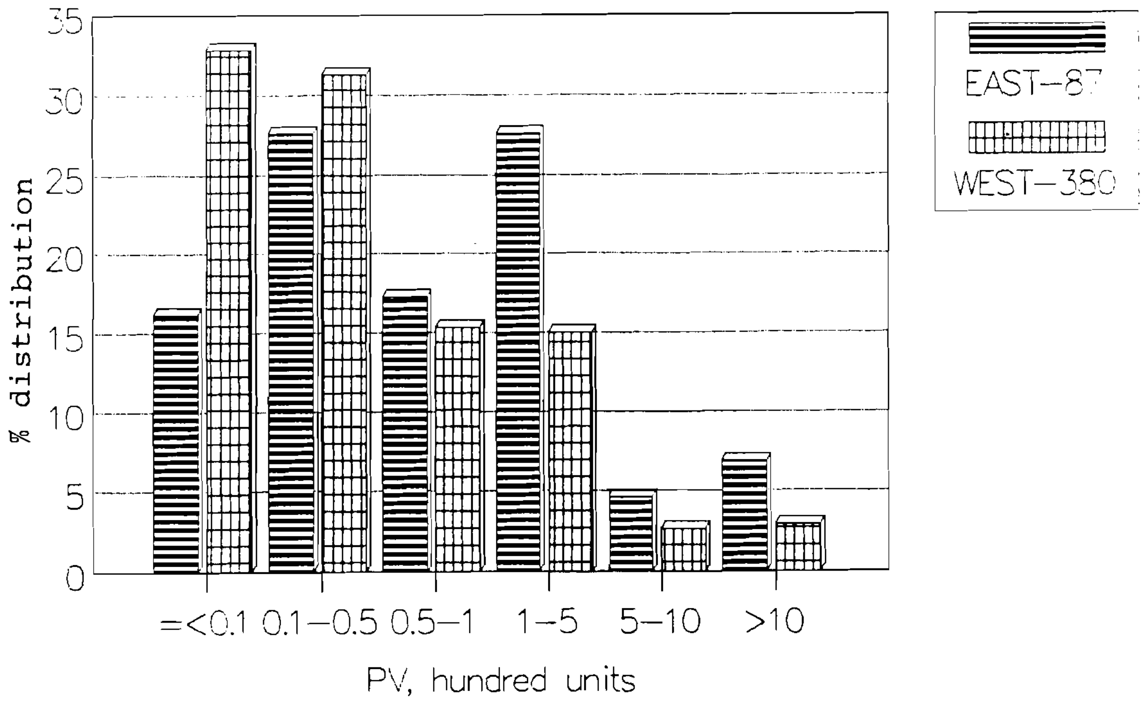

Figure 13. East-West comparison of FMS distribution over number of product variants (PV), %.

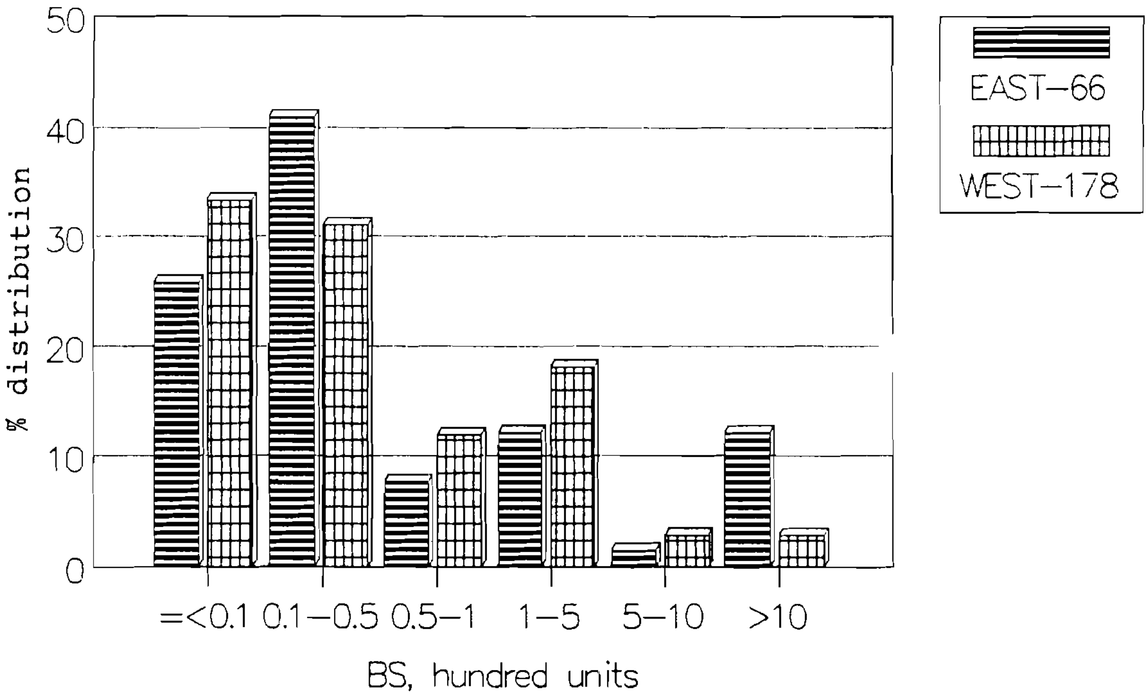

Figure 14. East-West comparison of FMS distribution over batch size(BS), %.

The main reason for a higher average batch size in an Eastern country lies in a much higher share of FMS with a big batch production mode. 12% of the Eastern FMS (probably substituted for conventional transfer lines) produce more than 1000 parts per batch, while only 3% of the Western systems have the same production mode.

The higher average number of product variants in the Eastern countries could be explained by a lower average part complexity. As was shown in [12], the ratio of the number of machining centers to the total number of NC-machines could be used as an indicator of the part complexity (a higher ratio means a higher complexity). This ratio is slightly higher for the Western FMS.

The average indicators of the flexibility (PV/BS ratio) are similar in the both samples and equal to approximately 0.92 for the Western FMS and 0.98 for the Eastern FMS.

We also compared the distributions of two efficiency indicators -- in-process-time and personnel reduction, see Figures 15 and 16, respectively. They were chosen as they offer enough observations for such an analysis.

In both cases we could observe extremely high shares of the Eastern systems with relatively low reductions (52% with an IPT = 1-2 and 60% with a PER = 1-2). Almost all of them belong to Czechoslovak cases. The second reason for the lagging behind of the Eastern FMS in these two indicators is a relatively low share of the systems with a high efficiency. Practically, only in 7 Eastern cases the IPT was reported to be more than 4, and in 7 cases the PER was reported to be more than 4.

4. Findings and Conclusions

The above analysis of the international comparison allows to draw some conclusions, which are based on statistical averaging and which consequently show probabilistic features.

Among the users of FMS in the world there are two definite leaders, namely Japan and the United States. Each of them uses over 150 FMS with a high average efficiency. The are followed by three other important users -- the FRG, the UK and France with about 100 FMS each. But their technical and economic records are usually lower than in the fist two countries.

The ranking shown in Table 4 generally reflects the relationship among the users.

We could retrieve some important differences in FMS use in the leading countries. The US systems are more expensive than the others, even if we take their high complexity into consideration. But their pay-back time is relatively moderate due to the high efficiency of their use.

The Japanese FMS are more strongly oriented towards higher flexibility than those of the other countries, and they show the

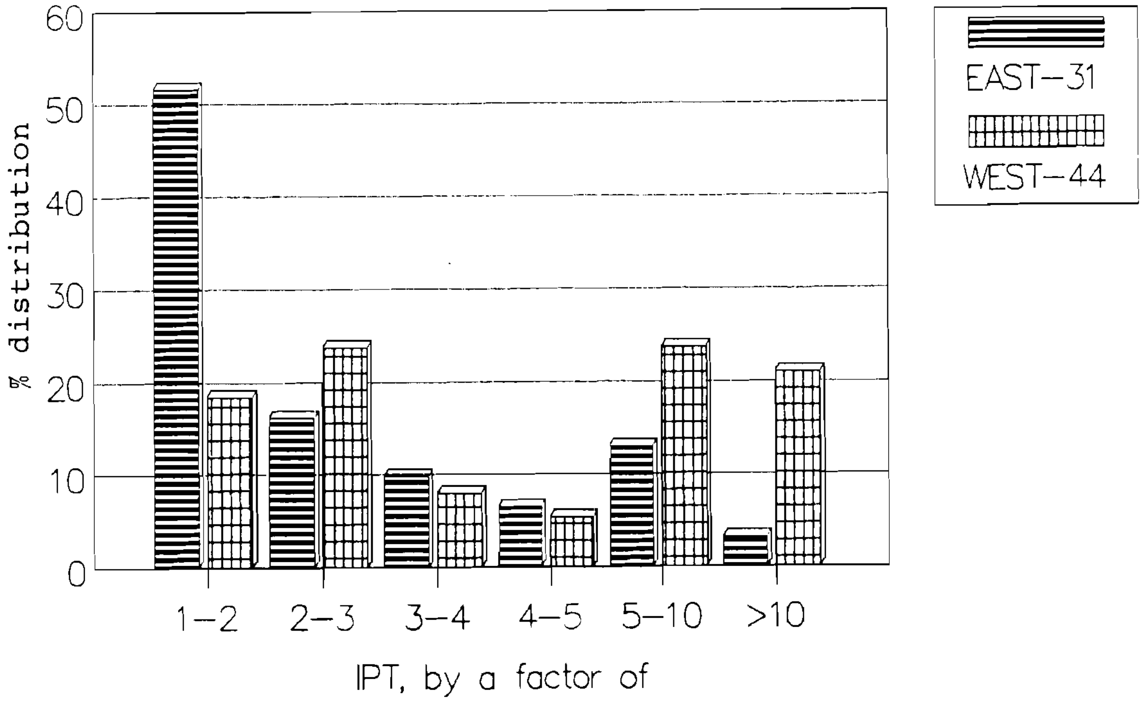

Figure 15. East-West comparison of FMS distrubiton over in-process time reduction (IPT), %.

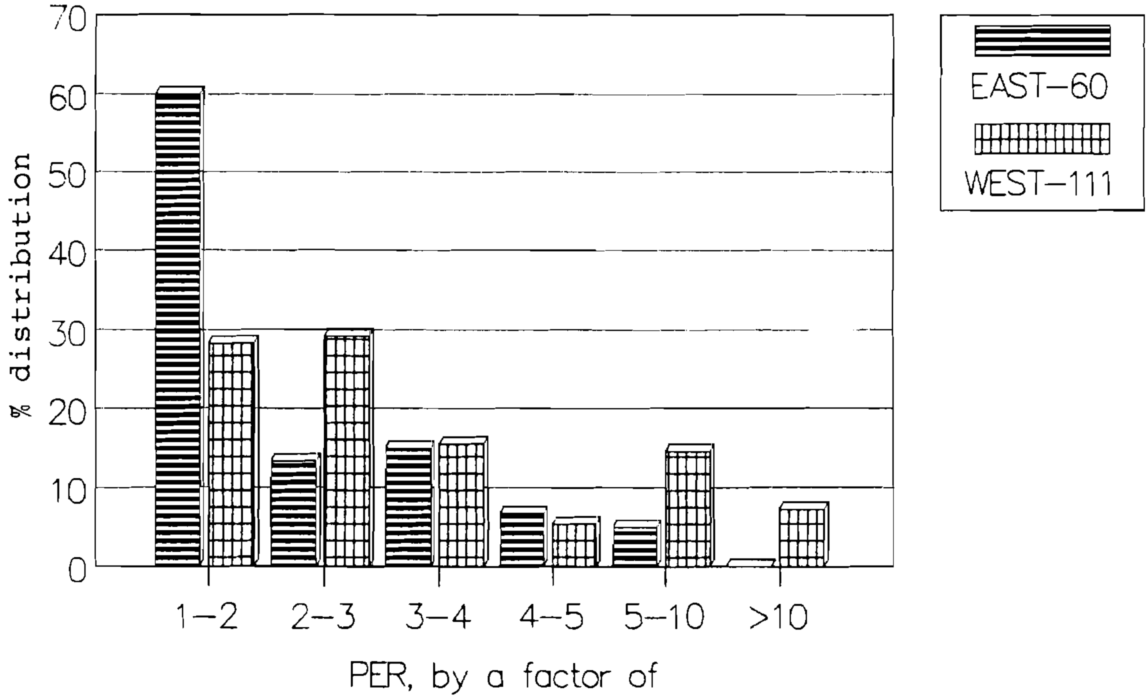

Figure 16. East-West comparison of FMS distribution over personnel reduction (PER), %.

Table 4. Ranking of main FMS users (1 = best)

Country	Indicators								
	N of FMS	TC	PBT	PV/BS	VIP	PER	NOM	LTR	UCR
FRA	5	4	4	-	-	-	-	-	-
FRG	4	3	5	4	4	3	4	3	4
JAP	1	2	3	1	3	1	2	1	3
UK	3	5	1	3	2	4	3	4	1
USA	2	1	2	2	1	2	1	2	2

highest average lead time reduction. Japan is the leader in FMS use in more progressive areas. 36% of the Western systems installed in electronics and instrument industries belong to Japanese companies, and 31% of the FMS used in assembling operations are in Japan. The Japanese FMS provide the highest average personnel reduction, while the US FMS are leading in work-in-progress and number of machines reduction.

The FRG is close to the leaders in technical complexity, while the UK has very good records in pay-back time and unit cost reduction.

The East-West comparison displays some advantages of the Western FMS in several efficiency indicators, in-process time, personnel and number of machines reduction and, as a result, in pay-back time. At the same time, the Eastern FMS show records equal to the Western FMS with regard to technical complexity, capacity utilization increase, as well as to unit cost and floor space reduction.

The operation modes for the Eastern and Western FMS are different. The first ones produce more product variants, but by bigger average batch sizes. This could probably be explained by the higher share of FMS substituting for several conventional transfer lines in the Eastern countries.

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