Applying Total Productive Maintenance - TPM Principles in the Flexible Manufacturing Systems

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ABSTRACT

The flexible manufacturing systems (FMS’s) are applied to get a better productivity, a better process and a product quality and a better flexibility to have better tools to meet the customers demands, and to stay competitive on the international markets.

It is important, that these systems are also effectively used and that the utilization rate of the single machine tools connected the system is as high as possible. The new maintenance methods like TPM, total productive maintenance have a very important role to really effective use the highly automated production systems like FMS.

In this rapport first the problem, the failures and operational disturbances is described. The TPM as a possible tool for reaching a higher utilization rate in the single machine tools is presented. Finally some concrete measures to implement the TPM in highly automated production like in flexible manufacturing (FM) are given.
DEFINITIONS:

NC – machine tool = Numerical, computer controlled machine tool, e.g. for turning or milling. The NC – and CNC are meaning the same.

FMM = Flexible Manufacturing Module
FMC = Flexible Manufacturing Cell
FMS = Flexible Manufacturing System
FMF = Flexible Manufacturing Factory

OEE = Overall equipment effectiveness:

OEE = Equipment availability x Performance Efficiency x Rate of Quality Products (1)

Kobetsu –Kaizen = individual maintenance of the machine operator for making continuous improvement in small steps in the process

Jishu – Hozen = autonomous maintenance

Hinshitsu – Hozen = quality maintenance, to ensure that the plant is in perfect condition to produce 100% quality products

ADC = automatic data collection

PPT = planned production time

MDT = Mean down time = expectation of the down time

\[
MDT = \frac{\text{Down time}}{\text{Number of failures during planned production time}} \quad (2)
\]

MDT = MTTR + MWT \quad (3)

MTTR = Mean time to repair = expectation of time to restoration

MWT = Mean waiting time = expectation of time for restoration to start
MTBF = Mean time between failures = expectation of the operation time between failures

MTBF = Planned production time – down time
----------------------------------------------- (4)
Number of failures during planned production time

Availability = the ability of an item (a machine) to be in a state to perform a required function under given conditions at a given instant of time over a given time interval

Availability (A) = Planned production time – down time
----------------------------------------------- X 100 % (5)
Planned production time

Availability (A) = MTBF
-------------------------- x 100 % (6)
MTBF + MDT

Because MDT = MTTR + MWT

Availability (A) = MTBF
-------------------------- x 100 % (7)
MTBF + MTTR + MWT

Absolute availability is based on calendar time (8760 h / a = 730 h / month = 183 h / week). Planned production time includes all the available hours in a year (8760 h).

A_{abs} = Calendar time (8760h / a) – down time
------------------------------- x 100 % (8)
Calendar time

MTBF_{abs} = Calendar time (8760h / a) – down time
------------------------------- x 100 % (9)
Number of failures during calendar time

A_{abs} = MTBF_{abs}
------------------- x 100 % (10)
MTBF_{abs} + MDT
Relative availability is based on a planned production time. The values are real and they indicate the real failure behaviour state of an individual machine tool.

\[ A_{rel} = \frac{\text{Planned production time (8, 16, 24 h) } - \text{down time}}{\text{Planned production time}} \times 100\% \quad (11) \]

\[ \text{MTBF}_{rel} = \frac{\text{Planned production time (8,16,24 h) } - \text{down time}}{\text{Number of failures during planned production time}} \times 100\% \quad (12) \]

\[ A_{rel} = \frac{\text{MTBF}_{rel}}{\text{MTBF}_{rel} + \text{MDT}} \times 100\% \quad (13) \]
1. INTRODUCTION

Maintenance is not an expense; it is an investment in improved manufacturing. Investment in maintenance, one of the basic functions of a firm, returns improved quality, safety, dependability, flexibility and lead times (Teresko, 1992). Over the past decade there has been increased recognition that in a world class manufacturing (WCM), maintenance is not a separate, isolated function that makes repairs and performs assorted activities as needed. Rather, maintenance is a full partner striving together with the other functions to achieve the firm's strategic goals (Etienne-Hamilton, 1994).

The new production principles like JIT, Just in time manufacturing and Lean – manufacturing were putting new demands to the effectiveness of the maintenance function in the industry and the same tendency will continue in the 2000'ies.

To reach a good product and process quality, a high productivity and a short lead time, the challenges of the 2000th century in the so called Agile Manufacturing AM, companies invest in the flexible manufacturing systems, FMS's.

To get the flexible manufacturing systems running effectively, the emphasis in the maintenance must be put on the following issues:

To be really competitive and effective, the metalworking company must apply total productive maintenance (TPM) principles and concentrate its efforts to eliminate or at least minimize the so called SIX BIG LOSSES (Nakajima, 1988):

1. Equipment failure = sporadic and chronic equipment failure / breakdowns
   Sudden and unexpected sporadic breakdowns are infrequent and result from the deterioration of the mechanical and electrical operating components. For example a hydraulic error in tool changer of the CNC – machine tool or an electrical error in the CNC – control etc.
   Chronic breakdowns, which are the result of the defects in equipment, tools, materials, and operating methods, occur frequently, resulting in small amounts of lost time. For example, unpredictable cutting tool breakdowns in the chip-breaking of difficult materials, mistakes in the choice of the manufacturing methods etc.

2. Set up and adjustment = make-ready and equipment adjustments. With shorter run lengths, smaller batches and more make-readies, reduction in make-ready time and new job adjustments, emphasis is being placed on time – to – good counts. For example, when a new job comes to a machine tool, tooling and fixtures have to be changed.

3. Equipment idling and minor stoppages = material abnormalities and slight machine malfunctions that can be overcome by replacing materials or resetting press components.
F ex incoming material has not equal quality, the automating tool changer is not working properly.

4. Reduced running speeds
F ex while numerous reasons are advanced for running presses and bindery equipment at slower than rated speeds, less than label-speeded operations represent a productivity loss.

5. Defects in process / defect products = Defective end products, for whatever reason must be treated as a loss and therefore eliminated.
F ex dimensions a dimension are not inside of the tolerance area. The products have some surface damages etc.

6. Reduced equipment yield - start up losses. Start-up loss is lost time after the make-ready is complete and production sheets/signatures are being counted, but at a reduced speed. The losses are generally accepted as a process variable, but account for considerable productivity loss.

As we see in the following figure (Fredendall, 1997), these six factors have really a big impact on the competitive factors of a company, especially in a small or medium sized company. They have an influence on the delivery times, flexibility, cost and quality as the figure 1 is showing.
FIGURE 1. Impact of maintenance on competitiveness (Fredendall, 1997)

2 FLEXIBLE MANUFACTURING SYSTEMS AND FAILURES

2.1 WHAT IS A FLEXIBLE MANUFACTURING SYSTEM?

It is difficult to find an exact definition for the flexible manufacturing system, FMS, in the literature. There is a variety of opinions on this subject among the FMS experts worldwide. Generally, FMS refers to flexible, highly automated system aiming at advanced automation and a high level of flexibility in manufacturing of parts in the small batch production. The most applications are in the manufacturing using metal cutting technologies like turning, milling, drilling and boring but the same concept can be use also e.g. in sheet metal working. In the Figure 2 a FMS application based on warehousing technology is shown.
FIGURE 2 A FMS for machining cylinder heads of medium – size Diesel – engine parts
In this context, flexibility refers to flexibility of time, space, ability to respond to rapid market changes, product life cycles, reduction of manual labour, substantial reduction of production costs, and maximum efficiency of the computer controlled production equipment associated with the FMS—technology. Certainly, any operable factory can be termed a manufacturing system, and flexible is a relative adjective at best. However, FMS—technology relies on the following distinguishing characteristics: (Lakso, 1988, also Lakso, Kuhmonen, 1995)

- Capability for unmanned production and to manufacturing with limited manpower.
- Capability to cope with changes in production volumes and in rapid response to market changes.
- All tool changing and material handling systems are fully automated.
- FMS—systems can include a wide range of monitoring functions for unmanned production.
- FMS can be equipped with very powerful fault diagnostic systems for all modules and their peripheral equipment in the entire system.
- There can be from just a few, up to several NC—machine tools in an FMS. Furthermore, it is possible to expand an FMS step by step in various stages over a period of time.
- Capability to machine high-priority parts rapidly featuring “almost fully zero set-up time”.
- An overall FMS—host computer, that controls and coordinates the material flow, the functions of both machine tools and conveyance system so as to achieve flexibility. Freedom of choice of software as for programming language, structure and supplier.
- Capability of random processing of any parts of the family of parts in any machine tool with almost or totally zero set-up time in Flexible Manufacturing Systems with parallel machines.
- The route of work pieces to be machined can be freely chosen and independent on the machine tools.
- An FMS may include complementary functions beside machine tools, e.g. automatic washing stations, integrated, robot—deburring stations or also measuring stations, like coordinate measuring machines etc.
- Possibility to use any machine tool in the system as single ones in stand-alone use, if required.
- Capability to react and adapt quite new components introduced in the present family of the parts in systems having a flexible fixture system.

- The family of parts can vary from just a few, up to several hundreds of different kinds of work pieces.
- Night-time, weekend and holiday operation is possibly unmanned, if due to existing work load.

The basic FMS—patterns based on layouts, transport systems, number of machine tools and on the total FMS—control system can be abbreviated as
follows (Metalworking Engineering and Marketing, 1984):

FMM = Flexible Manufacturing Module
FMC = Flexible Manufacturing Cell
FMS = Flexible Manufacturing System
FMF = Flexible Manufacturing Factory

FMM consists of a stand-alone NC-lathe or machining center equipped with a transport function such as a robot, automatic pallet changer (APC), magazine and monitoring functions for unmanned production.

FMC is above the FMM in the hierarchy, and it consists of two NC-machine tools included an automatic transport system, various functions and sensors for automatic operation.

FMS is made up of three or more NC-machine tools, which are integrated to each other by an automatic transport system. FMS possesses advanced auxiliary functions for machining operation, monitoring functions and a comprehensive computer control function, and requires NC-data control, scheduling and production control.

At the FMF (factory level) all the machining process in the entire factory has been changed to FMS. The whole factory has to be systemized with a host computer and several sub-computers, i.e. supported by computers. The highest level of FMS and FA (Factory Automation) means, that CIM (Computer Integrated manufacturing) is put into practical application, and FMS-technology is in use through the entire process from ordering to shipping of the finished products. Figure 3 classifies FMS's considering the variety of workpieces and lot sizes. Figure 4 presents the basic FMS-patterns based on layouts and transport systems.
FIGURE 3 FMS’s considering lot sizes and variety of workpieces. (Metalworking Engineering and Marketing, 1984)
FIGURE 4. The basic FMS patterns based on layouts and transport systems.
2.2 INFLUENCE OF FAILURES IN FMS

Demands for the reliability of the production equipment is high, when JIT (Just In Time) principles are in use. Failures of the production equipment do not influence only to production process, but also strongly on the whole customer oriented business chain. Below have been listed just a few of the consequences, which failures of key machine tools (FMS’s and stand – alone NC – machines can consistently cause (Lakso, Kuhmonen 1996):

- Increase throughput time ( lead time).
- Leads to lack of capacity and bottlenecks.
- Inventories and WIP (Work in Progress) will grow strongly.
- Repairing is non value-added work.
- Decrease reliability of delivery, image and reputation of the company
- Difficulties to reach high utilization rate
- Short investment payback periods are difficult to reach due to low utilization
- Unmanned periods cannot be taken into use
- Leads to unnecessary investment ( over investment )
- Causes among the whole organisation a situation like chaos
- Adds in all possible way manufacturing costs and weakens competitiveness
- The pay – back time of the system is longer than planned

2.3 TYPE OF FAILURES IN A FMS

A failure is any abnormality from required function of a machine. IEC 50 defines a failure as “the termination of the ability of a machine to perform a required function “. Both definitions also show, that a failure does not have to be a breakdown of a machine.

The different types of operation in the FMS – technology requires, that failures have to be divided into different categories. This requirement is based on different production stages. Firstly completely unmanned production, secondly production with limited manpower and thirdly production with attending manpower ( = manned production). In each individual operation type an effect of a failure on the production process is quite different. At each stage the reaction to a failure is also different.

Fundamentally three types of failures can occur in FMS’s (Lakso, Kuhmonen 1996)

Type 1 : a failure interrupts production ( manned or limited manpower)
Type 2 : a failure interrupts an unmanned production
Type 3 : a failure exist but it does not interrupt production.

The characteristics for these 3 different types of failures are listed in table 1.
Table 1. Failure types and classification in FMS – technology (Lakso, Kuhmonen, 1996) (ADC = automatic data collection)

<table>
<thead>
<tr>
<th>TYPE 1</th>
<th>TYPE 2</th>
<th>TYPE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>- long down time</td>
<td>- short down time</td>
<td>- failure appears but it does not affect production</td>
</tr>
<tr>
<td>- requires a repair man</td>
<td>- removable by skill of the operators</td>
<td>- can be repaired outside the planned production time</td>
</tr>
<tr>
<td>- not repetitive</td>
<td>- repetitive</td>
<td>- collected manually / ADC</td>
</tr>
<tr>
<td>- breakdown</td>
<td>- failure data is collected by ADC</td>
<td>- can be a symptom for a becoming failure</td>
</tr>
<tr>
<td>- failure data is manually collected</td>
<td>- all failure values can be calculated</td>
<td>- doesn't have down time</td>
</tr>
<tr>
<td>- all failure behavior values can be calculated</td>
<td>- has a great influence on success of unmanned production</td>
<td>- calculation of the failure behavior is impossible</td>
</tr>
<tr>
<td></td>
<td>- automatic recovery functions are possible</td>
<td></td>
</tr>
</tbody>
</table>

The failure behavior can be defined separately for each failure type. This requires, that collected failure data is classified in these three groups. Type 3 failures is possible to define only as a mean time between Failure (MTBF) value.

3. WHAT IS TOTAL PRODUCTIVE MAINTENANCE, TPM?

A great amount of companies find, that in spite of the huge improvements in the productivity in the last years, there is still a big potential to be better in utilizing the machine tools and in reaching the better productivity goals. Like the Japanese say, “to discover the mountain of possibilities”. (Johansson 1996). One main method to meet this challenges is the TPM, Total Productive Maintenance. TPM is a systematic approach to understanding the equipment’s function, the equipment’s relationship to
product quality and the likely cause and frequency of failure of the critical equipment components (Nakajima, 1988).

A formal definition and concept is given by Nakajima, 1988, also Suzuki 1992:

1. TPM is aimed at maximizing equipment effectiveness through the optimization of equipment availability, performances, efficiency and product quality.

2. TPM establishes a maintenance strategy (level and type of PM, productive maintenance) for the life of the equipment.

3. TPM covers all departments such as the planning department, the users and the maintenance department.

4. TPM involves all staff members from top management down to shop floor workers.

5. TPM promotes improved maintenance through small group autonomous activities.

3.1 HISTORY OF THE TPM

After the second world war the Japanese Industry realized, that they must have a higher quality in the products to compete on the world market. The Japanese companies were importing the management – and manufacturing technologies from the USA, and then tailored them to their needs.

To be effective in the maintenance their imported the concept of the preventive maintenance from the USA for over 40 years ago. Later were also the principles of the productive maintenance, the maintenance prevention and the reliability engineering imported.

The company Nippondenso co. was the first to start with the productive maintenance, 1969 they introduced TPM, to meet the challenges in growing amount of the automation and the new demands, the automation was creating to the maintenance and to the whole company. In 1971 the same company got the first “Distinguished Plant Prize“, given by the JIPM, Japanese Institute of Plant Maintenance (Nakajima, 1988).

To eliminate waste, Toyota became one of the first companies to implement TPM (Nakajima, 1988). Toyota measures six categories of equipment losses throughout its production system. These are (also Fredendall 1996): 1) equipment failures, 2) setup and adjustment, 3) idling and minor stoppages, 4) reduced speed, 5) defects in the process, and 6) reduced yield (Nakajima, 1986). These six losses are combined into one measure of overall equipment effectiveness (OEE), which is:

\[
OEE = \text{Equipment availability} \times \text{Performance Efficiency} \times \text{Rate of Quality Products}
\]
In the year 1995 there were about 800 companies or company units using the TPM in Japan (Johansson, 1996). Also the European companies have started to apply TPM, one of the very first has been the Swedish car manufacturer Volvo in the Gent factory in Belgium.

In Sweden especially the IVF (Institut för verkstadsteknisk forskning) has made big efforts to implement TPM in the Swedish companies, also in the small - and medium – Sized enterprises.

3.2 THE ADVANTAGES OF THE TPM

A systematic and long – term work with the TPM has an influence especially on the following elements in the company : (Johansson, 1996)

- PRODUCTIVITY is improving through fewer losses in the company
- QUALITY is also been improved as a result, that the failures and malfunctions are reduced and the order and method are focused
- THE COSTS are lower, because the losses, and other not value generating work are reduced
- THE DELIVERY TIMES can be kept better, because the production without disturbances is easier to plan
- ENVIRONMENT AND SECURITY are better, because leakages are tightened.
- MOTIVATION is higher, because the responsibility and rights are delegated and the investments in the personal is done, in the form of education.

TPM reduces equipment losses by investing in people who can then improve equipment availability, improve product quality and reduce labor costs (Takahashi, 1981). To maximize equipment effectiveness TPM establishes a thorough system of maintenance for the equipment’s entire life span. This TPM system requires all employees working in autonomous small groups to work together to eliminate equipment breakdowns. Everyone is involved since every component of the manufacturing system-including operations, product design, process design and management-impacts equipment maintenance (Nakajima, 1988).

Reducing equipment breakdowns without increasing the total cost of maintenance is possible. Maquire (1992) reports one-third or $66 billion of the more than $200 billion that U.S. industry spends each year on plant equipment and facilities maintenance may be wasted. However, many companies are effectively using maintenance to improve plant efficiencies (e.g., Kuehn, 1992). For example, DuPont reported savings of $200 million a year from improved maintenance practices and other leading companies (e.g., DuPont, Magnavox and Texas Instruments) are improving maintenance using TPM techniques (Robinson and Ginder, 1995).
Robinson and Ginder (1995) demonstrate that improving the OEE increases the effective capacity, which allows decreased lead time and reduced cost per unit as the same capacity produces more throughput. The model shown in Figure I proposes, that improved overall equipment effectiveness creates capabilities in the firm, which lead to a competitive advantage in one or more dimensions-cost, quality, delivery and flexibility.

Nakajima's model (1988) of how TPM increases OEE is included in Figure I. As shown in equation (1), OEE increases as equipment availability increases, the performance efficiency increases and the rate of quality products increases. The model in Figure I proposes, that increases in OEE improves the firm's capabilities. Increasing equipment availability reduces buffer inventories needed to protect downstream production from breakdowns and increases effective capacity. The fast changeovers, increased capacity and reduced buffer inventories lead to decreased lead times since jobs are not waiting as long in queues. This capability of short lead times improves the firm's competitive position in terms of delivery and flexibility since it is easier to deliver multiple products or versions of products when lead times are short. The reduced need for buffer inventory directly reduces inventory costs and increasing effective capacity allows more throughput and lowers the cost per unit. Increases in the performance efficiency reduce the need for buffer inventories and increases effective capacity. This reinforces the benefits gained from the increased equipment availability. Increases in the rate of quality products not only reduces buffer inventories and increases effective capacity, but this increase means that there is less scrap and rework, which not only reduces costs, but also yields a higher rate of quality. (Frendall, 1997)

The competitive advantages of better product and process quality, improved deliveries and increased flexibility would be nullified if they were obtained with excessive maintenance in investments, which could make a firm's costs noncompetitive.

However, TPM increases maintenance activities without increased costs. The high costs of maintenance activity often comes from inadequate planning of support requirements for machines, inadequate consideration of the machine's reliability, ignorance of the relationship of maintainability to machine design and poor design of logistic support capability (Blanchard, 1981). TPM directly addresses these issues by involving all of the functions in creating the solution.

### 3.3 TPM – TQM (TOTAL QUALITY MANAGEMENT) MANY SIMILARITIES

Both the TPM and TQM are aiming to:

- prevent the problems
- eliminate the waste
- everybody is responsible for the development work (collective responsibility)
The final goal is to deliver a product, which is filling all the quality requirements of the customer, and that all the costs can be predicted.

It can be said, that the maintenance and the quality are two different features of the same issue. So, that the maintenance is long–term quality control. The maintenance is concentrating on the machine, processes and slow trends, meanwhile the quality control is dealing with tools, wear–off and the management of fast changes.

4 PLANNING AND IMPLEMENTATION OF TPM

4.1 NAKAJIMA (1992) 5 DEVELOPMENT ACTIVITIES

According to Nakajima (1992), the five development activities of TPM are as follows.

4.1.1 ELIMINATE SIX BIG LOSSES

Eliminate the 'six big losses' and thereby improve the effectiveness of the equipment.

Losses due to downtime:
1. Equipment failure - from breakdowns
2. Setup and adjustment - from exchange of die in molding machines, presses, and so on

Speed losses:
3. Idling and minor stoppages - due to the abnormal operation of sensors, blockage of work on chutes, etc.
4. Reduced speed - due to discrepancies between specified and actual speed of equipment

Losses due to defects:
5. Process defects - due to scarp and rework
6. Reduced yield - from machine start-up to stable production
4.1.2 DEVELOP A MAINTENANCE PROGRAM

Develop an autonomous maintenance program.

The seven steps of autonomous maintenance are:

1. Initial cleaning: Clean to eliminate dust and dirt mainly on the body of the equipment: lubricate and tighten; discover problems and correct them.

2. Countermeasures at the source of problems: Prevent the causes of dust, dirt, and spattering of liquids; improve those parts of equipment that are hard to clean and lubricate; reduce the time required for cleaning and lubricating.

3. Cleaning and lubrication standards: Establish standards that reduce the time spent cleaning, lubricating, and tightening (specify daily and periodic tasks).

4. General inspection: Follow the instructions in the inspection manual; quality circle members discover and correct minor equipment defects.

5. Autonomous inspection: Develop and use autonomous inspection check sheets.

6. Orderliness and tidiness: Standardize the individual workplace control categories; thoroughly systemize maintenance control:
   - Inspection standards for cleaning and lubricating
   - Cleaning and lubricating standards in the workplace
   - Standards for recording data
   - Standards for parts and tool maintenance.

7. Fully autonomous maintenance: Develop a company policy and goals for maintenance; increase the regularity of improvement activities. Record the mean time between failures (MTBF), analyze the results, and design countermeasures.

These steps are based on the five basic principles of operations management: organization, tidiness, purity, cleanliness, discipline.
4.1.3 DEVELOP A SCHEDULED MAINTENANCE PROGRAM FOR THE MAINTENANCE DEPARTMENT

This is usually done in cooperation with industrial engineering. The leveled schedule greatly helps the development of a regular maintenance program.

4.1.4 INCREASE THE SKILL OF OPERATORS AND MAINTENANCE PERSONNEL.

The operators should work with the maintenance people at the time PM work is done on their equipment, discussing problems and solutions. Part of the operator's job is to keep records on the performance of the equipment, so the operators must learn to be observant.

4.1.5 DEVELOP AN EQUIPMENT MANAGEMENT PROGRAM

A record of the use of machines and tools denoting how much they were used and who used them.

4.2 TOTAL PRODUCTIVE MAINTENANCE IMPLEMENTATION

Nakajima (1992) outlines 12 steps involved in developing and implementing a total productive maintenance program:

Step 1: Announce top management's decision to introduce TPM.
- state TPM objectives in company newsletter.
- place articles on TPM in company newspaper.

Step 2: Launch educational campaign.
- for managers, offer seminars/retreats according to level.
- for general workers, provide slide presentations.

Step 3: Create organizations to promote TPM.
- form special committees at every level to promote TPM.
- establish central headquarters and assign staff.

Step 4: Establish basic TPM policies and goals.
- analyze existing conditions.
- set goals.
- predict results.

Step 5: Formulate master plan for TPM development.
- prepare detailed implementation plans for the five foundational activities.

Step 6: Hold TPM kickoff.
- invite external customers, affiliated and subcontracting companies.

Step 7: Improve effectiveness of each piece of equipment.
- select model equipment.
- form project teams.

Step 8: Develop an autonomous maintenance program.
- promote the seven steps.
- build diagnostic skills and establish worker
- procedures for certification.

Step 9: Develop a scheduled maintenance program for the maintenance department.
- include periodic and predictive maintenance.
- include management of spare parts, tools, blueprints and schedules.

Step 10: Conduct training to improve operation and maintenance skills.
- train leaders together.
- have leaders share information with group members.

Step 11: Develop initial equipment management program.
- use MP design (maintenance prevention).
- use start-up equipment maintenance.
- use life cycle cost analysis.

Step 12: Perfect TPM implementation and raise TPM levels.
- evaluate for PM prize.
- set higher goals.

Seger (1994) is giving the following conclusions about the TPM – implementation:
- TPM can be implemented in various types of companies and in every department of the company
- TPM should be implemented in stages and systematically
- facts, which are making the implementation of the TPM easier, are e.g. the enthusiastic management, which is keen on investing in the TPM, there is a budget with resources for the TPM activities, information and motivation for the TPM.
- Some companies are implementing TPM to survive, the others to become
a world class manufacturer
- Companies implementing TPM are normally using the JIPM basic concept, but they are adapting it to their own company, and to its goal—setting and problems.
- Impressions in the companies, implemented the TPM are, that they are very clean, smart, effective, no waste, but a very god quality, very few breakdowns and a good work environment.
- TPM is a very good tool to reach the set goals of company, as zero defect, no breakdowns, cutting down the expenses.
- Astonishing many companies, which have implemented TPM, have not been dealing with any big problems, beside implementation requires a lot of work.
- The results in the implementation of TPM are impressive, the attitude and the motivation are changing, their competence level is becoming higher, everybody in the company is working to reach the preset goals. The company is achieving great improvements in productivity, reducing of defects, downtime and costs.
- The most important thing is to start the activities to improve the total efficiency of the plant and machines and also the independent maintenance.

4.3 DANISH TPM – PRINCIPLES, A GOOD APPLICATION MODEL FOR FLEXIBLE MANUFACTURING

Bundgaard, 1996 is describing, that TPM is a program, supported by “the eight pillars”:

1. “Kobetsu - Kaizen “, or the fight against the major 6 big losses through cross – organizational small – group activities.

2. “Jishu – Hozen “, or the activities in which each operator performs daily inspection through the cleaning activities. Through these activities the goal is to let the operator assume a constant increasing responsibility for his own working place and his equipment.

3. Planned maintenance based on corrective, time – based and predictive maintenance.

4. Training and education of leaders, operators and maintenance people. Part of the training of operators will be through “One – point lessons “ accomplished by the maintenance staff.

5. Establishing a system to ensure, that we get products, which are easy to manufacture and production system, which is easy to operate.

6. “Hinshitsu- Hozen “, or activities to set equipment conditions to eliminate defective products.

7. Activities in departments supporting the production to ensure increasing efficiency in offices. (Office TPM)
8. Establishing safe working environment and protection systems.

In Denmark few enterprises are working against a management – decided full TPM program, the major part will be TPM sub – activities.

Demands for the reliability of the production equipment is high, when JIT (Just In Time) principles are in use. Failures of the production equipment do not influence only on production process, but also strongly on the whole

5 SIX BIG LOSSES IN THE FLEXIBLE MANUFACTURING

THE DATA TO BE ANALYZED

Kuhmonen , 1997 was investigating the utilization rate of 4 highly automated flexible manufacturing systems under a period of 87 weeks 1995 - 1996. This are in use at well known big Finnish mechanical engineering companies, mainly exporting their products.

Lakso, Kuhmonen 1995 were systematically collecting the data in 10 highly automated flexible manufacturing systems including 16 NC–machining centers, 5 NC – lathes and 4 stacker cranes in the Finnish metal industry, in the well-known companies, applying the JIT – manufacturing philosophy in the small-batch manufacturing for high-quality products. The data collection was made 1994, statistical period 9 months, and it was repeated 1995 in a 7–month period. In the most of the cases the data collection has started from accepted taking into use of NC – machine tools.

Lakso, 1988 was following the utilization rate of the FMS manufacturing parts for diesel engines and its 3 NC – machining centers for his doctoral thesis during 95 weeks in 1985 – 1987.

Lakso, 1983 was already 1982 – 1983 investigating the utilization of the manually operated, stand-alone, NC – lathes, NC – boring and milling machines and machining centers in 10 different Finnish companies. Nearly hundred different NC – machines were monitored and 23 different reasons for non-productive use of the NC – machine were applied.
5.1 EQUIPMENT FAILURE

Equipment failures are causing the most of the downtime in the flexible manufacturing systems, in the single NC – machines and in the peripheral equipment, like a stacker crane. Especially the unpredictable operational disturbances seem to be the most dominant problem in the flexible manufacturing. Equipment failure can be divided into the technical failure and operational disturbance in a following way (Kuhmonen, 1997):

![Equipment Failure Diagram](image)

The technical failure and operational disturbance and their causes are defined in a following way (Kuhmonen, 1997):

**TAB 2. General features of failure types in FMS (Kuhmonen, 1997)**

<table>
<thead>
<tr>
<th>Technical Failure</th>
<th>Operational Disturbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>- long down time</td>
<td>- short down time</td>
</tr>
<tr>
<td>- mean time between failure</td>
<td>- MTTF is short (depending on the nature of the operational disturbances)</td>
</tr>
</tbody>
</table>
Theoretical and empirical research of failures and reliability of components have long been practiced in the electronics and aircraft industry. However, the research for the reliability for machine tools are very rare. Although machine tools frequently can fail during operation, little is known about the reasons and rules of failures on which failure behavior is based (Yazhou et al., 1995).

The breakdowns in technical failures (in this chapter further called failures) can be divided into two categories according to their development. The soft (or trend failures) develop gradually with time. These are failures, which condition monitoring systems are supposed to detect. Soft failures are typical for many mechanical elements, where wear causes a gradual degradation of the element.

Hard failures occur instantaneously. These failures are impossible to predict by condition monitoring. Typically they involve failures of electrical elements (Martin, 1994, Davies, 1994).

Preventive maintenance is used to reduce the both type of breakdowns as much as possible.

5.1.2 OPERATIONAL DISTURBANCES

Operational disturbances can be considered as a sub type of failure for the machine tool or for the manufacturing system which has a short down time. Operational disturbances are removable by the operator and they occur frequently. Very often the ultimate cause of the operational disturbance cannot be fully explained. In some cases its origin is technical e.g. a malfunction of a limit switch. Often it can be the misuse of the machine tool and the origin of the operational disturbance is human. Skills, education, attitudes and the knowledge of the FMS functioning are all definitely affecting the occurrence of operational disturbances. Complexity of the FMS and complexity of machine tools establish a favorable ground for operational disturbances to be developed (Kuhmonen, 1997). Maintenance standards IEC 191, 1990; CEN/TC 319, 1996 do not mention about any term corresponding to the presented definition. A number of terms describing operational disturbances can be found from references. Operational disturbances are called “technical disturbances” (Klimartin, Hannam, 1981), “operating malfunctions”
There are always operational disturbances in FMS. They are a part of FMS’s every day operation. Operational disturbances are removed and their number might be temporarily decreased, but there are always new disturbances developing. Operational disturbances can be seen as one of the most important factors in the economic use of a FMS. Without the possibility to run FMS unattended and unmanned, its economic competitiveness is lost.

Operational disturbances have following general characteristics:
- Operational disturbances interrupt an automatic cycle in the working process of a machine tool or prevent an automatic cycle to start.
- Operational disturbances are repeated and frequent. This is why they are often seen as a feature of a machine tool, not as a problem. They are a part of a machine tool’s everyday operation and to remove them, is one of the tasks of an operator.
- Operational disturbances are removed by the skills of the operator. Typically this is done according to the information given by the diagnostic system in the machine tool. Removing of operational disturbances is a part of operators’ occupational expertise (Blumberg, Alber 1982). As much as 1.5 hours of a FMS operator’s daily work can consist of operational disturbance removal (Toikka et al., 1991).
- Typically operational disturbances have short downtimes from seconds to few minutes. During the unattended operation operators are nearby to remove operational disturbances. However, during the unmanned operation an operational disturbance can cause longer down times, because the operator is no longer present to restore the automatic cycle. In the worst case the whole unmanned shift can be lost, if the error occurs in the first minutes.
- Data about operational disturbances is difficult and laborious to collect because of their rapidness and frequency. Often operational disturbances are seen as a feature of machine tool’s normal operation, which makes it difficult for the operator to understand them as a storable problem. This is causing that operational difficulties are difficult to quantify.
- Causes of operational disturbances are often hidden and causal relationships are typically unclear (Nakajima 1989).
- Production loss due to a single operational loss is insignificant (Nakajima, 1989).

5.1.3 HOW THE EQUIPMENT FAILURES REDUCE THE UTILIZATION

5.1.3.1.1. FOUR STUDIES WITH THE DATA COLLECTED IN THE FINNISH INDUSTRY

In the following examples only in the example Kuhmonen, 1997 conclusions are made about the operational disturbances. In the others they are just hidden with the technical disturbances and breakdowns like in the case Lakso, 1983 or in the machine failure time Lakso, 1988 and also Lakso, Kuhmonen 1995 are mainly following up
the total down time.

Lakso, 1983 found out, that the technical disturbances of the planned working time were 8.8 % at the NC – lathes, 11.1 % at the NC – Boring and milling machines and 7.4 % at the machining centers. This failure time was consisting of the technical failures 7.7 % and 1.1 % preventive maintenance of the planned production time at the NC – lathes, 6.8 % and 4.3 % at the NC – boring and milling machines, 7.1 % and 0.3 % at the machining centers.

Lakso, 1988 was presenting the collected data and the average times for three machining centers, all connected with a stacker crane in to a FMS:

Planned production time was 10324 h (the observation period 95 weeks), down time was 837 h (8.1 % of the planned production time, PPT), consisting of machine failure time 652 h (6.3 % of the PPT) and preventive maintenance time 185 h (1.8 % of the PPT).

Lakso, Kuhmonen 1995 received following results in their study:
16 machining centers were followed 9 months under 1994. The average planned production time was 4768 h, the average down time was 208 h, 4.8 % from the planned production time. In the same study they were also following 5 NC – lathes, which had the average down time of 128 hours, 2.8 % of 4522 h planned production time. The observations presented here must be only technical failures, because the number of failures is varying from 3 to 20 under this 9-month monitoring period.

Lakso and Kuhmonen, 1995 are unfortunately not given also any average about the ratio machine failures / preventive maintenance. This ratio is can be company-dependent, so that a company having the emphasis on the preventive maintenance, thus applying more TPM – principles, is having the part of the preventive maintenance more of the total down time, and then minimizing the technical failures.

Finally Kuhmonen, 1997 was monitoring partly the same machine tools as in the 1995 during 1995–1996. The 17 NC - machine tools are working in 4 different FMS’s. The average planned production time for a week was 134.2 h. The FMS’s were also in use in the weekend, and the average planned production time was 7100 hours/year. The number of detected operational disturbances in the study (Kuhmonen, 1997) was 27318 causing a total down time of 15671.8 h. The number of technical failures was 957 and they have a total down time of 6418.5 h. The sum of the collected automatic cycle time (effective production time) was 110201.8 h, which is means an average 6482 h of automatic cycle time per machine tool. The total planned production time for all the machine tools in the study was over 160000 hours, which means an average 9500 hours of production follow – up time for each machine tool.

The average utilization rate was 68.3 %, the min value 58.3 %, the max. value 83 %. (automatic cycle time / planned production time)

Operational disturbances occur on machine tools every 8.6 h. They decreased the availability by 9.4 % and have a mean down time MDT of 0.53 h. Technical failures occur every 613.8 h, decreasing availability by 4.3 % and MDT is 13.8 h. So according to this study the effect of operational disturbances on machine tools is over doubled compared to technical failures, 9.4 % versus 4.3 %.

As the conclusion of this study (Kuhmonen, 1997) the main improvements should be done to decrease the downtime due to the operational disturbances. To decrease the technical failures there must be a more effective preventive maintenance,
and this the only thing the single workshop can do, but also the efforts of the machine
tool manufacturers and component manufacturers to get more reliable products is a
way to the better efficiency.

5.1.3.2 OTHER CONCLUSIONS ABOUT THE DOWN TIME IN A FMS

Several references state, that the major number of failures (including operational
disturbances) in FMS's have a down time less than 10 minutes. According to
Hackstein, Budenberder, 1991 48 % of failure numbers have less than 10 minutes
down time. Hammer, 1987 has found, that 90 % of the failures in a FMS have down
time less than 6 minutes. They are representing 50 % of the total down time. Kuhmonen,
1994 found, that for sheet metal FMS's 62.7 % of detected failures have a down time
less than 15 minutes and 89.4 % of the failures were repeating more than 10 times.
Thilander, 1992 found, that for stand-alone machine tools failures less than 5 minutes
down time represent 57 to 66 % total number of failures.

When the reliability of automatic assembly systems was investigated, it was found,
that operational disturbances are a major economic risk. As an average operational
disturbances take place every 4.1 minutes and they have 0.83 minutes of down time
(Wiendahl, Ziersch 1985).

Summa summarum: to decrease the downtime in an FMS, the emphasis is to
be set to eliminate the operational disturbances.

5.2 SET-UP'S AND ADJUSTMENTS

The operation of the FMS is highly automated, the work piece change, the tool change
and very often also the set-up change to produce a new, different type batch of
products is carried out fully automatically. The machines in the system have a standard
set-up of tools in the magazine with the needed reserve tools for the family of work
pieces machined in the FMS, and a transport systems, f.ex. a stacker crane is loading
or unloading the material in the machine tools. The change of tools and other tool
service functions can be often carried out in the magazine of a machine center
meanwhile the machine is operating automatically.

The set-up and adjustment time is not a problem, and it is normally very near 0,
when the same batches are circulating in the weekly program of a FMS.

To drive in new jobs in the FMS can cause some set-up time, depending
how the job is prepared and a CAD-CAM simulation is done before the new job is
coming to the some NC-machine in the FMS.

5.3 IDLING AND MINOR STOPPAGES

All most these types of stoppages are operational disturbances, which are not actual
technical failures in the equipment, but are caused f.ex by the wrong identification of
the work piece, errors in the data communication, small mistakes in the NC—
programs, changing allowances in the raw materials, unequal structure of the materials to be machined or small malfunctions in the tool changer etc. Kuhmonen, 1997 found out, that to get the machine or system running after these kinds of “small” mistakes is taking under 5 minutes, but these kind of mistakes are occurring very frequently, in the study of Kuhmonen, 1997 27000 operational disturbances were occurring in 17 NC – machines during an average follow – up time of 9500 hours. These kind of mistakes cannot be eliminated with the more effective preventive or normal maintenance.

It is very dangerous, that there are a lot of companies, which are getting to use to accept these operational disturbances as a part of the normal life. In the worst case one small disturbance, f ex a malfunction in the tool changer can stop the whole unmanned production period of the NC – machine tool. Also in many, especially non-Scandinavian countries the automatic data collection, ADC is not used as a tool to follow up the machine utilization, and the companies cannot be aware of the downtime due to the operational disturbances at all.

An other type of non-productive time within the planned production time is the idle time caused by the organizational disturbances. Organizational disturbances in FMS are usually a consequence of insufficient integration of the FMS into the surrounding manufacturing environment causing e.g. interruptions in material supply (Henoch, 1988).

During the idle time caused by the organizational disturbances a machine tool is available for operation (i.e. there is no failure or operational disturbance in the machine tool), but the organization is unable to use it. Causes for organizational in FMS are the lack of work, absence of an operator, modification of fixtures, missing tools and tool maintenance, lack of raw material and NC – program (Heisel, Hammer 1992, also Hackstein, Budenbender 1991, and Lakso, 1988).

Typically the idle time caused by organizational disturbance is short. Hackstein, Budenbender 1991 found that 62 % of organizational disturbances in FMSs have idle time less than 10 minutes and they cause only 16 % of total idle time. Shah’s, 1991 study of 23 FMS’ s showed, that the idle time due to organizational disturbances for machine tools in FMS is varying from 5.4 % to 12.5 %. Lakso, 1988 has found, that the average idle time for three machining centers was 10.9 %. Hammer, 1987 has measured an average of 6% idle times for machining centers in FMS. Kuhmonen, 1997 found out, that the organizational disturbances were totally about 18 % in average of the planned production time at four FM – systems.

5.4 REDUCED SPEED

Often the optimum running speed in the metal cutting machines is not exactly known (Torvinen, Vihinen, 1997). The reasons to reduce the cutting speed or feed rate or both in a NC – machine are f ex. mechanical problems (vibrations due to construction of the machine tools or use of wrong milling geometry and/or milling methods f ex.), the incomplete quality or the scare not to overload the equipment. The companies often have to adjust many of their cutting processes as a consequence of the uncertainty, that appears in the machining conditions. The degree of the utilization
of the systems for process monitoring and control is low, despite the fact that systems are available as machine integrated systems or even as retrofit systems acquired later than the machine itself (Bäckström, 1999).

5.5 PROCESS DEFECTS

Quality defects and rework losses are reducing the effective production time. For example, in the FMS established for the actuator parts of industrial valves (the one of the systems in Kuhmonen, 1997 study) the number of rejected parts has been about 0.7% in the beginning of 90’s (Rossi, Ylä-Mononen et al., 1992). Insufficient time, a limited volume of data for process model development and control, increased quality requirements and shorter series are situations, when traditional quality control methods are not working properly. This means, that the control of process performance needs to be moved into machining process and thus monitoring of in-process variables instead of traditional post-process data, such as e.g. part dimensions. (Bäckström, 1999).

5.6 START–UP LOSSES

During the start–up phase a machine or a system may first manufacture parts, which must be rejected because of the bad quality, until the normal operation level is reached. This kind of problems are not occurring in the machine tools.

6. HOW TO APPLY TPM - PRINCIPLES TO ELIMINATE OR AT LEAST DECREASE THE SIX BIG LOSSES AT THE FMS.

Because of the nature of the losses at the FMS the best results are reached by using some simple TPM – principles according to the Danish TPM – model described in 3.4. A complete TPM – can very seldom be implemented, because it is too heavy to realize, and also because the technical failures are not the biggest problem causing the downtimes, but the operational disturbances. For example, Kuhmonen, 1997 found out, that the operational disturbances are the biggest losses in the operation of the flexible manufacturing systems, but he was not giving a clear action plan based on TPM – principles to eliminate the losses. In the following this kind of action plan or at least some parts of it are created.
6.1 HOW TO START THE TPM IMPLEMENTATION

From Nakajima’s, 1992, 12 implementation stages a very important role has the 4’th stage and its part analyze existing conditions. The very effective tool for executing the analyzing work is the using of automated data collection, ADC. Automatic data collection is a method, which continuously monitors machine tool operation, recording even the smallest changes in machine tool states. According to this data it is possible to obtain a complete view of FMS’s and its machine tools operation time distribution, failure behavior and their association with each other.

When the existing conditions are known by applying the automatic data collection ADC, the goals for improving the availability and productivity can be set according to Nakajima, 1992.

6.2 DECREASING THE OPERATIONAL DISTURBANCES

As already concluded in the part 5.1.1.2 and 5.1.1.3 and also in 5.4 the operational disturbances give the biggest potential for reducing the down – time in machine tools of a FMS. A typical operational disturbance and its recovery can be as following: The automatic tool changer ATC of the machine tool is getting stuck at the moment of the tool changing, and cannot anymore released automatically. The operator is needed to release the tool changer by a manual movement or to press automatic tool change cycle start bottom two times. The operator knows exact, how to overcome this kind of situation. It belongs to his professional skills. But also this kind of small malfunctions can disturb the whole system to operate. The operator knows that when he is drilling that certain hole in the product, the tool changer is getting stuck, and he has do the same procedure again to get the machine automatically running again.

It is very clear, that this kind of disturbance should not occur during the unmanned operation. Waiting for the next this kind of “standard” operational disturbance is not the task of the operator, but to do completely something else, like to load and unload work pieces or the tool service, or even find some improvements to have the better productivity in the system. Thus operational disturbances should be totally eliminated in the system.

To eliminate the operational disturbances is however difficult, it depends on the nature of the operational disturbance. Often the causes leading to a operational disturbance are not obvious and cannot be instantaneously understood. To determine the exact location and the real cause of operational disturbances is extremely difficult (Wiendahl, Ziersch, 1985). An operational disturbance is often resulting from a complex combination of causes as shown by Nakajima, 1989 in the diagram above.
Operational disturbances are mainly related to positioning and tolerance of workpieces, tool changes and material handling (Wiendahl, 1988). The component, which has caused the operation disturbance is in 80% of the cases a sensor or an actuator, which is placed near the machining process e.g. pallet changer components. Thilander, 1992 found out, that the main causes for operational disturbances were related to electrical components and tool maintenance. Thilander states, that the most of the operational disturbances could have been avoided by effective preventive maintenance (i.e. inspection and cleaning).

Methodologies to decrease operational disturbances are generally similar (Toikka, Kuivanen 1993, Takashi, Osada 1990, Nakajima 1989). The problem of operational disturbances can be resolved with the development of operator expertise to prevent and remove operational disturbances. The origin, diagnostics, removal and prevention of operational disturbances are so closely related to the every day operation of FMS, that the only potential for operational disturbance control are the operators.

In the first phase, the concept and significance of operational disturbances are introduced to the operators. They should be fully aware about the different failures and malfunctions causing operational disturbances. This should already belong to the base education of the FMS – operators. The installing of automatic data collection system should be installed already in the beginning of the operation of the FMS, latest when the operators are starting to be informed about the operational disturbances. (Step 2 and 4 in Nakajimas, 1992 TPM - model)

To decrease the operational disturbances the following things are also important:
- Increase the skills of the operators and maintenance personal, let them work
together in the productive maintenance, PM work. The PM is the best tool to reduce the down time caused by operational disturbances, also technical failures.

- The seven steps of the autonomous maintenance program (Nakajima, 1992) are all important, especially clean and order in the working place. (The TPM - activities of “Jishu – Hozen”). Give also more and more responsibility to the operators.
- In the JIT – manufacturing the responsibility to control the produced parts has the operator, he is also regulating the process to produce quality, f.ex with tool-offsets.
- Operators training is critical to the reliability and productivity in FMS (Kuhmonen, 1997).
- Human factors affecting availability and utilization rate of operating the FMS are more significant than the technical factors (Heisel, Hammer, 1992). Therefore, FMS should provide a stimulating environment for developing the competence of its operators (Mårtensson, Stahre, 1992).
- Apply the principle of continuous improvement, “Kaizen”, and the eliminating of the errors and mistakes, “Poka – Yoke” in the production and maintenance.
- Keep regular meetings i.e. once a month in the production teams and production shops to follow the operational disturbances and to get proposals, how to eliminate them.

Jackson, Wall (1991) discovered, that a significant part of the down time reduction was not a result of quicker response to correct the failure but the reduction in the number of failures / operational disturbances. By concentrating in failures operators were able to prevent them. With time, operators learn new skills which allow them to diagnose and prevent problems more efficiently than specialized repair technicians.

To get better results in a long term co-operate with the machine – tool and transport system manufacturers to get more reliable and intelligent equipment. Take use strategies and techniques to make machining and material handling easier in flexible manufacturing conditions. By means of various sensors, computer communication, process knowledge, operator know – how and organization of data a new kind of flexibility is addressed. The intended flexibility includes not only a variety of fixed cases, but also a control feasibility of unforeseen situations (Bäckström, 1999).

6.3 IMPROVING THE AVAILABILITY; UTILIZATION AND PRODUCTIVITY BY ELIMINATING OTHER LOSSES

To reduce technical failures (breakdowns), increasing of the PM, preventive maintenance is the most effective way to reach good results. Also the development of the NC – machine tools and its components like NC – control, motors, valves, and electrical components is very important to get more reliable equipment.

Here it is very important, that the customer contact with the machine tool manufacturers is close, that man is fully aware of, which kind of equipment the customer needs. The methods like QFD (quality function deployment) and Takuguchi – method are very useful for the tool manufacturers in this respect.

To eliminate organizational losses apply better planning methods, increase the co-operation with the product planning and production planning by using methods like concurrent / simultaneous engineering. Apply new ordering/delivering routines with the raw material suppliers to get the materials just in time. See, that you have a good
tooling system for the NC – machine tools. Use CAD / CAM simulation to reduce or eliminate the NC – program testing time / set – up time. Give education to operators, and inform them about, how important it is to minimize the set – up times.

7. CONCLUSIONS

TPM is a very heavy system to apply in a company as a whole, especially in small – and medium - size enterprises, SME’s do not have the resources to fully implement the TPM. TPM sub – activities are the best way of take to use the TPM, here especially the Danish model is giving a good example.

Kuhmonen, 1997 was discovering, that the biggest problem in reaching a good availability and productivity in the FMS – operation are the operational disturbances. To eliminate them he is putting a big emphasis on the skills of the operator, also the importance of the automated data collection (ADC) is pointed out in his study. He is also giving the TPM as a possible tool to reach the better overall equipment effectiveness OEM in the FMS, but the concrete measures in implementing the TPM are partly missing. I suggest that the following measures should be taken:

- Take the automated data collection (ADC) in use to know exact, where the effective production time is being lost. This should be done in the same time with the implementation of the FMS. (Also Kuhmonen, 1997)
- Inform the operators about the results of the machine and system data, like the amount of total down time caused by the operational disturbances.
- Set goals to reduce the down time.
- Give education about the machine and its systems, and contribute to a activity of the operators to discover and eliminate the disturbances, the environment of continuous improvement.
- Also see, that the working places and tools are clean and the equipment and tools are kept in order.
- Give more and more responsibility to the operators.
- In the long – run co-operate with machine tool and other equipment manufacturers to force them to develop and manufacture more reliable and intelligent machines. The intelligent machine tools and peripheral equipment can correct the operational disturbances automatically.

The second problem causing downtime in a FMS are technical failures. To minimize these the best way is to increase the preventive maintenance, PM. Also the near contact to the machine manufactures is helping in the long – run to inform them, what the customers are really needing (early equipment management).

The third type of the downtime is caused by so called organizational disturbances. To reduce this time, like a set – time, a better co – operation between product – and production engineering should be started, f ex. concurrent engineering. Also a better simulation of the system and a standard – set up of tools should belong to the flexible
manufacturing system.

There is still a lot of potential to improve the utilization of the FMS's. As in the study of Kuhmonen, 1997 was found, the average automatic cycle time was only 68.3% of the planned production time in 17 NC – machine tools. By improving this number to 88.3% would give us yearly over 1000 more productive hours at one NC – machine, if the machine is running in the 3 – shift work with unmanned night shift. Applying the TPM – principles is one important tool to reach this.

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