Influences on the Availability of Flexible Manufacturing Systems

U. Heisel, H. Hammer — Submitted by G. Pritschow (1), Universität Stuttgart/Germany
Received on January 16, 1992

SUMMARY:

A major prerequisite for the economical operation of Flexible Manufacturing Systems is a high level a availability. This is determined, on the one hand, by technical factors and, on the other hand, by limitations in the corporate organization and personnel. The paper presents results of a field study, in which reasons for breakdowns caused by technical errors and inadequate organization are viewed in relation to the effects of insufficient qualification and motivation of personnel.

KEY WORDS: Availability, FMS

1 Introduction

Results of numerous investigations allow statements to be made about economical aspects, performance in service and particularly availability of Flexible Manufacturing Systems [1, 2, 3, 4, 6, 7, 8, 9, 12, 14, 19, 20, 24, 27, 34]. The latter can, however only be specified exactly for the individual case and considerable scatter arises as can be found in the literature and by comparison of several practical examples. The effective system efficiency can vary from 65 % to 95 % whereby downtime due to technical problems can be between 3 % and 15 % and due to organizatorial problems between 5 % and 25 % [25].

The reason for each variance and in particular the possibilities of influencing its extent are largely unknown [16, 32]. Based on investigations with selected practical examples those quantities and their weightings influencing the effective efficiency were analyzed.
This paper deals with Flexible Manufacturing Systems of different designs depending on the requirements of different users. The selected companies were chosen from the following fields: general mechanical engineering, automotive industries, textile machines, printing machines, and special purpose machines. In regard to the system comparability those investigated were in each case composed of horizontal machining centers of the same design and connected by track vehicles. An integrated computer control system provided the automatic workpiece and tool supply. Thus the personnel worked independently of the pace of the machine tool and the production required a minimum of supervision as well as almost no set-up time during the job changes. Two thirds of the systems investigated comprised three or four interlinked machine tools with batch sizes between 5 and 200 workpieces. Small batch production as well as the continuous mass production were also represented. The average number of different workpieces was between 20 and 350 for mass production. The avarage pallet processing time was in the range of 5 to 300 minutes. All systems investigated had already been in operation for at least one year.

2 Determinations of the Effective and Technical Efficiency

The determination of the effective efficiency and technical availability of modern system controls occurs largely automatically by acquisition and evaluation of operational data. There is disagreement about the meaning of effective efficiency and technical availability. The following evaluation of results is based on the newly established definitions [30, 31]

The determined effective efficiency, technical availability, technical and organizational errors are average results taken over a longer observation period. The effective efficiencies have considerable scatter and the values lie in the range from 65 % to 95 % (81,3 % on an average) independent of the area of application. Relative to the effective efficiency the scatter of the technical availability is lower and lies in the range of 81 % to 99 %, 92,3 % on average.

The organizational non-productive time is equal to or higher than the technical non-productive time on a percentage basis. The reasons are the frequent changes of the workpiece spectrum, initial operations before safe production, modification of jigs and fixtures and tool problems during manufacturing. The low availability is caused by a wide variety of workpieces and very short pallet processing times.

In addition the long active repair time after breakdown is a contributory factor [11, 21]. One positive exception is in particular the high level of motivation of the personnel, supported by a premium wage system [10, 29].

3 Boundary Conditions for Manufacturing Engineering and Industrial Organization

In order to explain the reasons for the wide scatter of the efficiency levels of the systems investigated, the most important influences on the manufacturing engineering quantities were systematically analyzed. This refers, on the one hand, to the nature of production engineering itself, and all the workpiece related dependencies such as the number of workpieces, the pallet processing time or the number of tools used. On the other hand, the influences of all job and service conditions such as the number of job changes or the daily processing time as well as the organizational logistics and number of shift work personnel were investigated. Unexpected results were frequently obtained.

The effective efficiency viewed in relation to the primary type of manufacturing is shown in figure 1. The users are subdivided into the groups mass production, medium batch production and small batch production With mass production the effective efficiency is over 80 % on average, with medium batch production 78 % and one user achieved 84 % with small batch production. The results show that there is no direct relationship between the effective efficiency and the type of production. No direct inter-relationship between the effective efficiency and the number of different workpieces was found as shown in figure 2 The same applies for the average pallet processing time except where the processing time is greater than 20 minutes (figure 3). There is a clear decrease of efficiency with lower pallet processing time The presumption that the complexity of workpieces has no influence on the efficiency has not been validated [3, 16] Besides the machining time this statement can also be expressed by the necessary number of tools The investigations have shown that the efficiency with less than ten tools is clearly lower, which is attributable to the low pallet processing time As against this, there is no disadvantage with respect to the efficiency with a larger

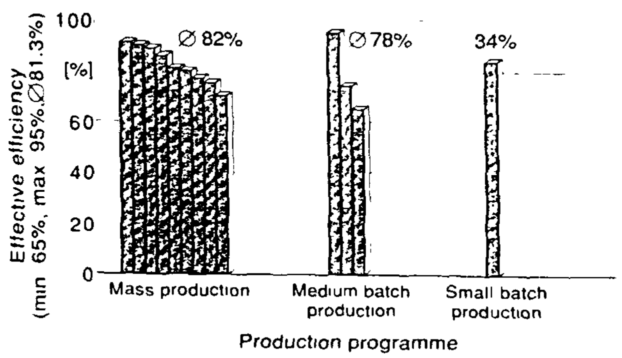

Figure 1: Effective efficiency as a function of the production programme

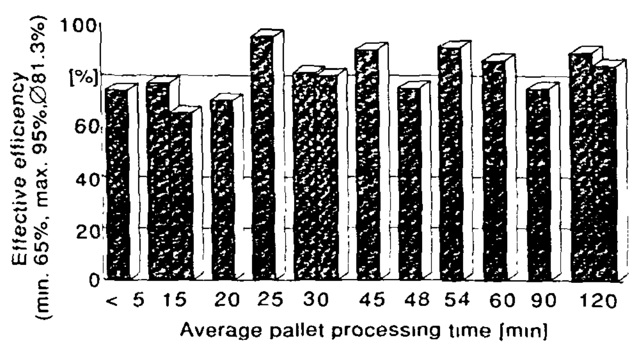

Figure 3: Relation between effective efficiency and the average pallet processing time

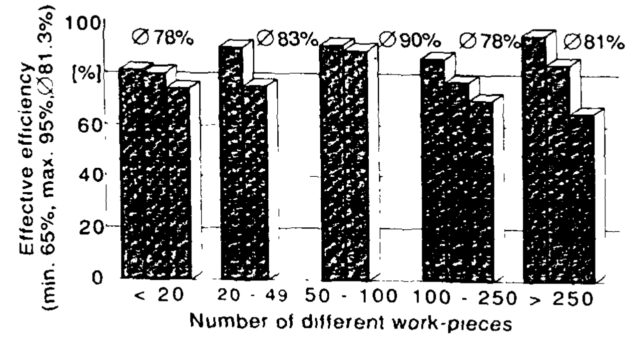

Figure 2: Comparison between effective efficiency and the number of different work-pieces

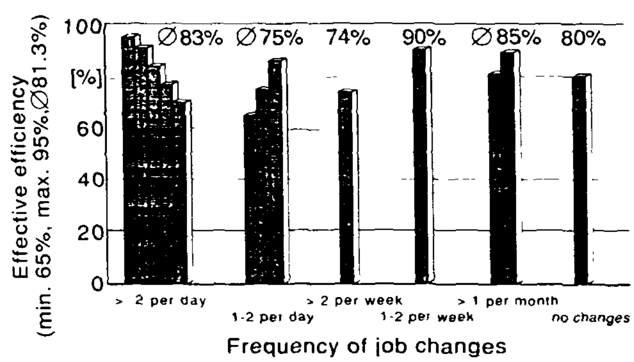

Figure 4: Effective efficiency as a function of the frequency of job changes

number of tools and increasing workpiece complexity. Investigations of the effective efficiency in relation to the frequency of the job change indicate that no regularity arises (figure 4). This parameter which is often regarded as a hindrance to optimal system use has not been verified for the practical examples investigated [16].

Shift work was investigated as a further influencing parameter. The majority of users (46 %) run systems on a three shift basis, followed by users (38 %) who run their system in the third shift with no personnel in order to machine only those workpieces previously set up. 8 % of the users run one complete shift with no personnel, and another 8 % manufacture only during two shifts. The kind of shift work has no clearly definable influence on the availability of FMS, as is often assumed [16].

The number of operators per shift is also of secondary importance in relation to the efficiency of Flexible Manufacturing Systems. The investigation of the distribution in relation to the number of operators per shift showed that in almost two thirds of all cases the systems were operated by one or two operators The analysis of the relationship between the effective efficiency and the number of machining centers per operator shows that no clear conclusions can be drawn Increasing the number of machine tools per operator increases the burden for the operator during system use A decrease of system efficiency is, however, only recognizable for four or more machine tools per operator.

4 Reasons for Technical and Organizational Downtime

As shown previously, downtime for technical reasons for the practical examples investigated amounts to 7.7 % on average. The results showed good correlation with the causes outlined in the literature [3, 9, 11, 16] which in most cases are of a simple nature and are technically easy to understand.

The systems available for fault recognition and elimination such as the error messages delivered by the control system and diagnostic handbooks are generally found to be fully adequate. The assessment of diagnosis systems depends essentially on the education and experience of the personnel.

A systematic training of the operator in the procedure for fault rectification is of particular importance. A higher efficiency can be achieved if the operator has adequate know-how in order to eliminate simple faults without the necessity to involve the service departement. Unnecessary time delays can thus be avoided (figure 5). The repair work to be undertaken by the operator should, however, be restricted to smaller tasks which do not require much time involvement such that major downtime problems due to a shortage of operating personnel can be avoided. In depth investigations in this regard have the objective of establishing new models of work organization [28].

For quick and effective fault repair a maintenance department is required with highly trained craftsmen in the area of mechanics, hydraulics, electronics and electrical technology. Without exception the employment of personnel with higher qualifications (foreman and technicians) contributes also to a high effective efficiency with low downtime for technical reasons (figure 6). Training at the plant of the system manufacturer, further education programmes and also the presence of maintenance staff during installation, assembly and initial operation of Flexible Manufacturing Systems means that the servicing staff has mostly such an in-depth knowledge that the system manufacturer is required for only less than 5 % of all faults arising

This investigation shows that downtime for organizational reasons amounts to 11.1 % on average thus clearly exceeds that due to technical reasons Above all, the non-productive times were obviously caused by missing tools and poor tool management. Particularly in the case of manufacturing with mainly short processing times and a large number of different tools considerable non-productive times were found to occur. Only few users make consistent use of a tool management system with computer controlled tool supply, tool disposition and data management to solve the above problems.

With regard to the workpiece supply downtime occurs due to the lack of unmachined parts [21]. Especially the supply of unmachined castings from external foundries leads frequently to problems. Transportation within the company is generally well organized by the majority of users, so that in this regard no downtime occurs. Non-productive periods due to operator absence do not occur very often. The availability of floating personnel and the deployment of foremen during illness or holiday of operators largely avoid a reduction of efficiency

5 Influence of Qualification, Wage System and Motivation of Personnel

Analysis of the production factor "man power" for the application of Flexible Manufacturing Systems is one of the key areas of this investigation. Besides the hierarchical personnel structure and job sharing a further interesting aspect is the qualification of the personnel working with the Flexible Manufacturing Systems [5, 13, 15, 17, 18, 22]. As a general principle, two almost identical groups can be distinguished from an educational point of view. 46 % of the users employ operators who are craftsmen with CNC-training, whilst 54 % of the users employ both craftsmen with CNC-training as well as semi-skilled workers. An evaluation of this situation, however, shows that there are no differences between both groups in regard to the efficiencies of Flexible Manufacturing Systems. This fact can be explained by the interest in further educational development of operating personnel, independent of the educational background of the individual employees. In this regard it is also of interest that the average age of the operating personnel of 92 % of all system users is only 30 years and less

The wage system has an important influence on the system efficiency. The investigated system users make use of the three wage systems: time wages, piece wages and premium wages. In figure 7 the effective efficiency in relation to the wage system is shown. 54 % of all users make use of the time wage system. The effective efficiency with this system is about 78 % on average. 15 % of the users apply the piece wage system with an effective efficiency of also 78 % on average. All other users (31 %) introduced the premium wage system and achieve the highest effective efficiency of 88 % on average.

Investigations regarding downtime for technical reasons in relation to the wage systems show the same tendency [10, 32]. The technical downtime for the cases of time wages and piece wages are approximately 8 % on average Users applying the premium wage system have only 6 % downtime on average.

The result is even clearer, when the organizational downtime in relation to the different wage systems is compared. The users with the time wage system have the highest organizational downtime rate (13 %) on average, followed by users with the piece wage system (11 %). Users with the premium wage system achieve organizational downtime of only 6 % on average. Thus the premium wage system for employees influences mainly the organizational downtime rate. The organizational downtime associated with the premium wage system amounts to only the half on average that for the time wage system.

Clear statements can also be formulated in regard to the motivation of the operating personnel. Motivation assessment is based on the subjective assessment by the people involved in the investigation. The result is, however, extremely interesting. There is a qualitative relationship between motivation of operating

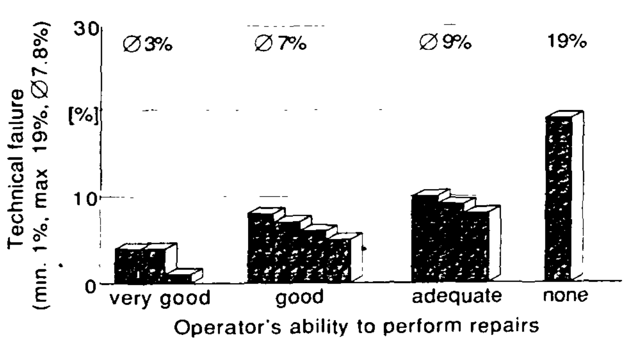

Figure 5: Technical failure in relation to the operator´s ability to perform repairs

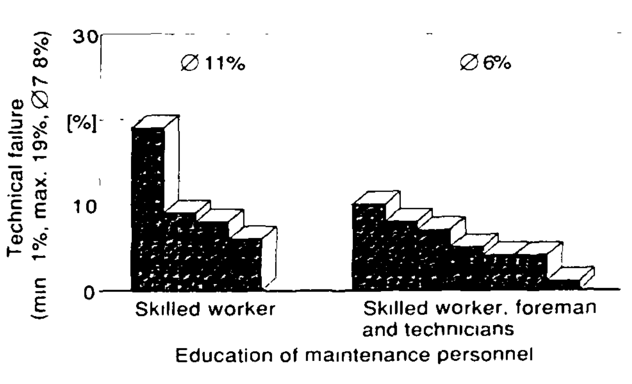

Figure 6: Comparison between technical failure and the education of maintenance personnel

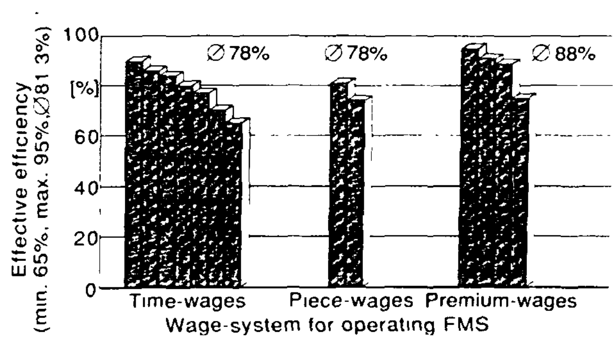

Figure 7: Relationship between effective efficiency and the wage-system for operating the FMS

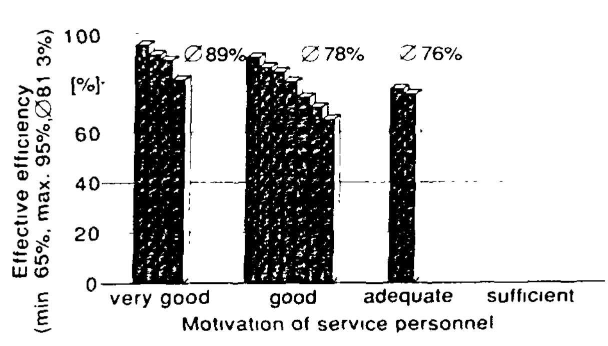

Figure 8. Effective efficiency as a function of the motivation of service personnel

personnel and the wage system applied. As compared with the time wage system the premium wage system results clearly in a higher level of motivation of the personnel.

The effects of this are shown clearly in the diagram showing effective efficiency in relation to the motivation of the operating personnel (figure 8). The degree of motivation is characterized in four stages. Users with highly motivated personnel obtained the highest effective efficiency (89 %) on average. Users with well motivated personnel obtained 78 % on average whilst users with adequately motivated personnel had an effective efficiency of 76 % on average.

6 Conclusions

From the investigations described above it follows that the factors influencing the availability of FMS such as type of production, production mix, rate of repetition and complexity of production are much less significant than the human factors which are characterized by qualification and motivation.

The individual represents the nucleus of production technology in spite of automatization and computer integration [23, 26, 29]. He is willing to operate at high performance rate when he is offered incentives and technical challenges and when an adequate motivation exists. In addition to this, he has to be satisfied with the system engineering and system conception. This requires that he has a good level of competence in his field of specialization at high efficiency. A considerable organizational effort is necessary in order to minimize non-productive time. This requires the complete integration of the FMS into its entire operative surroundings.

References :

1. Alberti, N., Noto La Diego, S., Passannanti, A., 1988, Cost Analysis of FMS Throughput, Annals of the CIRP, Vol. 37/1, p. 413 - 416
2. Bullinger, H.-J., Klein, A., 1989, Flexible Arbeitszeit im zukunftsorientierten Produktionsbetrieb, wt Werkstattstechnik 79, p. 605- 608
3. Bunse, P, Judica, N., 1989, Expertensysteme zur Verfügbarkeitsoptimierung flexibler Fertigungszellen, ZwF 84, Nr. 4, p. 211 - 214
4. Crookall, J.R., 1987, Education for CIM, Annals of the CIRP, Vol. 36/2, p. 479 - 494
5. Ebert, J., Herter, J., Thomas, H., 1989, Hersteller-Schulung für flexible Fertigungssysteme, ZwF 84, Nr. 12, p. 714 - 718
6. Eversheim, W., 1991, Zielsetzung heißt Flexibilität, Schweizer Maschinenmarkt, Nr. 12, p. 28 - 47
7. Hammer, H., 1985, Bausteine und Konzeptionen für flexible Fertigungssysteme (FFS), Technische Rundschau 21, p. 8 - 17
8. Hammer, H , 1991, Unterschiedliche Konfigurationen installierter flexibler Fertigungssysteme belegen Wirtschaftlichkeit, Werkstatt und Betrieb 124, Nr. 6, p. 433 - 437
9 Handke, G., 1983, Organisatorische Maßnahmen für das Verringern der Maschinenausfallzeiten, Maschinenmarkt 89, Nr. 49, p. 1139 - 1141
10 Heinrich, E., 1989, Prämienlohnsystem bei Einsatz von NC- und CNC-Maschinen in der Einzel- und Kleinserienfertigung, AV 26, Nr. 3, p 115 - 118
11 Holz, B , Gabler, W., 1985, Flexible Fertigungssysteme, Ingersoll Ingenieurgesellschaft mbH., Springer, Berlin.
12. Keller, A , Kamath, A , 1982, Reliability Analysis of CNC Machine Tools, Reliability Engineering 3, p. 449 - 473
13. Mahrin, B., 1991, CAD/CAM/CIM - zeitgemäße Qualifizierung für neue Fertigungsstrukturen, ZwF 86, Nr. 3, p. 151 - 154
14. Maschke, H., 1988, Mit Flexiblen Fertigungssystemen zu höheren Verfügbarkeiten, Werkstattstechnik 78, p. 109 - 113
15. Mertens, D., 1974, Schlüsselqualifikationen - Thesen zur Schulung für eine moderne Gesellschaft, Mitteilungen aus der Arbeitsmarkt- und Berufsforschung, Nr. 1, p. 36 - 41
16. Milberg, J., Reithofer, N., 1986, Einflüsse auf die Nutzungsdauer von Maschinen, Industrieanzeiger 108, Nr. 46, p. 58 - 63
17. Mücke, K., 1990, Weiterbildung erhöht Motivation und Produktivität, Werkstatt und Betrieb 123, Nr. 4, p. 319 - 321
18. N.N., 1988, Neue Techniken - neue Qualifikationen. Chancen für den Weg in menschengerechte Produktionsstrukturen, VDI-Z 130, Nr. 7, p. 12 - 17
19. Rauscher, K., 1989, Verfügbarkeit von Werkzeugmaschinen, Werkstattstechnik 79, p. 329 - 332
20. Reithofer, N., 1987, Nutzungssicherheit von flexibel automatisierten Produktionsanlagen, doctoral thesis, Munchen.
21. Reithofer, N., 1986, Einfluß von Kleinststörungen auf den Fertigungsablauf, Industrieanzeiger 108, Nr. 70, p. 34 - 35
22. Rose, H., 1991, Bedeutung des Erfahrungswissens für die Bedienung von CNC-Maschinen, ZwF 86, Nr. 1, p. 45 - 48
23. Roth, S., 1988, Selbststeuerung der Arbeit als Gestaltungsprinzip für CIM, VDI-Z 130, Nr. 6, p. 30 - 34
24. Seidel, R.H.A., Arndt, G., 1988, Productivity Improvement in Job Shop Production, Annals of the CIRP, Vol. 37/1, p. 421 - 424
25. Shah, R., 1991, Flexible Fertigungssysteme in Europa: Erfahrungen der Anwender, VDI-Z 133, Nr. 6, p. 16 - 30
26. Spur, G., Herter, J., Zurlino, F, 1990, Qualifizierung für flexible Fertigungssysteme durch die Herstellerunternehmen, ZwF 85, Nr. 11, p. 605 - 608
27. Steinhilper, R., 1985, Erfahrungen mit flexiblen Fertigungssytemen, VDI-Z 127, p. 583 - 589
28. Stephan, S., Arbeitsorganisation und Personaleinsatz an Flexiblen Fertigungssystemen, Forschungsbericht Fraunhofer Institut für Arbeitswissenschaft und Organisation (IAO) und Universität Leipzig Fakultat Wirtschaftswissenschaften, Stuttgart, 1992
29. Tarabusi, A., 1989, Den Menschen nicht unterbewerten! CIM-Konzept kritisch durchleuchtet, Schweizer Maschinenmarkt 89, Nr. 9, p. 22 - 25
30. VDI 3423, 1991, Auslastungsermittlung für Maschinen und Anlagen,- Beuth, Berlin.
31. VDI 4003, 1985, Allg. Forderungen an ein Sicherungsprogramm, Klasse A Verfügbarkeit, Beuth, Berlin.
32. VDW Forschungsberichte, 1991, Studie zum Thema 'Verfügbarkeit von Werkzeugmaschinen', Frankfurt.
33 Walther, E., 1985, Qualifikation und Entgelt für das Arbeiten in flexiblen Fertigungssystemen, Werkstattstechnik 75, p 187 - 189
34 Wiendahl, H -P., 1990, Throughput-Oriented Lot Sizing, Annals of the CIRP, Vol 39/1, p. 509 - 512