**DOKUZ EYLÜL UNIVERSITY**
**GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

# ADVANCED ANALYSIS SYSTEM FOR OPTIMIZED CHANGEOVER OPERATIONS

**by**
**Mahmut Kemal KARASU**

**May, 2008**
**İZMİR**

# ADVANCED ANALYSIS SYSTEM FOR OPTIMIZED CHANGEOVER OPERATIONS

**A Thesis Submitted to the**
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**In partial Fulfillment of the Requirements for the Degree of Master of Science**
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**by**
**Mahmut Kemal KARASU**



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## M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"ADVANCED ANALYSIS SYSTEM FOR OPTIMIZED CHANGEOVER OPERATIONS"** completed by **MAHMUT KEMAL KARASU** under supervision of **ASSISTANT PROFESSOR DOCTOR MEHMET ÇAKMAKÇI** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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World class companies are the ones who can provide what customers exactly want. The ability to adapt the organization to the changes in the market gives the key to keep in step with customer needs. One of the most important tools for this ability is quick changeovers.

What I tried to make in this study is to show the further improvement opportunities using advanced analysis system to changeover operations. During my study Mr. Ahmet DİNCER and Mrs. Fatma TOKMAKÇI helped me to learn MTM analysis systems in BOSCH, and Mr. Okan BEHZATOĞLU gave me the opportunity to see changeover operations in heavy-industries in JANTAŞ. I thank them all for their kind support. Of course I thank Ass. Prof. Dr. Mehmet ÇAKMAKÇI for his guidance never let me out of road during this study.

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## ADVANCED ANALYSIS SYSTEM FOR OPTIMIZED CHANGEOVER OPERATIONS


## ABSTRACT

In this study changeover operations are discussed in scope of Lean Manufacturing and Shigeo Shingo's approach called SMED (Single Minute Exchange of Dies) is explained. SMED approach is analyzed in terms of sustainability and a new analysis system is introduced to develop optimal changeover procedure which tries to provide a sustainable changeover process. On this way the new analysis system is handled under two main headlines; Macro analysis (using conventional SMED approach) and Micro analysis (using MTM / Method Measurement Time Systems). Macro and micro analysis results are documented as changeover procedures which provide the manual for operators to perform the best organized changeover operation.



**Keywords: SMED (Single Minute Exchange of Dies), Lean Manufacturing, sustainability, changeover, MTM (Method Time Measurement), Time Study, Change**

**EN İYİLEŞTİRİLMİŞ MODEL DEĞİŞİM OPERASYONU İÇİN İLERİ ANALİZ SİSTEMİ**

# ÖZ

Bu çalışmada model değişim işlemleri, yalın üretim kapsamında değerlendirilmiş, Shigeo Shingo'nun SMED (Tek haneli dakikada kalıp değişimi) yaklaşımı açıklanmıştır. SMED yaklaşımı, sürdürülebilirlik açısından analiz edilmiş ve en iyileştirilmiş, sürdürülebilir değişim sürecini verecek değişim prosedürünü ortaya koyan yeni bir analiz sistemi tanıtılmıştır. Bu amaçla yeni analiz sistemi iki ana başlık altında ele alınmıştır; Makro analiz (mevcut SMED yaklaşımı yardımıyla) ve mikro analiz (MTM / Metot Zaman Ölçüm sistemleri yardımıyla). Makro ve mikro analiz sonuçları, en iyi şekilde organize edilmiş değişim operasyonlarının uygulanması için operatörlere bir talimat sağlayacak şekilde dökümante edilmektedir.

**Anahtar Sözcükler: SMED (Tek haneli dakikada kalıp değişimi), Yalın Üretim, Sürdürülebilirlik, Değişim, MTM (Metot Zaman Ölçüm Sistemi), Zaman Etüdü**

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# CHAPTER ONE
# INTRODUCTION

## 1.1 Need for Perfection

The reality of the paradox between unlimited wants and scarce resources has been leading the mankind to find the ways of providing maximum output using minimum input. The reflection of this paradox to the production floor is called as continuous waste elimination.

On this way, Henry Ford was one of the first to realize that waste represents inefficient (and more costly) production processes. “Ford mandated the use of every possible bit of raw material, minimizing packaging, and material re-use. Reduced production time -- through the first moving assembly lines and development of products with interchangeable parts -- was also the result of Ford’s obsession for maximum production efficiency” (Romm, 1994).

But what Ford lacked, was a necessary responsiveness to ever changing consumer demands. His production systems meant that he could not produce variety in his automobiles. “By the end of the 1920's, competitors more oriented toward customer demand (and less towards efficiency) dominated the automobile market, and Ford’s manufacturing strategies were lost. Japanese manufacturers recovering from World War II were next to catch on to Ford’s ideals. In 1950, W. Edwards Deming pitched system- wide quality improvement concepts to Japanese managers. Shigeo Shingo and Taiichi Ohno then exploded these concepts by creating the Toyota “just-in-time” Production System which, like Henry Ford’s system, was rooted in a complete understanding of quality improvement and the sources of waste” (Romm, 1994). Then Womack and Daniel Jones spread this waste elimination methodology to the world by publishing their two famous books (Womack J.P., The machine that changed the world 1991), (Womack J.P., Lean thinking: banish waste and create wealth in your corporation 1996).

In the following years what makes companies embrace Lean Thinking and Lean Manufacturing was based on three reasons. The first one is - using Ford's philosophy - eliminating all non-value added aspects of the enterprise so that achieving *lower cost*, higher profit ratios and lowering the unit price which would be appreciated by the customer and increase the sales. The second one is *customer responsiveness* - which Ford couldn't but Ohno did- meet rapidly changing customer "just-in-time" demands through similarly rapid product mix changes and increases in manufacturing velocity. And the last one is the high and consistent *quality*.

## 1.2 What is Lean Manufacturing?

"As the simplest description, *Lean manufacturing* is the production of goods using less of everything compared to mass production: less human effort, less manufacturing space, less investment in tools, and less engineering time to develop a new product. Taichi Ohno, the founder of this process management philosophy created a great achievement on overall customer value using Toyota Production System (TPS) which mainly focuses on reduction of the original "*seven wastes*". But what other key important methodology that makes TPS successful was *Six Sigma* that emphasis on reduction of process variation and provides the smoothness of the process" (Maintenance2000, 2008). The implementation of smooth flow exposes quality problems which already existed and thus waste reduction naturally happens as a consequence. Using the combination of TPM and Six Sigma, the basic elements of Lean Manufacturing were settled as in figure 1.1.

### *1.2.1 Brief Description of the Lean Manufacturing Elements*

The main aim of Lean manufacturing is to minimize the chronic seven wastes;

- Overproduction (production ahead of demand)
- Transportation (moving products that is not actually required to perform the processing)
- Waiting (waiting for the next production step)

- Inventory (all components, work-in-progress and finished product not being processed)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Over Processing (due to poor tool or product design creating activity)
- Defects (the effort involved in inspecting for and fixing defects)

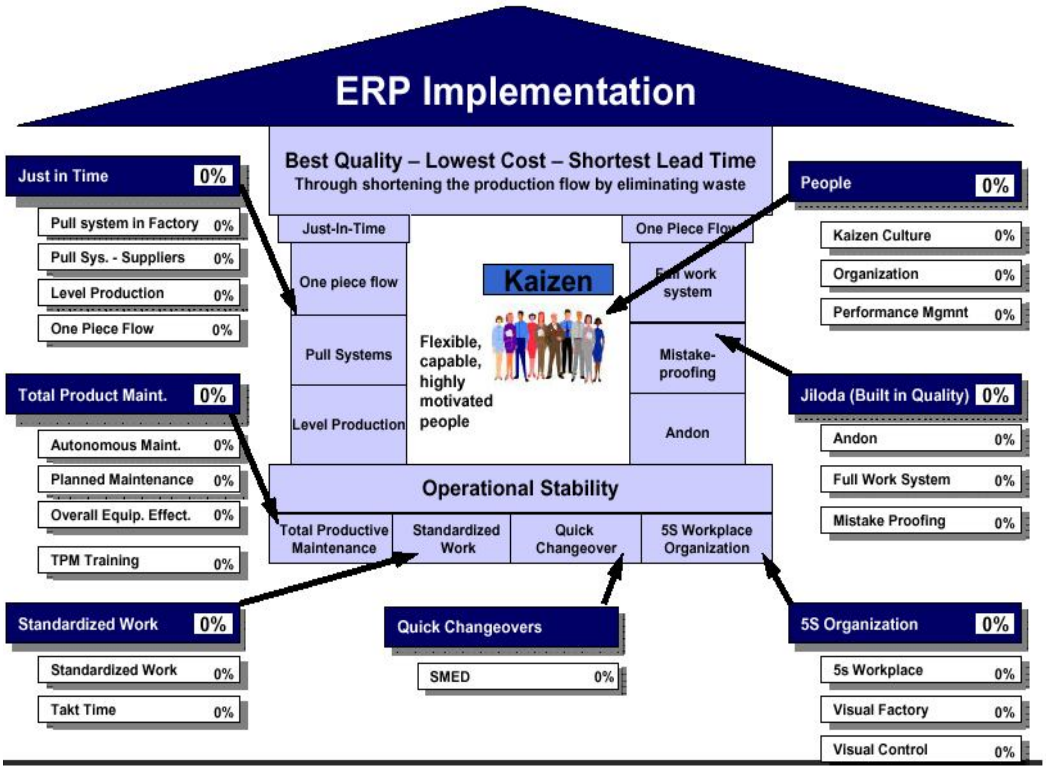



Figure 1.1 Basic elements of lean manufacturing (www.agillist.com 2003 Agillist Group Inc.)

Main tools of Lean Manufacturing can be analyzed under two main concepts;

1) **Just in time;** that directly related to techniques for perfect production flow.
2) **Quality tools (TPM & Six Sigma**) which provides the stability to make the desired results from JIT to come true.

*1.2.1.1 Just in time (JIT)*

The basic objective of Just in Time is making the production at the time that customers want, with demanded quantity, and providing desired quality level. Zero mistakes, zero setup times, zero stock, zero waiting time, and zero handling time are expected outcomes. In order to achieve these targets, JIT system requires some important necessities;

a. KANBAN – Pull production system for production flow
b. Line balancing techniques that can absorb demand fluctuations
c. Reducing setup / changeover times of the production equipment
d. Standardization of production operations to achieve balanced lines
e. Flexible production floor planning that provides workforce a flexible working environment. Another name is Process-based-layout that let the pieces flow through the production processes one-by-one, without waiting. (one-piece-flow system / min lot flow)
f. Multi-functional workforce
g. Problem solving teams and proposal system for continuous improvement
h. Visual control systems that prevents the production processes from stopping because of defected parts on the line
i. Efficient management system to implement enterprise-wide quality control approach

As can be understood from the necessities of JIT, some basic elements of Lean Manufacturing resides under JIT. They are;

**i) Kanban / Pull System:** Where the customer demands set the “pace” of the production processes. Real time demand data is got by the end of the assembly line and this demand data is used to define the required quantity of sub-assembly elements. These requirements are transferred to each preceding processes till reaching the first point of the streamline one-by-one via using information cards (called kanban). These cards are the orders for a production station coming from the next station which must be satisfied with the exact quantity and at the right time. So in this system each station is the customer of its preceding station whom requirements must be satisfied on time, with exact demanded quantity (no more or no less) and at desired quality. This system prevents the floor from unnecessary work-in-process stock, handling, storage, and waiting.

**ii) One-Piece-Flow:** In order to settle a pull system and make it work accurately, each pieces of a product must flow through the stations one-by-one without waiting. This can be provided only by placing the stations using process-based-layout. Doing so, the production lot quantity flows through the stations is set by ONE which secure the system from demand fluctuations and warrant flexibility without stacked up by WIP.

**iii) Full Work Control / Level Production:** One another vital necessity of Pull system is organizing a well leveled production processes combination. Formation of the pace of the whole system is strictly based on leveled pace of each station. If the production speed of a station per hour is bigger than its customer station, WIP will occur in front of the customer station unless these stations are leveled. In JIT system, level of the system is defined by demand and each station is leveled based on demand data. Change in demand will not be a problem since Kanban and pull system is used with a leveled production that can be easily modified by changing the pace speed.

**iv) SMED (Single minute exchange of dies):** Is the set of techniques to minimize the time needed for exchange of machine tools to get it ready for a new model production. These techniques will be analyzed in detail in the following sections.

*1.2.1.2 Quality Tools*

**i) Total Productive Maintenance:** The main aim of maintenance is preserving the functions of physical assets. In other words, carrying out tasks which ensures that our machines are capable of doing what the users want them to do, when they want them to do it. The possible maintenance policies can be grouped under four headings;

**1. Corrective** - wait until a failure occurs and then remedy the situation (restoring the asset to productive capability) as quickly as possible.

**2. Preventive** - believe that a regular maintenance attention will keep an otherwise troublesome failure mode at bay.

**3. Predictive** - rather than looking at a calendar and assessing what attention the equipment needs, we should examine the 'vital signs' and infer what the equipment is trying to tell us. The term 'Condition Monitoring' has come to mean using a piece of technology (most often a vibration analyzer) to assess the health of our plant and equipment.

**4. Detective** - applies to the types of devices that only need to work when required and do not tell us when they are in the failed state e.g. a fire alarm or smoke detector. They generally require a periodic functional check to ascertain that they are still working.

TPM emphasizes the importance of people, collaboration of production and maintenance staff working together. Overall manufacturing philosophy is represented mostly by TPM. The modern business world is a rapidly changing environment, so the last thing a company needs if it is to compete in the global marketplace is to get in its own way because of the way in which it approaches the business of looking after its income generating physical assets. So, TPM is concerned with the fundamental rethink of business processes to achieve improvements in cost, quality, speed etc. It encourages radical changes, such as;

- Flatter organizational structures - fewer managers, empowered teams,
- Multi-skilled workforce,
- Rigorous reappraisal of the way things are done - often with the goal of simplification.

The principal measure is known as the Overall Equipment Effectiveness (OEE). This figure ties the ‘six big losses’:

1. Equipment Downtime
2. Engineering Adjustment
3. Minor Stoppages
4. Unplanned Breaks
5. Time spent making reject product
6. Waste

to three measurable:

Availability (Time), Performance (Speed) & Yield (Quality).

When the losses from Time X Speed X Quality are multiplied together, the resulting OEE figure shows the performance of any equipment or product line. TPM sites are encouraged to both set goals for OEE and measure deviations from these. Problem solving groups then seek to eliminate difficulties and enhance performance.

**ii) 5S:** The objective of this Japanese approach is keeping working environment clean and tidy. These 5S are;

Sort: Define and remove unnecessary things from the working environment

Straighten: Place important things to easy-to-reach locations.

Scrub: Keep the machines and working floor clean

Stabilize: Set cleaning and control operations as routine activities.

Sustain: Make the 5S philosophies a life style.

**iii) Visual Factory:** Making basic duties and processes easy to understand and easy to reach for each operator. Documents for visual quality control, visual operator instructions etc.

**iv) Quality Diagrams:** Lean production starts by understanding the current process and continues by the efforts to improve these processes. On this way quality diagrams such as; flow charts, frequency histograms, Pareto diagrams, control charts and fishbone diagrams make the processes monitorable.

**v) Poke – Yoke (Mistake Proofing):** Is a simple and cheap tool that prevents producing defected parts or prevent these defected parts to enter the system. Poke-Yoke eliminates the mistakes before they occur. Some poke-yoke tools are mistake diagnose and alarm systems, limiting switches, gauges, and control lists.

### 1.3 Being a Chameleon

As indicated in section 1, efficiency improvements by waste elimination in conventional production operations are serious to keep in step with ever-changing customer demands. Successful enterprises are the ones who can provide the customers what they exactly want at the quantity demanded and when they exactly need. This is really very difficult task which requires becoming a *"chameleon"- adapt itself to environment quickly.*

It doesn't matter which parameter is changed by the customer; quantity or model of the product, all the production resources must be reorganized *quickly* in order not to miss the opportunities in the market. One of the most important resources is the machinery. The ability to adjust the machines to a new model or to a different production volume is vital to pace up with demand.

Most of the companies who have to struggle with these fast changing market conditions face great time losses because of shifting to another model's production. As it is emphasized in the academic papers; "Lean manufacturing systems must have the ability to achieve responsive, small batch manufacture so that they can meet rapidly changing market demands. Rapid changeover is a fundamental technique for attaining just-in-time (JIT) production and for addressing the issue of quality, flexibility and responsiveness (Spann, Adams, Rahman, Czarnecki, & Schroer BJ, 1999)."

In the following chapter why and how the companies should eliminate these time losses will be explained and the most popular technique "SMED" is introduced. In chapter three the need for advanced engineering to SMED methodology is explained in light of papers in the literature. A new analysis system is introduced and MTM-UAS system is given for further understanding of this analysis system. In chapter six implementation of the proposed system is taken place.

# CHAPTER TWO
# SINGLE MINUTE EXCHANGE OF DIES (SMED)

## 2.1 What is SMED?

*Single Minute Exchange of Die (SMED)* is one of the many lean production methods for reducing waste in a manufacturing process. It provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product. This rapid changeover is a key to reduce production lot sizes and thereby improving flow (Mura) which is a 'Lean' aim. It is also often referred to as *Quick Changeover (QCO)*. Performing faster changeovers is important in manufacturing, or any process, because they make low cost flexible operations possible.

The phrase "single minute" does not mean that all changeovers and startups should take only one minute, but that they should take less than 10 minutes (in other words, "single digit minute").

## 2.2 How SMED Come Up?

The concept arose in the late 1950s and early 1960s, when Shigeo Shingo, was consulting to a variety of companies including Toyota, and was contemplating their inability to eliminate bottlenecks at car body-molding presses. The bottlenecks were caused by long tool changeover times which drove up production lot sizes. The economic lot size is calculated from the ratio of actual production time and the 'changeover' time; which is the time taken to stop production of a product and start production of the same, or another, product. If changeover takes a long time then the lost production due to changeovers drives up the cost of the actual production itself. This can be seen from the table below where the changeover and processing time per unit are held constant whilst the lot size is changed. The Operation time is the unit processing time with the overhead of the changeover included. The Ratio is the percentage increase in effective operating time caused by the changeover. SMED is the key to manufacturing flexibility.

Table 2.1 Effect of changeover time over operation time (Shingo, 1985)

| Changeover time | Lot size | Process time per item | Operation time | Ratio |
|---|---|---|---|---|
| 8 hours | 100 | 1 min | 5,8 min | 480% |
| 8 hours | 1,000 | 1 min | 1,48 min | 48% |
| 8 hours | 10,000 | 1 min | 1,408 min | 5% |

Toyota's additional problem was that land costs in Japan are very high and therefore it was very expensive to store economic lots of its vehicles. The result was that its costs were higher than other producers because it had to produce vehicles in uneconomic lots.

The "economic lot size" (or EOQ) is a well-known, and hugely debated, manufacturing concept. Historically, the overhead costs of retooling a process were minimized by maximizing the number of items that the process should construct before changing to another model. This makes the changeover overhead per manufactured unit low. According to some sources optimum lot size occurs when the interest costs of storing the lot size of items equals the value lost when the production line is shut down. The difference, for Toyota, was that the economic lot size calculation included high overhead costs to pay for the land to store the vehicles. Engineer Shingo could do nothing about the interest rate, but he had total control of the factory processes. If the changeover costs could be reduced, then the economic lot size could be reduced, directly reducing expenses. Indeed the whole debate over EOQ becomes restructured if still relevant. It should also be noted that large lot sizes require higher stock levels to be kept in the rest of the process and these, more hidden costs, are also reduced by the smaller lot sizes made possible by SMED.

Over a period of several years, Toyota reworked factory fixtures and vehicle components to maximize their common parts, minimize and standardize assembly tools and steps, and utilize common tooling. This common parts or tooling reduced changeover time. Wherever the tooling could not be common, steps were taken to make the tooling quick to change.

The details of Shingo's technique will be analyzed in detail in the following sections. It is for sure that the success of this program contributed directly to just-in-time manufacturing which is part of the Toyota Production System. SMED makes Load balancing much more achievable by reducing economic lot size and thus stock levels.

Shigeo Shingo, who created the SMED approach, claims that in his data from between 1975 and 1985 that average setup times he has dealt with have reduced to 2.5% of the time originally required; a 97% improvement (Shingo, 1985).

## 2.3 What are the Effects of SMED?

The power of SMED is that it has a lot of other effects which come from systematically looking at operations; these include:

- Stockless production which drives capital turnover rates,
- Reduction in footprint of processes with reduced inventory freeing floor space
- Productivity increases or reduced production time
- Increased machine work rates from reduced setup times even if number of changeovers increases
    - Elimination of setup errors and elimination of trial runs reduces defect rates
    - Improved quality from fully regulated operating conditions in advance
    - Increased safety from simpler setups
    - Simplified housekeeping from fewer tools and better organization
    - Lower expense of setups
    - Operator preferred since easier to achieve
    - Lower skill requirements since changes are now designed into the process rather than a matter of skilled judgment
- Elimination of unusable stock from model changeovers and demand estimate errors
- Goods are not lost through deterioration

- Ability to mix production gives flexibility and further inventory reductions as well as opening the door to revolutionized production methods (large orders ≠ large production lot sizes)
- New attitudes on controllability of work process amongst staff

## 2.4 Steps of Setup Operations

### *2.4.1 Setup Operations*

A setup operation is the preparation or after adjustment that is performed once before and once after each lot is processed. There are two kinds of setup operations;

**Internal Setup:** This kind of setup can only be done when the machine is shut down. For example, a new die can only be attached to a press when the press is stopped.

**External Setup:** This kind of setup can be done when the machine is still running. For example, bolts to attach to the die can be assembled and sorted while the press is operating.

### *2.4.2 Basic Steps in a Setup Operation*

All setup operations that have not been improved through SMED are made up of four steps. These are;

1. Preparation, after-process adjustments, checking of materials and tools
2. Mounting and removing blades, tools, and parts
3. Measurements, settings, and calibrations
4. Trial runs and adjustments

Total setup time is divided by these four operations with the ratios given in the table below.

Table 2.2 Portion of basic setup steps before SMED implementation (Shingo, 1985)

| Steps in Setup | Proportion of Setup Time Before SMED |
|---|---|
| Preparation, after-process adjustments, checking of materials and tools | 30% |
| Mounting and removing blades, tools, and parts | 5% |
| Measurements, settings, and calibrations | 15% |
| Trial runs and adjustments | 50% |

**Preparation, after-process adjustments, checking of materials and tools**

Ensuring that all parts and tools are where they should be and that they are functioning properly. Also included in this step is the period after processing when these items are removed and returned to storage, machine is cleaned, and etc. In traditional setup, these steps are done while the machine is stopped however they can / must be done as external setup operations.

**Mounting and removing blades, tools, and parts**

This step includes the removal of parts and tools after one lot is processed, and the attachment of the parts and tools for the next lot. This step is obligatorily an internal setup step. Nevertheless as can be seen in Table 2.2 the time portion is relatively ignorable.

**Measurements, settings, and calibrations**

This step refers to all the measurements and calibrations that must be made in order to perform a production operation, such as centering, dimensioning, measuring temperature or pressure, and so forth. Although the machinery must often be stopped for this step, the SMED system teaches ways to do these tasks quickly by preparing while the machinery is still running.

**Trial runs and adjustments**

In the final step of a traditional setup operation, adjustments are made after a test piece is machined. The more accurate your measurements and calibrations are in the previous step, the easier these adjustments will be.

Correct adjustment of the equipment is one of the most difficult tasks in a setup operation (50% of total setup time). In a traditional setup, the time needed for trial runs and adjustments depends on personal skill. In traditional setup, the machine is not making the good products until the step is finished, so it is considered as a part of internal setup. But SMED teaches ways to eliminate this step completely, so that the machine makes good products right after it is started up (Shingo & Prod. Press Dev. Team, 1996). An example is figured below.

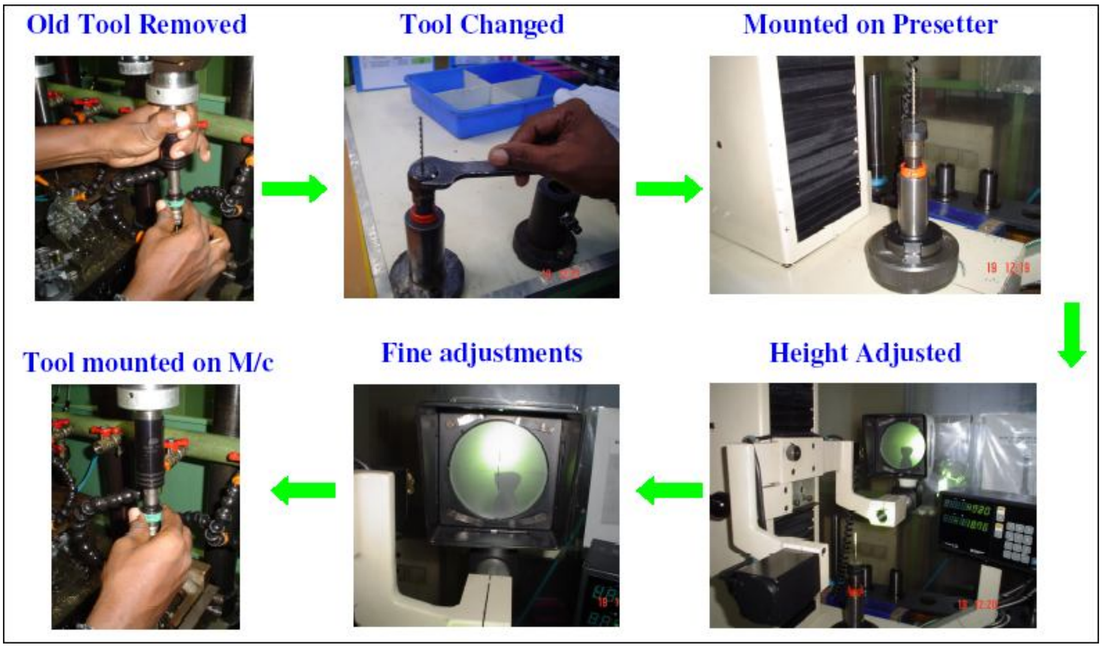



Figure 2.1 Basic steps of a setup operation (Presentation on total management system, J. Matthew, 2004)

Figure 2.1 shows the basic setup operations step by step. As the first step old drill is removed from the machine and the new one is prepared. A pre-setter is used to set required arrangements before mounting to the machine. The drill height is adjusted and after fine adjustment with special equipments the new drill is mounted to the machined and pilot run is executed.

In order for further understanding Figure 2.2 depicts the line output during the changeover process and shows the basic elements of setup operation.

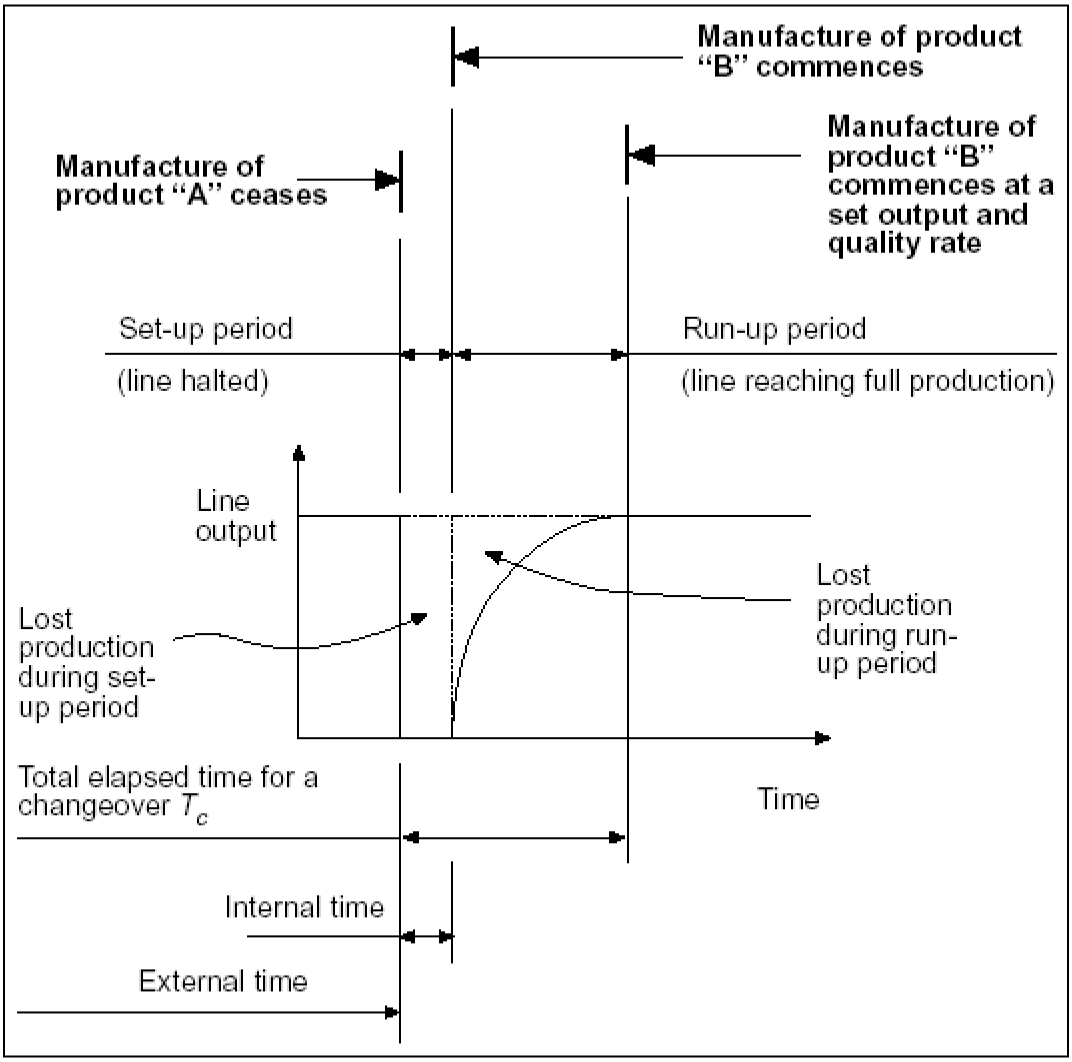



Figure 2.2 Line output during the basic elements of a setup operation (McIntosh R., 1996)

## 2.5 Three Stages of SMED

There are three basic stages of SMED technique. These are;

**Stage 1: Separating Internal and External Setup**

The most important step in implementing SMED is distinguishing between internal and external setup. By doing obvious things like preparation and transport while the machine is running, the time needed for internal setup, can be cut by 30-50%.

**Stage 2: Converting Internal Setup to External Setup**

Further reducing setup times toward the single-minute range involves two important activities: 1) reexamining operations to see whether any steps are wrongly assumed to be internal setup, and 2) finding ways to convert these steps to external setup by analyzing the true function of the operations.

**Stage 3: Streamlining All Aspects of the Setup Operation**

To further reduce setup time, the basic elements of each setup are analyzed in detail. Specific principles are applied to shorten the time needed, especially for steps that must be done as internal setup, with the machine stopped (Shingo & Prod. Press Dev. Team, 1996).

### *2.5.1 First Stage of SMED: Separating Internal and External Setup*

Certain tasks can clearly be done before machines are stopped for changeover. These include lining up the right people, preparing parts and tools, making repairs and bringing the parts and tools closer to the equipment. However in practice it can be observed that many external setup operations are done as internal setup.

There are three ways to separate the internal and external setup operations. These are; using checklists, performing function checks and improving the transport of dies and other parts.

#### *2.5.1.1 Checklists*

These lists include what are the things during setup and next operation. These items can be;

- Tools, specs and workers required
- Proper values of operating conditions such as temperature, pressure.
- Correct measurements and dimensions required for each operation.

Checking items off the list before the machine is stopped helps prevent oversight and mistakes that otherwise might come up after internal setup has begun. It helps the operator to avoid errors. Specific checklists must be established for each machine or operation. An example of a checklist is given in Figure 2.3.

| | | | |
|---|---|---|---|
| **Operation Checklist** | | | |
| **Equipment:** | | | |
| **Operation:** Changeover to 3 lb size | | | |
| **Date: 4/8** | | | |
| | **Employees trained for setup and operation (need 2 people)** | | |
| | Jack B. | → | Arthur C. |
| → | Mark A. | | Kyle B. |
| | **Tools needed** | | |
| → | Automatic nut driver | | |
| → | Wrench | | |
| → | Rolling Cart | | |
| | **Parts Needed** | | |
| | Elevator Plate – 3 lb. size | | |
| → | Compression Plate – 3 lb. size | | |
| → | Feed Augur | | |
| | Vacuum hose, towels, brushes for clean down | | |
| | **Standard Operating Procedure to follow** | | |
| → | XOS 01 (Changeover) | → | XOD 03 (clean down) |

Figure 2.3 Checklist example (Shingo, 1985)

### *2.5.1.2 Improved Transport of Parts and Tools*

Dies, molds, tools, jigs and other required things for changeover are needed to be moved from the storage areas to the machines and back to the storage areas after setup operation finished. To shorten the time the machine is shut down, transport of these items should be done during external setup. Likewise, these parts should be moved back to the storage areas when the machine is started up for the next production. See figure 2.4.

In previous transportation model, the machine is stopped, the die is dismantled, the new die for next model's production is carried from the storage area and brought nearby the machine and mounted, the ex-die is removed to the storage area and the machine is started again. This model is really a time wasting process and SMED teaches to use improved transportation model;

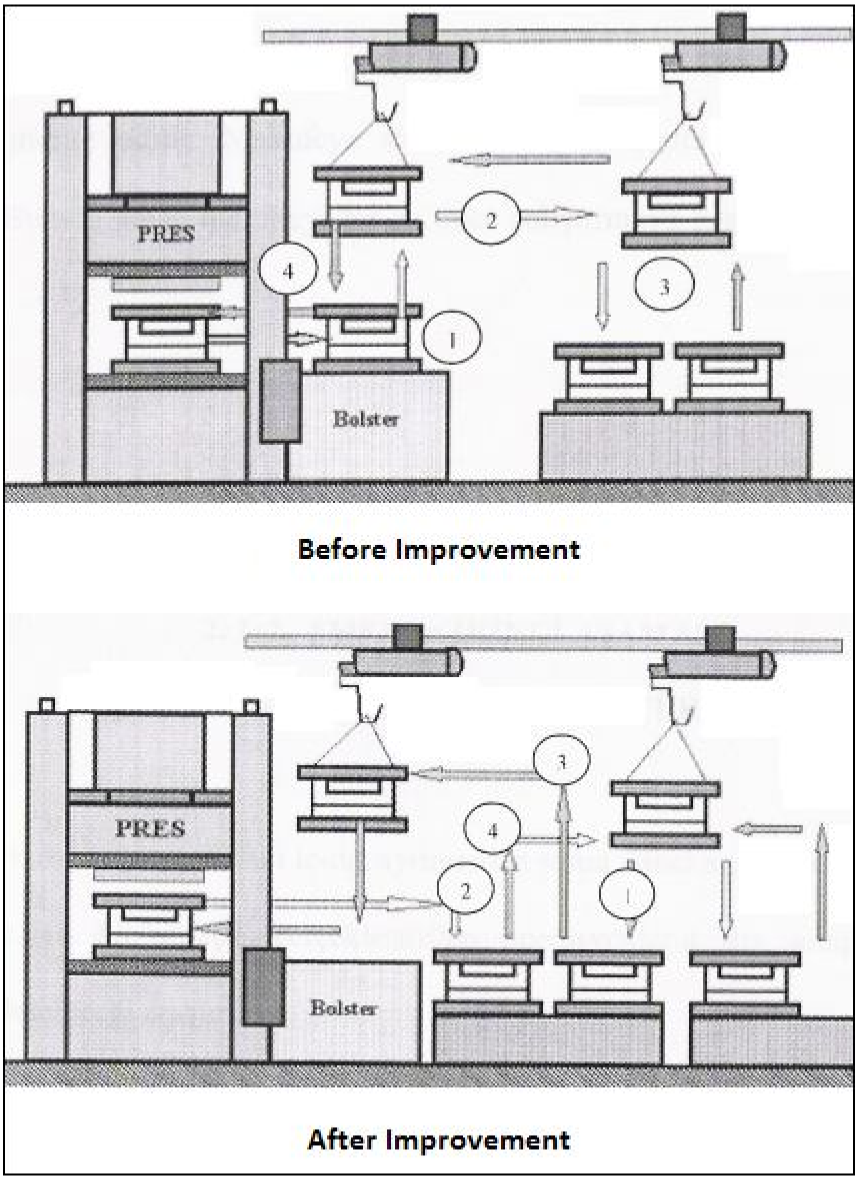



Figure 2.4 Improved transport of dies (Shingo, 1985)

The die for next model's production is gotten ready while the machine is still continues current model's production and placed nearby the machine by a carrier. Then the machine is stopped and the die is dismantled and removed near the machine via carrier. The new die is mounted and the machine is started. As the last operation the ex-die is taken to the storage area. Here is the sole aim is minimizing time loss because of changeover.

### *2.5.2 Second Stage of SMED: Converting Internal Setup to External Setup*

At the first stage of the SMED internal and external operations are distinguished. The ways to convert internal setup operations to external setup operations are explored in the second stage of SMED.

SMED uses three basic techniques for this conversion;

1) Defining requirements for internal setup in advance
2) Standardizing important functions
3) Using inter-mechanism

#### *2.5.2.1 Defining requirements for internal setup in advance*

All required parts, equipments and conditions are gotten ready before internal setup. Some of these conditions can be; where the equipments should be placed, what the temperature and pressure values must be etc.

As an example depicted in figure 2.5, a machine which uses wire spool, needs new one when the current one has finished. Since a forklift cannot be available at any time, the machine may have to wait for the new spool without working. To avoid such internal setup time loses, a stock spool holder will be placed to the machine and the wire stock is put on this stock holder. When the current spool finishes, the one in the holder will be moved to the machine easily.

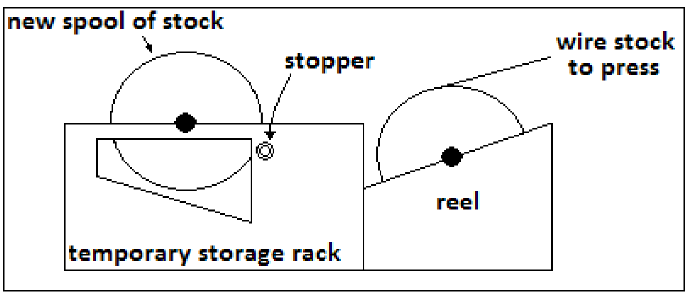



Figure 2.5 Temporary holder for wire stock (Shingo, 1985)

Another example is preheating machine parts or materials-outside the machine- to the temperature needed for processing. Some companies conserve energy by using heat given off by other equipments for this task.

*2.5.2.2 Function Standardization*

When tools or machine parts in a new operation are different from those in the previous one, operator must make time consuming adjustments during changeover – often with the machine shut down. Standardization-keeping something the same from one operation to another- helps get rid of this internal setup.

SMED uses a targeted approach called function standardization. It would be expensive and wasteful to make the external dimensions of every die, tool, or part the same. Function standardization avoids this waste by focusing on standardizing only those elements whose functions are essential to the setup. This technique might be applied to dimensioning, centering, securing, expelling, or gripping etc.

Implementation involves two steps:

1) Look closely at each individual function in your setup process and decide which functions can be standardized.
2) Look again at the functions and think about which can be made more efficient by replacing the fewest possible parts.

As an example, the feed bar on a transfer die press. The feed bar performs three operations: gripping the product, sending the product to the next process, and returning the feed bar to its original position. When changing to a different product, only the gripping function needs to change to match the new shape, dimension, or material. There is no need to replace entire bar, it is enough to switch the finger section attached to the tip.

The classical example of function standardization is standardizing the clamping function of press dies. Adjusting the shut height of the die requires a great deal of skill. It is for sure that changing the die is an internal setup operation. But function standardization can shorten the internal setup time dramatically by avoiding unnecessary shut height adjustments.

In Figure 2.6 there are two types of dies. Die A has a 20-inch shut height and die B has a 15-inch shut height. Without function standardization, operators changing from one die to another would have to make a lot of adjustment. Function standardization solves the problem by using the simple shim devices to make the shut height and clamping height the same for both dies. As a result the same clamping bolts can be used for both dies. This cuts out most of the adjustment work.

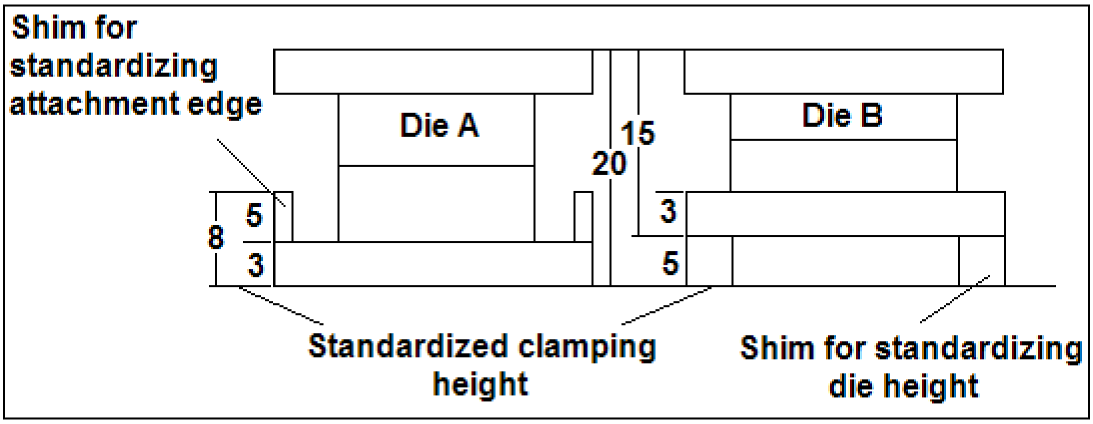



Figure 2.6 Example of function standardization on die press (Shingo, 1985)

Some pictures regarding to function standardization is given below. In Figure 2.7 the height of the drill is standardized by using a simple shim. In Figure 2.8 function standardization is implemented to multi head spindles by changing the lower part of the equipment. The time gain for each example is given.

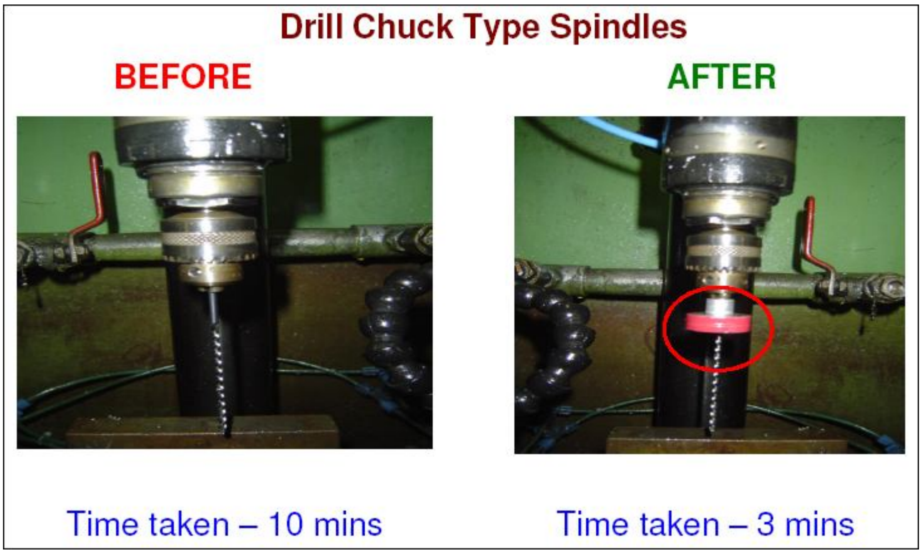



Figure 2.7 Function standardization on a drill (Presentation on total management system, J. Matthew, 2004)

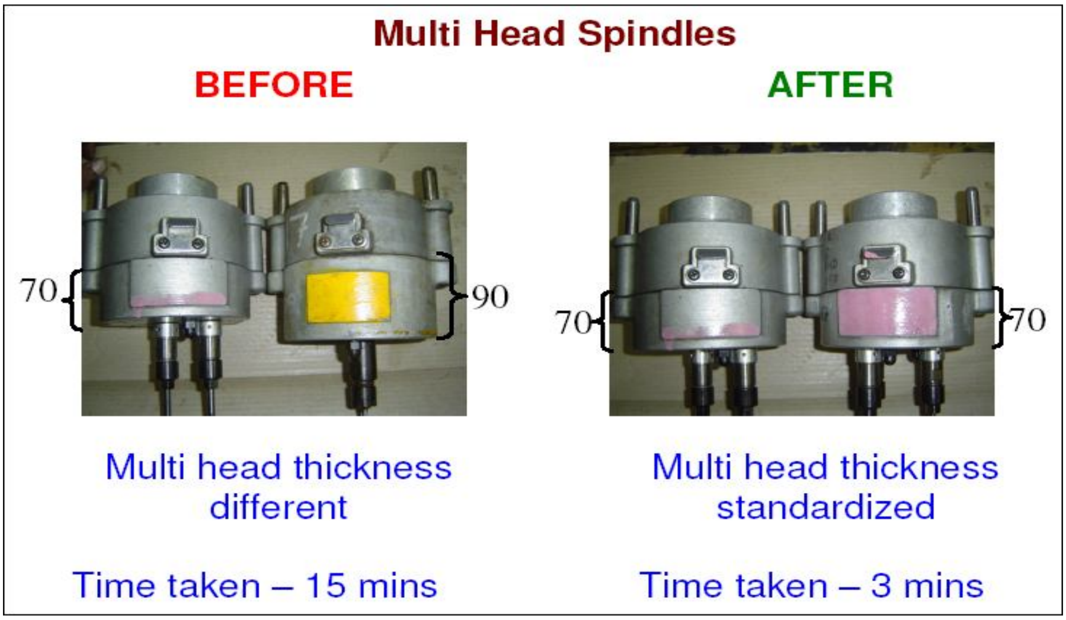



Figure 2.8 Function standardization on a multi-head spindles (Presentation on total management system, J. Matthew, 2004)

As noted, this technique can be applied to dimensioning, centering, securing, expelling, or gripping. As the best practice setting up a press can be analyzed. The press must be positioned in the center of the bolster. In traditional ways relatively small dies is put on the bolster cursory and the operator pushes the die since the holes of the die fits to the holes on the bolster. This is a time consuming and dangerous operation since if the holes are not fit properly damages on the die or on the product may occur.

The operation can be improved with function standardization as shown in Figure 2.9. A centering jig is attached to the machine so that the edge of the jig is a fixed distance from the center of the die and shank (center of the bolster). This jig has V-shape projections to the left and right of the center.

Another function standardization technique is *die cassette system* which help to gain a great deal of time (figure 2.10). A press consists of two main parts. One is “moving part” which provides mechanical function by applying pressure via going up-and-down. The second part is “fixed” and gives the shape to the material. The moving part does not change during production. The only part that needs to be changed is the fixed part since the shape changes from model to model. So there is no need to change moving part of the die.

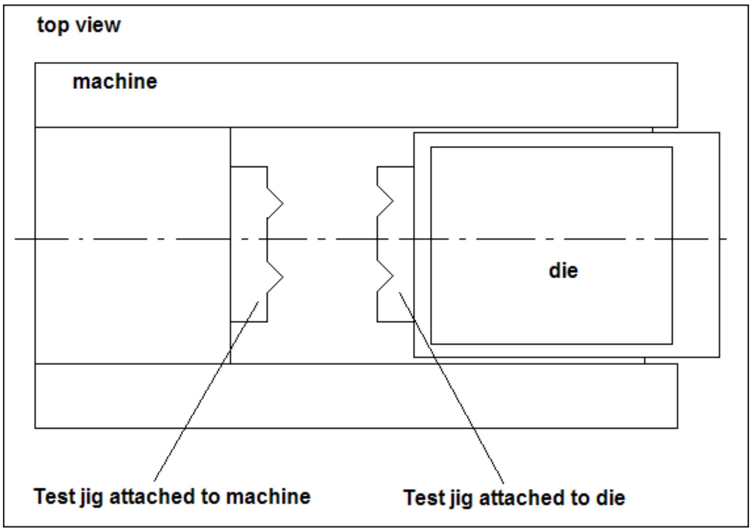



Figure 2.9 Centering jigs (Shingo, 1985)

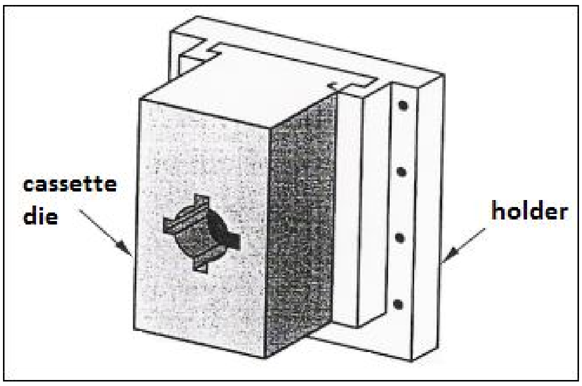



Figure 2.10 Die cassette system (Shingo, 1985)

Using intermediary jigs is one of techniques to convert internal setup operations to external setup operations. Intermediary jigs has specific dimensioned surface. In practice lot of die with different sizes are used on a press machine. Intermediary jigs are used to prepare preceding model's die while the machine is running with current model. When the production of the current model finishes, new jig is placed. Here the tip is, standardizing the dies - which have different dimensions and need different positioning requirements - by using an interface.

### *2.5.3 Streamlining All Aspects of the Setup Operation*

In this last stage of SMED all of the internal and external setup operations are improved. As in stage 2, each setup operation are checked closely again. This last stage leads in nearly all cases to setups within the single-minute range.

#### *2.5.3.1 Streamlining External Setup*

External setup improvements include streamlining the storage and transport of parts and tools. Small tools, dies, jigs, and gauges are essential equipments needed in setup operations and must be well managed not to cause any time waste. It is very important to define;

How these equipments must be organized?
How they must be maintained to make them ready for next operation at any time?
How many of these items should be kept in stock?

Here is the aim is of course minimizing the time needed for external setup operations since setup is not a direct-value added operation. In Figure 2.11, the two figures show the improvement on tool inventory. As an obvious result it will be much easier to find the tool required.

Another example is using color codes and location numbers for each die. Especially in big production facilities, there may be lots of dies. As can be seen from figure 2.12 color and/or number coding eases finding the right tool at the quickest way. Also die usage frequency helps to define which dies are use more frequently and which are less. So, popular dies will be located in storage area where easier to reach to the machines.

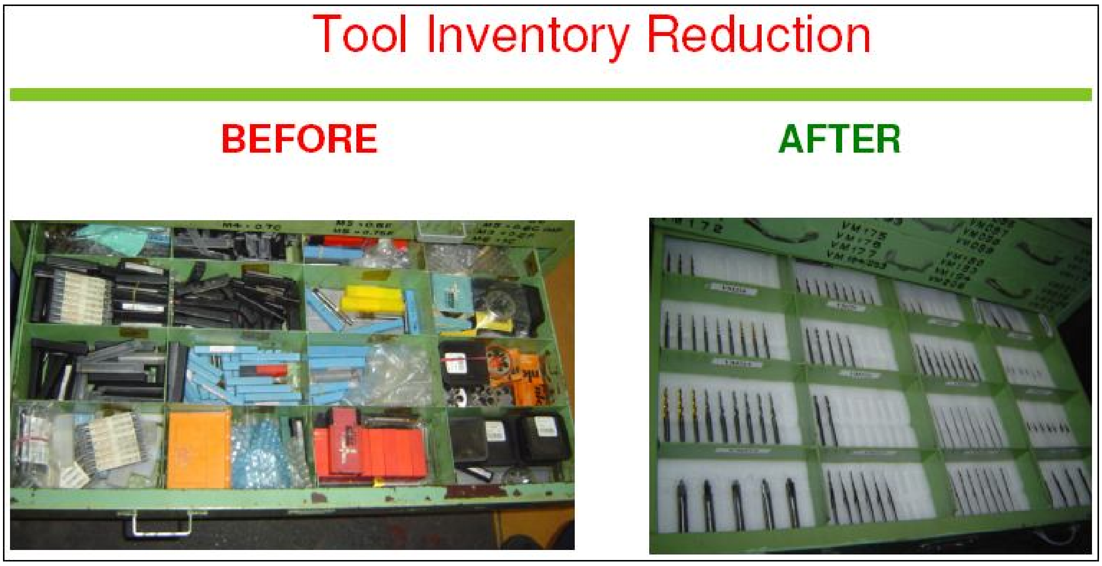



Figure 2.11 Tool inventory reductions (Presentation on total management system, J. Matthew, 2004)

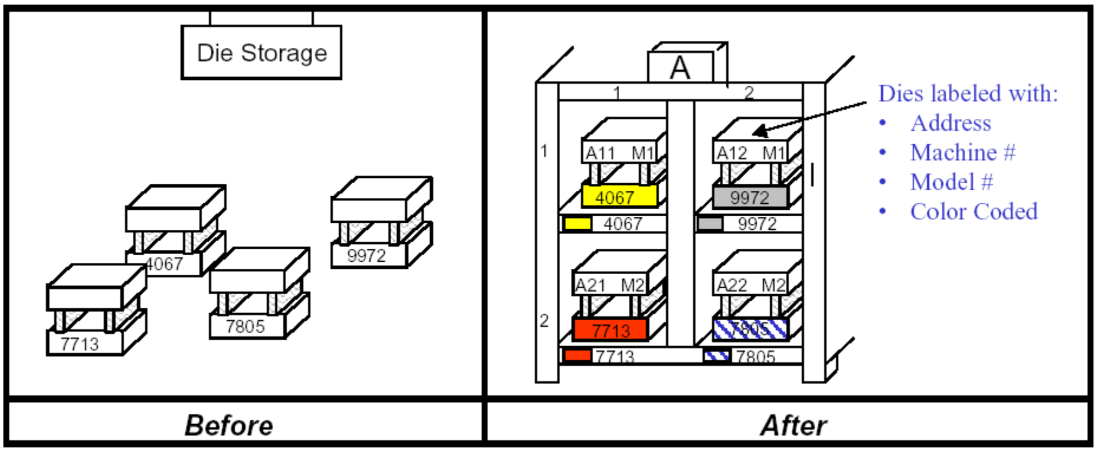



Figure 2.12 Numerical and color coding for die storage (Presentation on total management system, J. Matthew, 2004)

*2.5.3.2 Streamlining Internal Setup*

SMED approach uses 4 basic ways for streamlining internal setup operations;

- ❖ Parallel operations
- ❖ Using functional clamps
- ❖ Eliminating Adjustments
- ❖ Mechanization

*2.5.3.2.1 Implementing Parallel Operations.* Machines such as large presses, plastic molding machines, and die-casting machines often require operations at both the front and back of the machine. One-person changeovers of such machines causes waste of time because of the movement back and forth from one end of the machine to the other.

Using parallel operations the time needed for internal operations can be reduced dramatically. Two (or more) people located one at each end of the machine will eliminate unnecessary movements. But here an important thing is maintaining reliability and operations safety and minimizing the waiting time. A procedural chart can be used to indicate the sequences of task for each operator and the time needed for each task. Each time a worker finishes his task he must signal to inform the others to maintain safety, reliability and to minimize waiting time. A very popular example for this technique is pit-stop operations in racing.

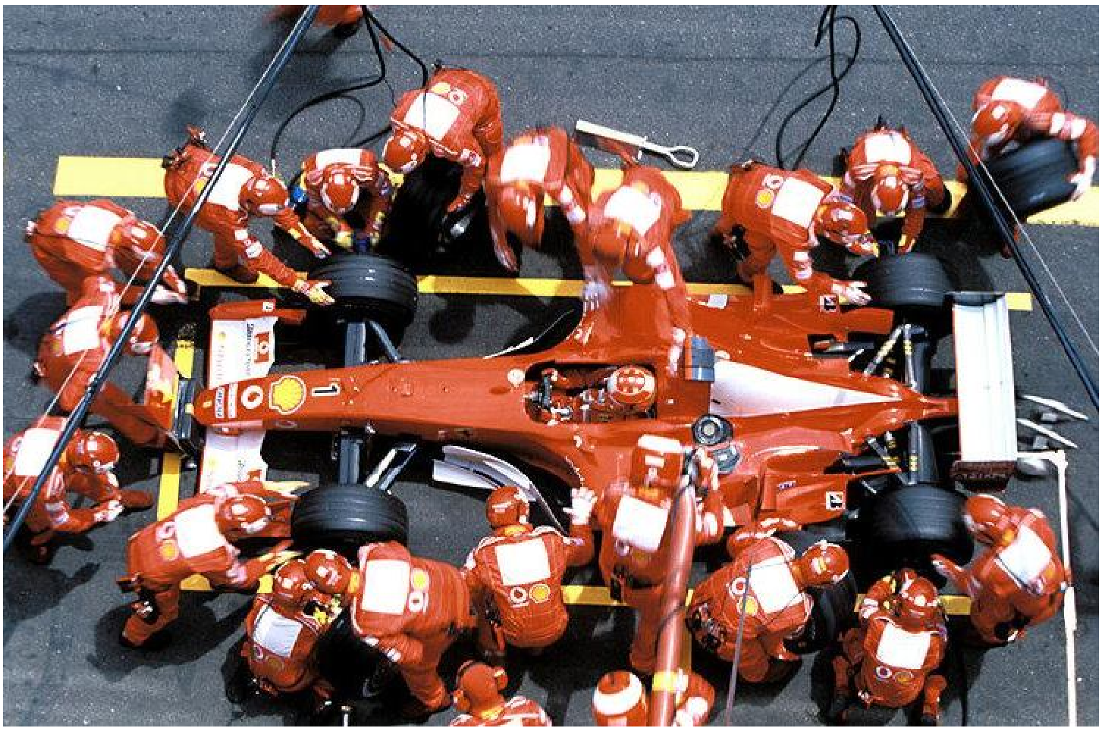


Figure 2.13 Parallel operations example

*2.5.3.2.2 Using Functional Clamps.* In traditional setups, bolts are often used to attach dies or tools directly to the machine. But in SMED system, bolts and nuts are the enemies since they slow down internal setup because of three reasons;

- Bolts get lost; they can disappear under machines or roll into floor grates.
- Bolts get mismatched; they aren't always standardized even for the same machine.
- Bolts take too long to tighten.

SMED uses devices called functional clamps to save time and energy. Most of them can stay attached to the machine without being lost. Functional clamps can be grouped under three headlines;

- One-turn method
- One-motion method
- Interlocking method

*One-turn Methods:* Some examples of one-turn method functional clamping devices are;

- Pear-shaped hole method
- U-slot method
- Clamp method
- C-shaped washer method
- Split thread method

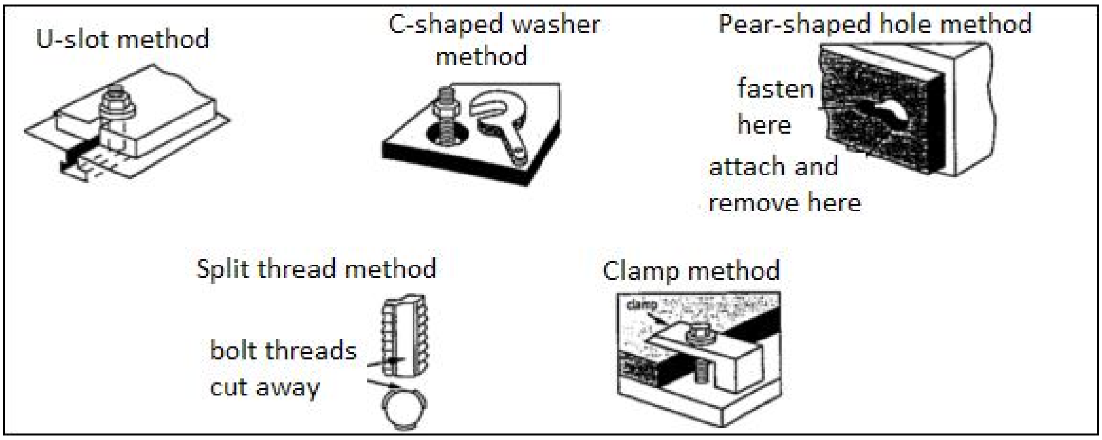



Figure 2.14 One-turn methods (Shingo, 1985)

*One-motion Methods:* Some examples of one-motion method functional clamping devices are;

- Cams and clamps
- Wedges and taper pins
- Spring stops
- Magnets or vacuum suctions

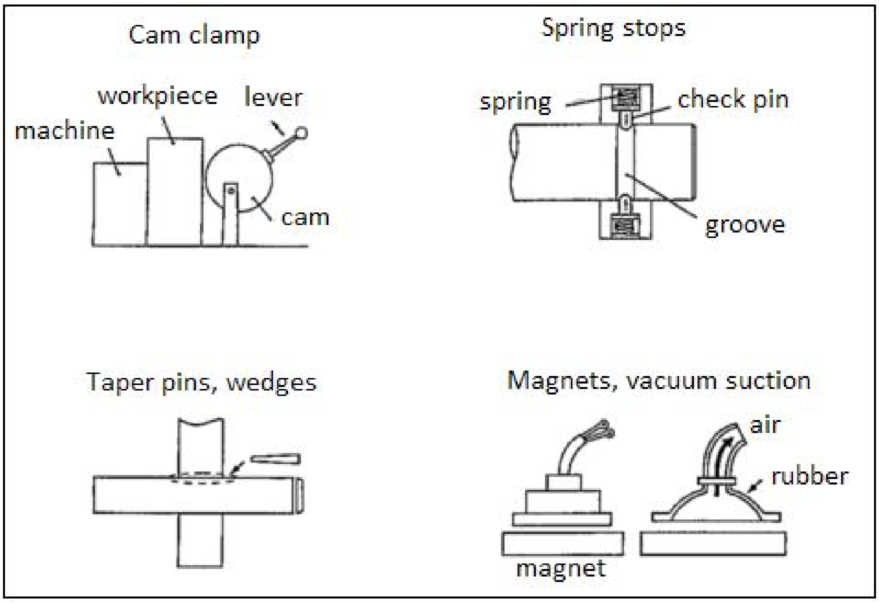



Figure 2.15 One-motion methods (Shingo, 1985)

*Interlocking Methods:* The very simple explanation of interlocking methods is fitting and joining two parts together without the use of a fastener. As an example in figure 2.10 (die cassette system) there is no bolt to clamp the die to the machine. Instead both the base plate of the die and the machine cradle are provided with tapered surfaces. Attachment and centering precision are achieved by locking those tapered sections together.

*2.5.3.2.3 Eliminating Adjustments.* As given in table 2.2, trial runs and adjustments can account for 50% of the time in a traditional setup. So theoretically if adjustments can be eliminated, a lot of machine downtime will be saved. Here the point is eliminating not reducing.

Eliminating trial runs and adjustments is done by making good settings before start up the machine. The number of trial runs and adjustments that will need to be made depends of how accurately or inaccurately centering, dimensioning and condition setting are done. The practical techniques for eliminating adjustments are;

- Using a numerical scale and making standardized settings
- Making imaginary center lines and imaginary reference planes visible
- Using the least common multiple (LCM) system

*Using a Numerical Scale and Making Standardized Settings:* Eliminating adjustments require operator to rely less on intuition and more on constant numerical values for machine settings. The adjustments based on intuition will not be exactly the same with the previous ones.

Using the scales with constant numerical values on it will lessen the adjustment problems. Depending on the sensitivity of the setting operation the sensitivity of the scaling units will change. As the sensitivity increases gages and digital indicators are preferred.

*Visible Center Lines and Reference Planes:* In traditional methods centering operations are done mostly based on operator's intuition and trial-error approach. Visible center lines and reference planes make centering easy and fast-to-accomplish and avoid mistakes. See figure 2.16.

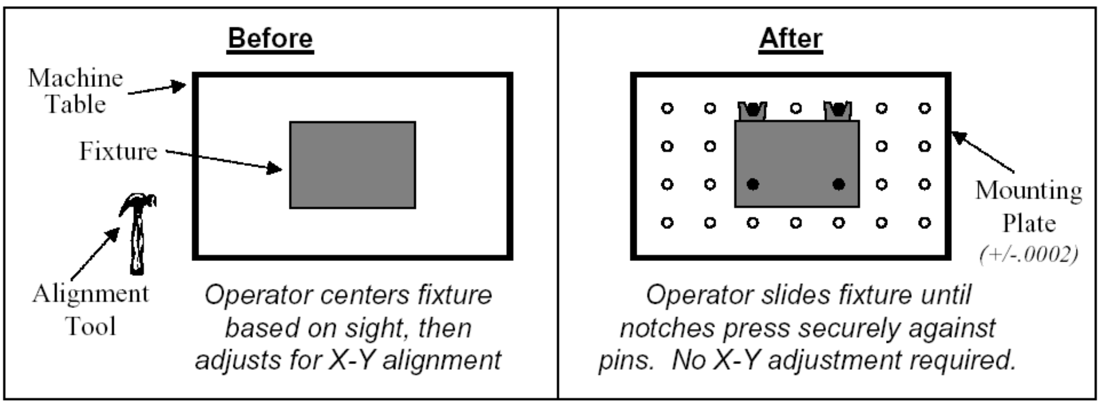



Figure 2.16 Visible center lines and reference planes

*Least Common Multiple (LCM) System:* On one machine similar operations are done but with different dimensions, patterns or other functions. The aim of the LCM is combining these same operations into a mechanism. During changeover, the mechanism stays in the machine, and only the function changes. In an LCM system, the function is changed by making a quick setting, such as by rotating tools on a spindle or flipping a switch. So two principles of the LCM are;

1. Leave the mechanism alone and modify only the function
2. Make settings, not adjustments

The most favorite example is limit switches. See figure 2.17.

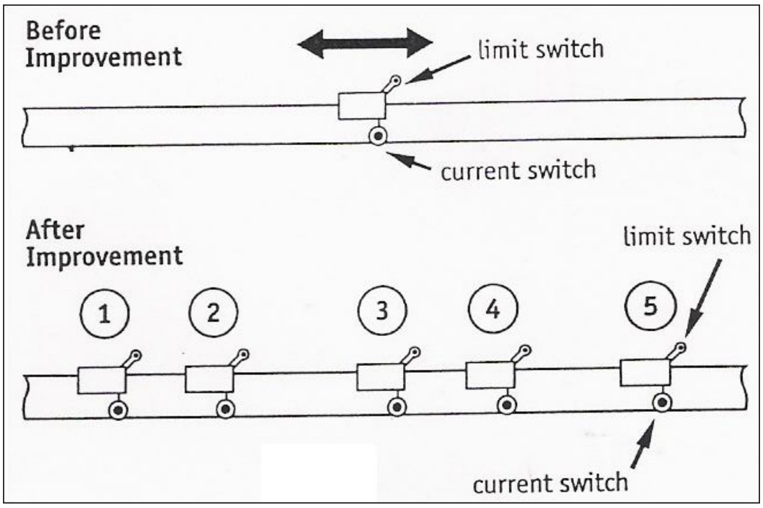



Figure 2.17 Example of LCM system-limiting switches (Shingo, 1985)

In that example one limit switch was used to control the end point of machining in the production of shafts. Let's assume that we have five different kinds of shafts and we are using one switch. For each kind of shaft the position of the switch has to be changed and adjustments and trial runs must be accomplished each time. After the improvement by LCM, five limit switches, one for each different shaft type, are used to control the end point of machining. Thus, for different types of shafts, there is no necessity to adjust the position of switch and perform the trial runs which let the operator acquires a great time saving.

A lathe that is designed to cut several different patterns can be given as an example. Instead of changing the lathe each time for different patterns, this special lathe is used by a simple rotative motion. See figure 2.18.

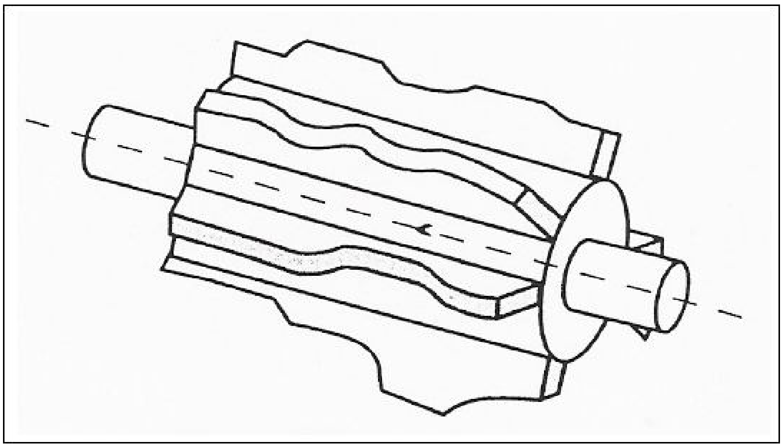


Figure 2.18 Example of LCM system multi-shape spindle (Shingo, 1985)

*Mechanization:* It is for sure that mechanization is so essential in changeover operations especially moving large press-dies, die casting dies, and plastic molds etc. But mechanization doesn't help to improve the method only by itself. It must be implemented to the improved processes in changeover operations to gain their real benefit. Otherwise the bad process would be automized.

Practical techniques in mechanization for changeover are;

- Using forklifts for insertion in machines
- Moving heavy dies on bolster
- Tightening and loosening dies by remote control
- Using electric drives for shut height adjustments
- Using the energy from presses to move dies

# CHAPTER THREE
# NEED FOR ADVANCE ENGINEERING TO SMED METHODOLOGY

## 3.1 SMED Steps are Implemented, Is it over?

In chapter 2, SMED methodology is introduced in detail. Many companies have been reported the success stories using SMED methodology. Also there are lots of academic papers published. In this chapter brief literature overviews will be given and one of the biggest lacks in SMED methodology "THE SUSTAINABILITY" will be highlighted and a new methodology will be introduced to overhaul this lack.

## 3.2 What Is Written in the Papers?

In the literature, the current steps of SMED technique are discussed. Most of the papers analyze SMED in scope of TPM (Bamber & Dale, 2000; Chand & Shirvani, 2000; Eti, Ogaji & Robert, 2004; McAdam & McGeough, 2000; Prado, 2001; Sun, Yam & WaiKeung 2003). Case studies in different manufacturing environments are reported in several papers (Gilmore & Smith, 1996; Moxham & Greatbanks, 2001). Besides the benefits of SMED, some critics are placed because of the sequential implementation progress of the method (McIntosh, Culley, Gest, Mileham & Owen, 1996). Motivation of human factor in setup operations are discussed in several academic texts (McIntosh et.al., 1996; VanGoubergen & VanLandeghem, 2002). Very benefical papers are published about the impact of design on setup operations (McIntosh et.al., 1996; Mileham, Culley, Owen & McIntosh, 1999; Patel, Shaw & Dale, 2001; VanGoubergen et.al., 2002).

In Mileham and his friends' study about the impact of design, they show the trade off between the setup time improvement and the design tools in terms of cost and time (Mileham et.al., 1996). See figure 3.1.

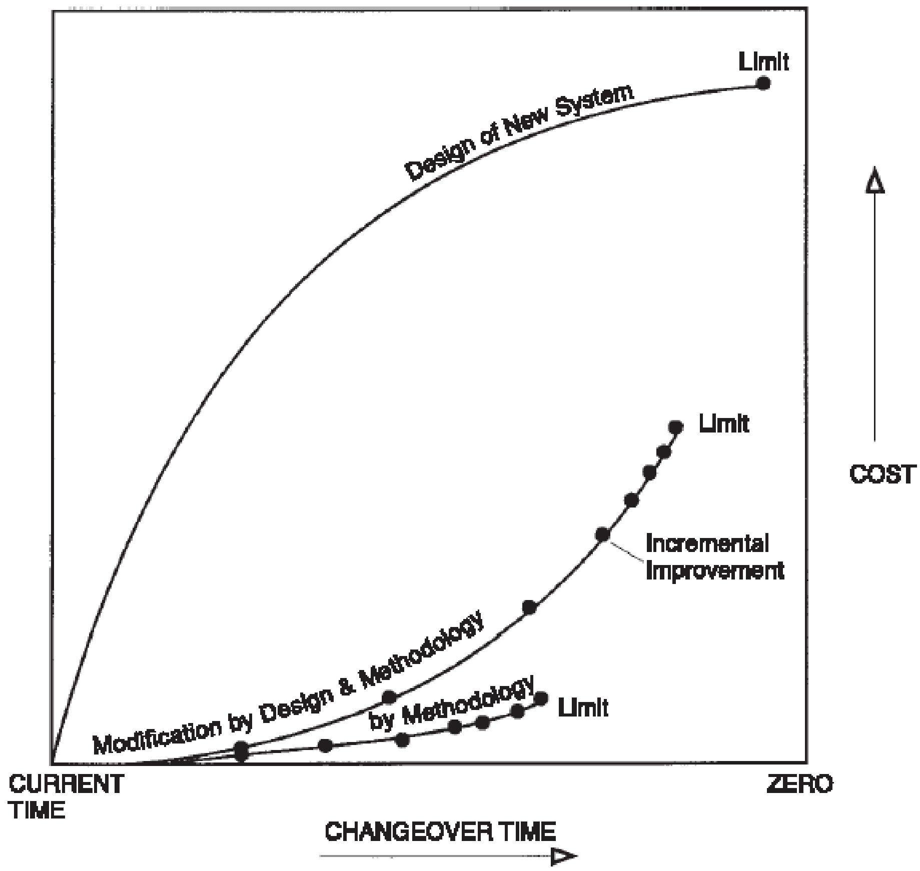



Figure 3.1 The trade-off between the setup time improvement and the cost of design tools (Mileham et. al. 1996)

As can be seen from this figure, the cheapest way of improving the setup operations can be achieved by methodological changes however the upper point of the improvement is relatively low. As its counterpart, using a new design for setup operations (specialized fasteners, special die locaters etc) can lead the setup time to a minimum but the cost of this new system would be very high. The combination of these two options can propose a reasonable point in terms of cost and time improvement.

***Preserving the success is more important and difficult than achieving this success.*** That is why Mileham and his friends also want to point that the improvements attained by design changes are more sustainable than the methodological changes. This is true since when the new design is implemented to the machine, the operator will have to use these new equipment obeying its instructions.

What must be understood from this is setup time improvements under cost pressure is not only the objective function but also the sustainability must be taken into consideration to preserve the efforts on the way to minimize the changeover time. So, they should have added the sustainability factor to their figure.

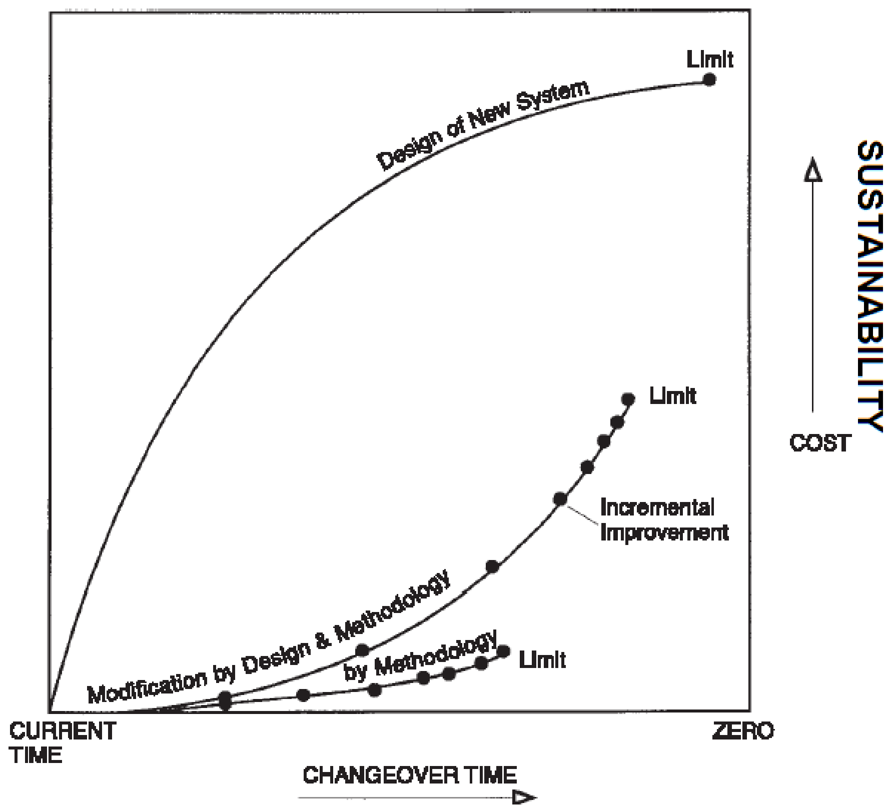



Figure 3.2 Sustainability factor added trade-off (Milehan et. al., 1996)

So it would be more understandable that design based changes provide better setup time improvement and sustainability than methodological changes. With another saying if only methodological changes are used, the improvements will disappear by time inevitably. This hypotesis is also proved by a research conducted by . See figure 3.3 (McIntosh et.al., 1996).

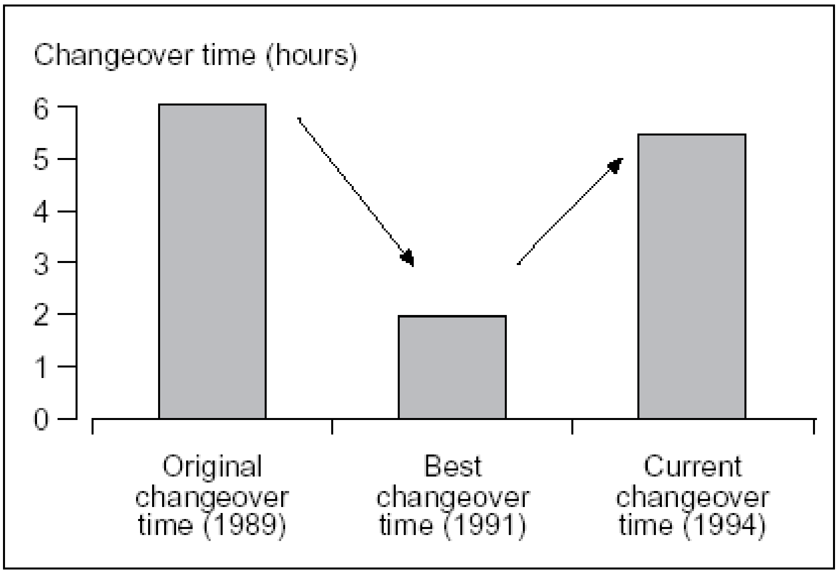



Figure 3.3 Sustainability of changeover times (McIntosh et. al., 1996, page 10).

Then it is obvious that a new methodology must be created to make the setup improvement that is achieved by methodological changes more sustainable since SMED tends to use methodological changes for improvements not design based changes. It must not be forgotten that SMED arose in economical scarcities and these limitations are valid more wildly today.

At this point the paper prepared by Cakmakci and Karasu shows how to create this new methodology. They describe the sustainability as “Keeping the achieved success level at a desired point and not letting it to drop down” (Cakmakci & Karasu, 2006). They also inspire from pitstop opertions in racing and introduce the motion-time study to setup operations. In the next section this new model will be introduced.

### 3.3 Detailed Analysis of Changeover Operations

Time is one of the most valuable asset of a company which must be used efficiently and effectively. Just like in racing. One second is important in formula-1 racing to win the race. Pit stops are necessary to finish the race since the tires get worn out and the fuel tank must be re-filled. Just like production. The changeovers must be performed to change the dies and continue to race (production). In F1 racing advanced engineering is used for automobile design, tire types, ergonomics, and of course for pitstops.

What is performed in the pits is one of the most difficult and vital task in F1. A pitstop is studied choreography and only the best are good enough to ensure comprehensive service for driver in the race against the clock. Every individual role is practised thousands of times and must be carried out perfectly. A pitstop operation is the highest level of a changeover operation in production.

In the figure 3.4, a 7.3-sec pit stop operation is depicted. Pit stop operations are the best examples of "parallel operations in SMED". Each pit crew has a specific job that must be accomplished within a limited and balanced time. Using advanced engineering each body movement is optimized and standardized.

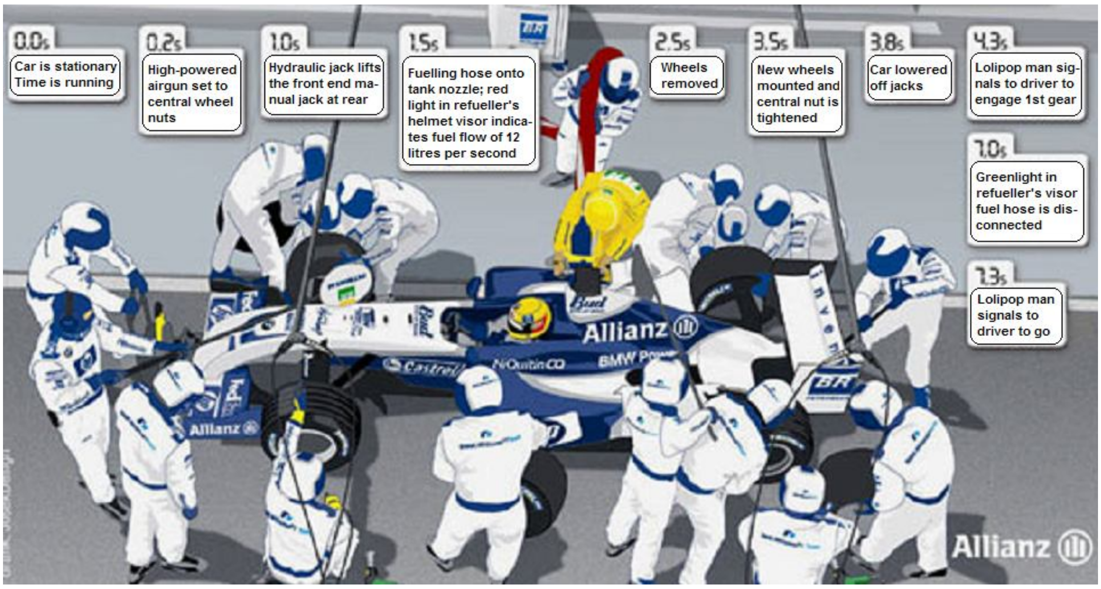



Figure 3.4 Pit-stop example

So why the same engineering techniques cannot be applied in changeover operations? Cakmakci and Karasu analysed a setup operation in a rim factory where big dies are used in production and changeover operations take long times. What they do beyond of macro changeover method, is analyzing each body motion one-by-one using the famous German oriented motion-time study analyze system MTM. They emphasize that SMED technique focuses on the setup elements and tries to improve them by applying method engineering but there is no study on micro method engineering which is so called as “motion study”.

Frank and Lillian Gilbreth were the founders of the modern motion study technique. They defined the technique as the study of the body motions used in performing an operation, to improve the operation by eliminating unnecessary motions, simplifying necessery motions, and then establishing the most favorable motion sequence for maximum efficiency (Niebel & Freivalds, 2003).

**SMED steps as macro methodological improvements** and **Motion Study as micro methodogical improvements** and combine these improvements into a standardized and documentized instruction. They depict their model as in figure 3.5 Cakmakci & Karasu, 2006).

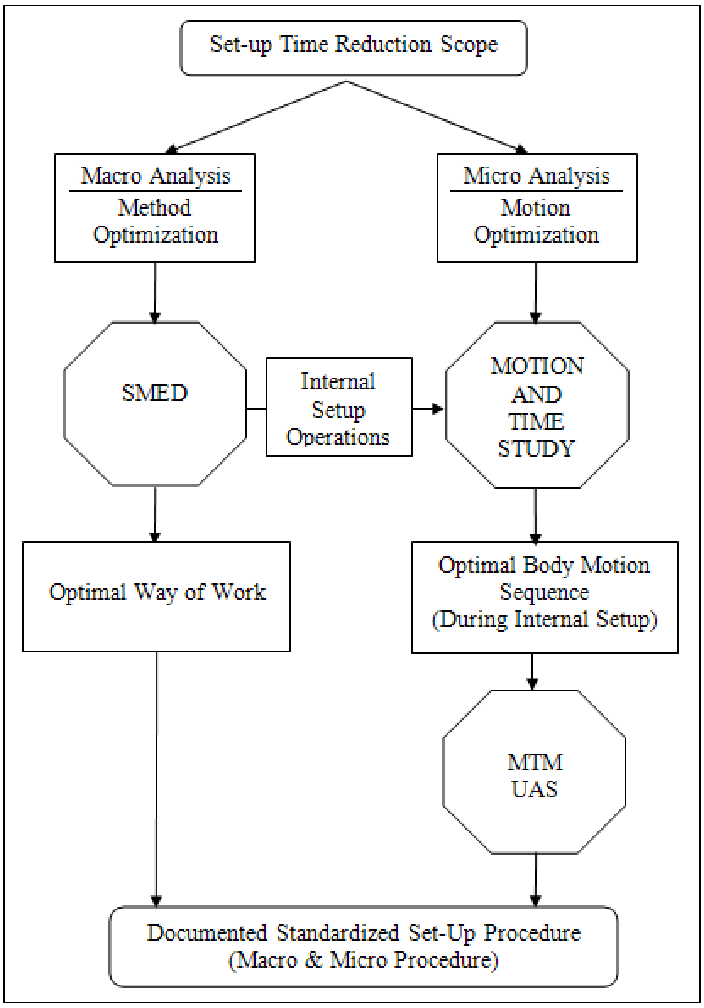



Figure 3.5 Macro and micro analysis method for changeover operations

In this model, changeover operations are analyzed under two optimization perspective; macro and micro optimization. All SMED steps are applied to the current setup method and the improvements are recorded. After SMED implementation, internal setup operations are focused by micro optimization. In this phase all body movements of the operators are analyzed in detail, unnecessary motions are eliminated, necessery motions are improved and best motion sequence is defined. The improvents by micro optimization is recorded via MTM system and internal setup operations are documented in MTM charts as instructions. At the same time the instructions that show the optimal way of work for external operations are defined and documented. As a consequence macro and micro procedure is settled.

A question may be asked. Why they did not analyze external operations by MTM? The answer for this question is also coming from F1 pitstop again. There is no need to analyze the body motions of the pitstop crew one-by-one till the car arrives the pitstop dock. It is adequate to define the optimal way of work for external operations. But internal operations are vital since the car is waiting and losing time. Just like this SMED is adequate to define the best method for external operations but not enough only by itself for further improvement and standardization of the internal operations.

Before the application of this new model on a case study, MTM system will be described in the following section for further understanding.

# CHAPTER FOUR

# METHOD TIME MEASUREMENT SYSTEMS

## 4.1 Work and Time Study, Predetermined Time Systems and MTM[1]

There are two basic methods of determining time. One is experimental methods and the other is computational methods (See figure 4.1). Experimental methods are based on observation and self report. These methods measure the actual time of an operation. The most common technique is stopwatch time measurement. The list of activities, their durations, and the frequency of their occurrence are kept as the resulting report.

Computational methods are based on three stages; *comparison and estimation*, *compilation* and *calculation of work cycles*. The first stage is the comparison of the work procedures for which the time standards are to be determined with similar activities for which time standards have already been set. The estimation is based on standard times for the procedure based on historical records or experience (comperative estimation). In the second stage "compilation", systems of predetermined times are settled. These systems are called as "Method Time Measurement" (MTM) and "Work Factor" (WF). Then standard times are recorded on "catalogue of task times" and "nomographs". The third and the last stage is the calculation of the work cycles using formulas based on nomographs, like getting, releasing, turning etc.

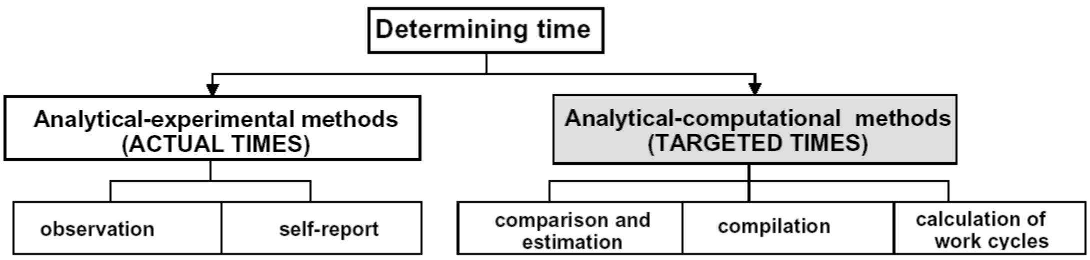



Figure 4.1 Time determination methods

[1] Basic information about MTM systems is retreived from MTM-German Manuals 1998

In method time measurement (MTM) systems the method determines the time. Thus MTM is a predetermined motion-time system (PMTS). Predetermined motion-time systems are methods to fractionalize manual and on the part of the working person suggestible operational procedures in elements of motions and to assign motion time standards to these elements.

The application of a PMTS system can be analyzed in three steps;

1. Desing of the working system
    a. Planning of the operating process
    b. Optimization of the operationg process
    c. Design of tools and equipment
    d. Design of the manufacture
2. Time determination
    a. Formation of planned times
    b. Determination of standard time for performance-related renumeration
    c. Pre-costing
3. Work instruction

    Description of the operating processes for education and instruction materials

The history of PMTS development begins by Frederick Winslow Taylor in 90s. Fractionalization of tasks and measurement of subtracted times were performed by Taylor. Frank Bunker Gilbreth detected that human motions can be put down to seventeen fundemental motions – which he called as "Therbligs"- by dint of film shots in 1911. The proposals of the development of a system of pre-determined times are given by R. Thun in 1925. Work factor term was introduced in 1934 and MTM was introduced in 1940. At the end of 1940s work factor and MTM is published. In the next section the development of MTM-1 is given to explain PMTS in detail.

**4.2 Development of MTM-1**

For the development of MTM-1 motion sequences and their actuating variables in different working situations with different working persons by means of film shots are recorded. These film shots provided single pictures with a rate of 16 pictures per second. Then these pictures was enumerated to determine the actual times. *Lowry-Maynard-Stegemerten (LMS) method* was applied to compensate interpersonal performance variation. As a result MTM-1 metric cards are created.

In Lowry-Maynard-Stegemerten method, MTM standard performance value is defined as;

actual time according to video analysis / time recording · median LMS-performance level of the evaluation group = **MTM standard performance**

Here, the standard performance of 100% is described within the LMS method as "performance of a moderately high trained person who can show this performance in prepetuity without work fatigue."

Performance index according to LMS method is given in the figure 4.2.

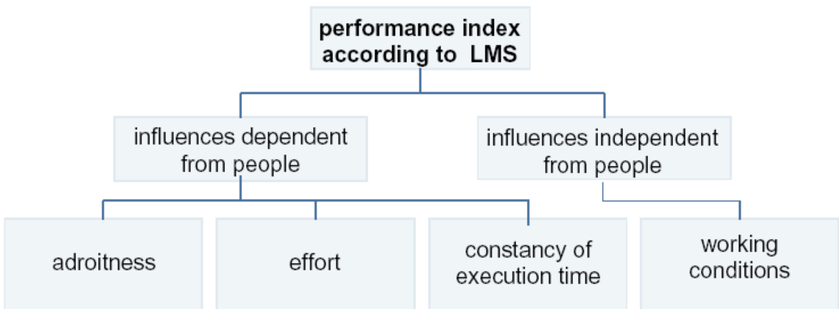



Figure 4.2 Performance Index according to LMS

As the result of the development, MTM-1 metric card is created. This card comprises the time values for fundamental motions subject to time actuating variables. Time values are stated as TMU (Time measurement unit).

1/100.000 h = 1 TMU

0,036 s = 1 TMU

MTM-1 system defines fundamental motions for four fundemental motion systems;

1) *Five fundamental motions of the finger-hand-arm system*

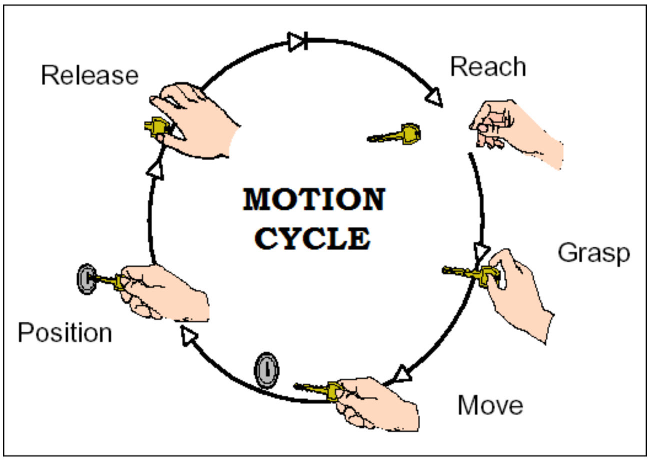



Figure 4.3 Five fundamental motions of the finger-hand-arm

2) *Three additional fundamental motions of the finger-hand-arm system*

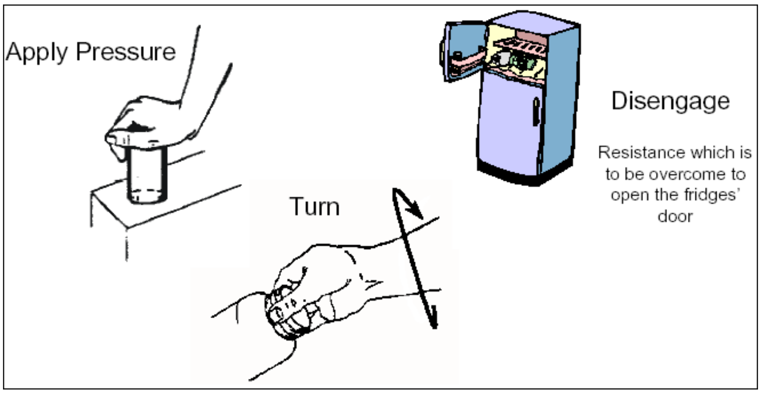



Figure 4.4 Three additional fundamental motions of the finger-hand-arm

3) *Two fundamental motions of the eyes*

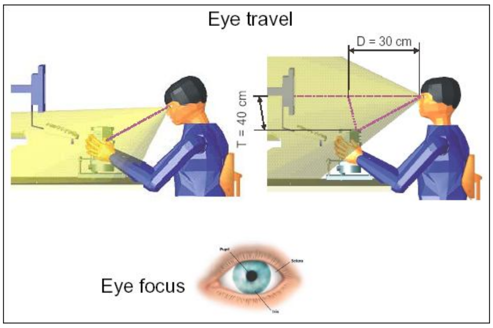



Figure 4.5 Two fundamental motions of the eyes

*4) Fifteen fundamental motions for body movements*

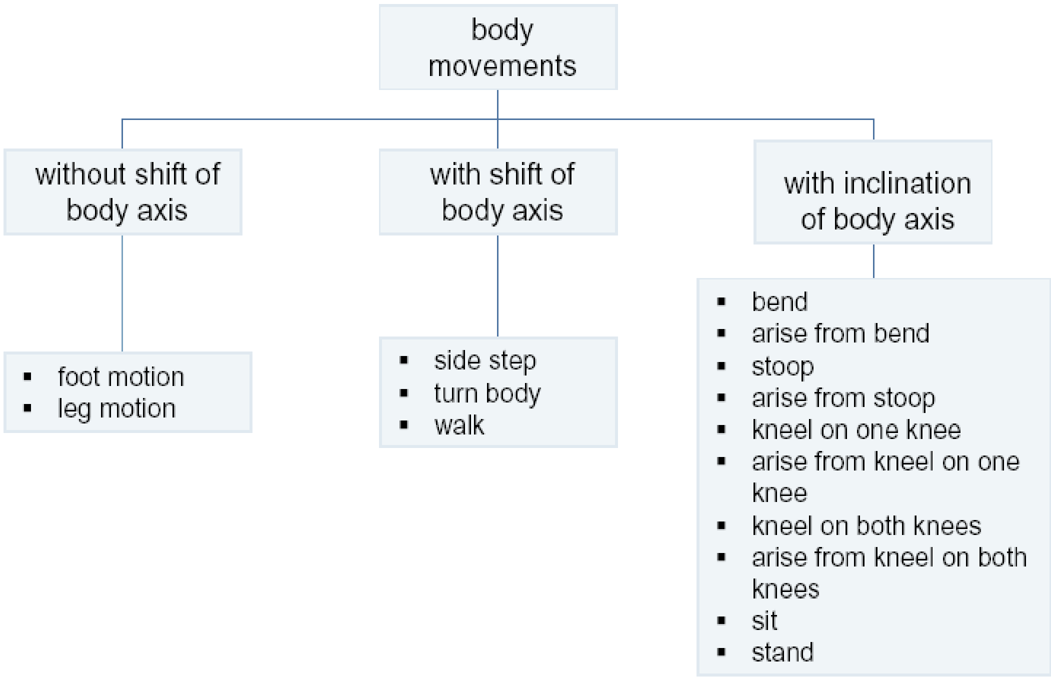



Figure 4.6 Fifteen fundamental motions for body movements

Example **Reach**

"Reach" is the fundamental movement to move a finger or hand to a determined or undetermined location. MTM-1 metric card contains the time values depending on the distance moved, case of motion, type of motion path. These are the time actuating variables of reach motion (see figure 4.7 and table 4.1)

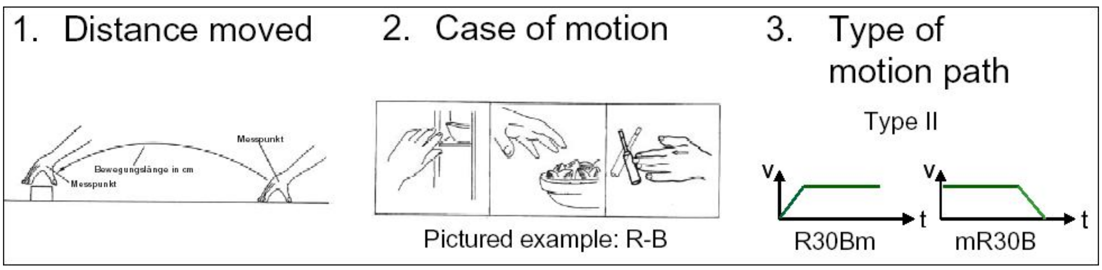



Figure 4.7 Time actuating variables of reach motion (MTM-German Manuals, 1998)

Table 4.1 Metric card data for reach motion (MTM-German Manuals, 1998)

| Distance moved in cm | Time TMU | | | | | | | Case and Description |
|---|---|---|---|---|---|---|---|---|
| | R-A | R-B | R-C R-D | R-E | mR-A R-Am | mR-B R-Bm | m-Wert für B | |
| **2 or less** | 2,0 | 2,0 | 2,0 | 2,0 | 1,6 | 1,6 | 0,4 | **A** Reach to object in fixed location, or to object in other hand or on which other hand rests. |
| **4** | 3,4 | 3,4 | 5,1 | 3,2 | 3,0 | 2,4 | 1,0 | |
| **6** | 4,5 | 4,5 | 6,5 | 4,4 | 3,9 | 3,1 | 1,4 | |
| **8** | 5,5 | 5,5 | 7,5 | 5,5 | 4,6 | 3,7 | 1,8 | |
| **10** | 6,1 | 6,3 | 8,4 | 6,8 | 4,9 | 4,3 | 2,0 | |
| **12** | 6,4 | 7,4 | 9,1 | 7,3 | 5,2 | 4,8 | 2,6 | **B** Reach to single object in location which may vary lightly from cycle to cycle. |
| **14** | 6,8 | 8,2 | 9,7 | 7,8 | 5,5 | 5,4 | 2,8 | |
| **16** | 7,1 | 8,8 | 10,3 | 8,2 | 5,8 | 5,9 | 2,9 | |
| **18** | 7,5 | 9,4 | 10,8 | 8,7 | 6,1 | 6,5 | 2,9 | |
| **20** | 7,8 | 10,0 | 11,4 | 9,2 | 6,5 | 7,1 | 2,9 | |
| **22** | 8,1 | 10,5 | 11,9 | 9,7 | 6,8 | 7,7 | 2,8 | **C** Reach to object jumbled with other objects in a group so that search and select occur. |
| **24** | 8,5 | 11,1 | 12,5 | 10,2 | 7,1 | 8,2 | 2,9 | |
| **26** | 8,8 | 11,7 | 13,0 | 10,7 | 7,4 | 8,8 | 2,9 | |
| **28** | 9,2 | 12,2 | 13,6 | 11,2 | 7,7 | 9,4 | 2,8 | |
| **30** | 9,5 | 12,8 | 14,1 | 11,7 | 8,0 | 9,9 | 2,9 | |
| **35** | 10,4 | 14,2 | 15,5 | 12,9 | 8,8 | 11,4 | 2,8 | **D** Reach to a very small object or where accurate grasp is required. |
| **40** | 11,3 | 15,6 | 16,8 | 14,1 | 9,6 | 12,8 | 2,8 | |
| **45** | 12,1 | 17,0 | 18,2 | 15,3 | 10,4 | 14,2 | 2,8 | |
| **50** | 13,0 | 18,4 | 19,6 | 16,5 | 11,2 | 15,7 | 2,7 | |
| **55** | 13,9 | 19,8 | 20,9 | 17,8 | 12,0 | 17,1 | 2,7 | **E** Reach to indefinite location to get hand in position for body balance or next motion or out of way. |
| **60** | 14,7 | 21,2 | 22,3 | 19,0 | 12,8 | 18,5 | 2,7 | |
| **65** | 15,6 | 22,6 | 23,6 | 20,2 | 13,5 | 19,9 | 2,7 | |
| **70** | 16,5 | 24,1 | 25,0 | 21,4 | 14,3 | 21,4 | 2,7 | |
| **75** | 17,3 | 25,5 | 26,4 | 22,6 | 15,1 | 22,8 | 2,7 | |
| **80** | 18,2 | 26,9 | 27,7 | 23,9 | 15,9 | 24,2 | 2,7 | |

In table 4.1 the TMU value according to reach distance versus case of reach is given. For example if the object to be reached is at 10 cm distance and is a single object then the TMU value is set by 6,3.

Example **Grasp**

"Grasp" is the fundamental motion which is accomplished to keep one or several times in check with fingers or hand, so that the following fundamental motion can be carried out. The time actuating variables for grasp motion are; mode of grasping, position of item, constitution of item. The MTM-1 metric card for grasp motion is given in table 4.2.

Table 4.2. Metric card data for grasp motion (MTM-German Manuals, 1998)

| Case | TMU | Description | |
|---|---|---|---|
| **G1A** | 2,0 | ***Pick Up Grasp:*** | Small, medium or large object by itself, easily grasped. |
| **G1B** | 3,5 | Very small object or object lying close against a flat surface. | |
| **G1C1** | 7,3 | > 12 mm Ø | Interference with grasp on bottom and one side of nearly cylindrical object. |
| **G1C2** | 8,7 | 6 bis 12 mm Ø | |
| **G1C3** | 10,8 | < 6 mm Ø | |
| **G2** | 5,6 | ***Regrasp.*** | |
| **G3** | 5,6 | ***Transfer Grasp.*** | |
| **G4A** | 7,3 | > 25x25x25 mm | ***Select grasp:*** Object jumbled with other objects so search and select occur. |
| **G4B** | 9,1 | 6x6x3 bis 25x25x25 mm | |
| **G4C** | 12,9 | < 6x6x3 mm | |
| **G5** | 0,0 | ***Contact, sliding or hook grasp.*** | |

Some measurement example for different grasp motion is given in figure 4.8.

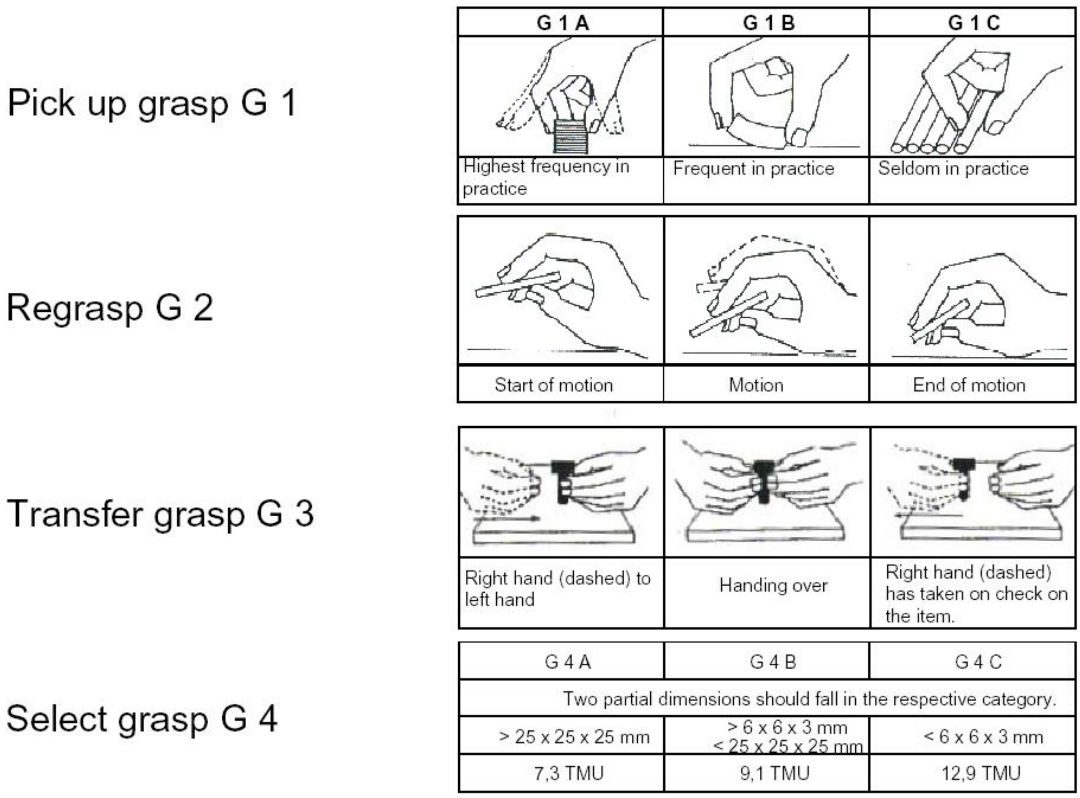



Figure 4.8 Some measurement example for different grasp motion (MTM-German Manuals, 1998)

**Application of MTM-1 on an example**

Application of MTM-1 begins with the segmentation of the motion sequence in elements as reaching, grasping etc. Then the time actuating variables for every single motion element, i.e. distance moved, or weight of item is determined. These motion elements and actuating variables are coded based on time cards. Using these cards the elementary motion times are extracted. As the last step, these elementary motion times are summed to obtain the basic motion time in demand.

In the table below, MTM-1 analyze is given for assembling a bolt.

Table 4.2 MTM-1 analyze for assembling a bolt (MTM-German Manuals, 1998)

| *Description of the motion sequence* | *Necessary information for the time allocation* | *Coding* | *Time Value* |
|---|---|---|---|
| **Reach** for bolt | • Distance moved: 40 cm<br>• bolt is mixed with others | **R 40 C** | **16,8 TMU** |
| **Grasp** at bolt | • admeasurements: ∅ 8 x 12 mm<br>• bolt is mixed with others | **G 4 B** | **9,1 TMU** |
| **Move** the bolt to apparatus | • Distance moved: 40 cm<br>• accuracy of placing: move object to exact location | **M 40 C** | **18,5 TMU** |
| **Position** the bolt to hole | • assembling tolerance: close<br>• symmetry: fully symmetric<br>• handling: easy | **P2SE** | **16,2 TMU** |
| **Release** of bolt | • opening the fingers | **RL 1** | **2,0 TMU** |
| ***Cumulative time need*** | | | ***62,6 TMU ≈ 2,25 s*** |

## 4.3 Possibilities and Limitations in the Application of MTM-1

Application of MTM-1 gives good results in;

- ✓ Mass production in large batches
- ✓ Limited model variety
- ✓ Short-cyclical workflows
- ✓ Exactly defined basic conditions

- ✓ Experienced, highly trained employees
- ✓ Detailed-oriented designed work stations

All these basic requirements are the consequences of the first method engineering systems at the beginning of the Industrial Revolution. Taylor segmented the work sequences into very little operations and assigned a worker for each of these simple operations. It was really a useful method since the demand was so high and the supply was so limited. The most important objective was producing as much and quick as possible. In those times there was no need to fight for product variations to attract the customers. These highly trained workers were performing very short-cyclical operations with perfect accuracy.

But as the number of producers increased the market started to change. The battle for demand arose. The demand-supply balance was changed to supply side. That means the suppliers had to affect the customers to get more market share or even preserve current share. Product life cycles started to shorten, product alternatives had to be increased, and necessity of producing in small batches became the most important objective to survive in the market due to the frequently-changing production requests.

These effects were analyzed in detail at the beginning of this report in which Lean Manufacturing principles are explained. These changes also affected the measurement systems. The creators of MTM system defined the requirements for the new analysis system. These requirements were;

- High analysis speed
- Sufficient accuracy of the time data
- Transparency and reproducibility of the time data

Their objective of this new system was the accommodation to the ***method level*** in the application areas of "single-part and small series production" and "series production". Here the term "method level" characterizes the quality of the work flow subject to the executer's skill, as well as the level of organization of the working system. The actuators of the method level can be depicted as in figure 4.9.

**4.4 The actuators of the method level and deciding the analysis system**

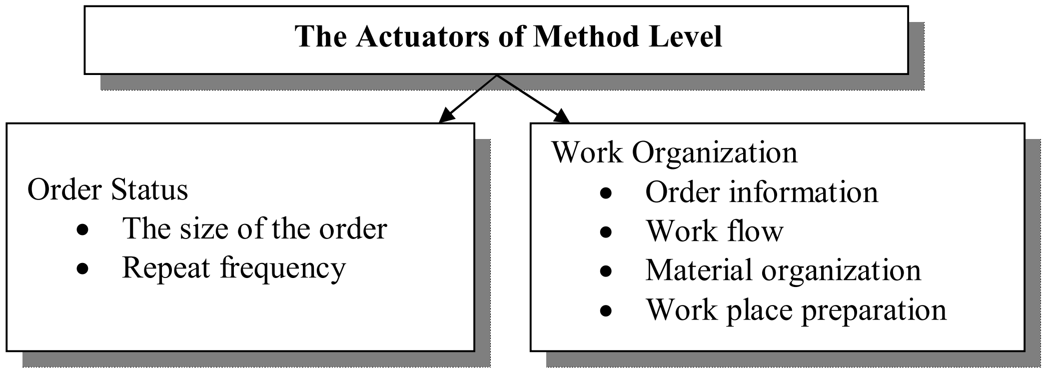



Figure 4.9 Actuators of the method level

The level of these actuators helps to choose the analysis system.

***4.4.1 Order Status***

Order status is related with the quantitative aspect of the production. It is based on the routine of the workers. The most important elements of order status are the lot size and the order repeat frequency.

Lot size is the average quantity of the products that a worker produces or assembles per month. Thus lot size effect is analyzed under two cases;

- Single-part small series production
- Series production

If;

[Repeat frequency of similar order in a month] x [Average lot size] > 200;

Then the production type is series production

If not;

Then the production type is single-part small series production

#### *4.4.2 Work Organization*

Work organization is related with the qualitative aspect of the production. The elements of work organizations are;

*4.4.2.1 Order Information*

*Fundamental Motion:* Detailed description of the fundamental motion elements

Reach / Grasp / Place

*Sequence of Motions:* The sequence of the fundamental motion elements

Reach (to the bolt) > Grasp (the bolt) > Move (the bolt to the die) > Place (the bolt to the die) > Release (the bolt to the die hole)

*Fundamental Operation:* The description of the limits of an operation

Mounting the bolts to the die

*Sequence of Operations:* The description of the operation sequences

Die mounting

*Work process:* The description of the whole production process

Changeover

*4.4.2.2 Work Flow*

*Short-cyclical / no change work flow:* Predefined, fixed repetitive motion elements with short cycle

*Short-cyclical / changing work flow:* Changing motion elements with short cycle

*Long-cyclical / less change work flow:* Little variations from cycle to cycle and with long cyclical motions

*Long-cyclical / more change work flow:* Big variations from cycle to cycle and with long cyclical motions

*Free to arrange work flow:* The flow changes during the cycle.

*4.4.2.3 Material Organization*

Material organization means the way of preparation the materials depending on the person who carries the material to the work area, or the person who takes the material to the work space.

*Bring Principle (Optimal):* The materials are carried to predefined use area. There is no function of the worker in material organization.

*Bring Principle:* The materials are carried from the common storage are to the workers working area by the worker himself.

*Take Principle:* The materials are placed to the predefined area in the production. The worker takes the materials depending on the production flow.

*Search Principle:* The materials are not placed to a predefined area. The worker searches the materials and takes to the working area.

*4.3.2.4 Work Place Organization*

*Special organization for a unique work flow:* Special elements, unique model

*Special organization for limited altered work flow:* Special elements, limited

*Standard work place organization:* Basic elements, provides limited variability

*Universal work place organization:* Multi-function elements, wide variety

*Free to arrange work place organizations:* No predefined element

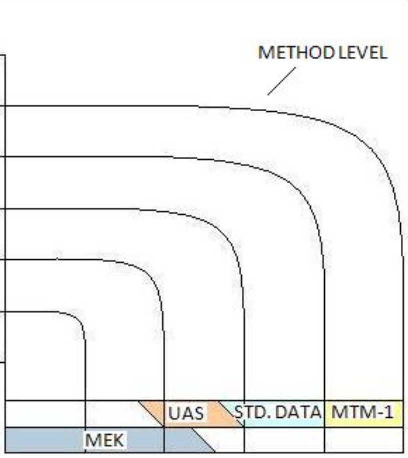
These arrangements are considered with the distance tolerance, which shows the certainty of the places of each apparatus, measurement tools and other equipments at the work place.

All these actuator of the method level is combined on table 4.3 and helps to decide which analysis system should be used.

Table 4.3 MTM system decision matrix (MTM-German Manuals, 1998)

| | WORK ORGANIZATION | | | | |
|---|---|---|---|---|---|
| | ORDER INFORMATION | WORK FLOW | MATERIAL ORGANIZATION | WORK PLACE ORGANIZATION | Distance Tolerance |
| 5 | Fundamental Motions | Short-cyclical no change | Bring Principle (optimal) | Special org. Unique workflow | < ±2,5 |
| 4 | Sequence of Motions | Short-cyclical changing | Bring Principle | Special org. Limited alter. Wf | < ±7,5 |
| 3 | Fundamental Operation | Long-cyclical less change | Taking Principle | Standard org | > ±7,5 |
| 2 | Sequence of Operations | Long-cyclical more change | Taking Principle (Include prep.) | Universal org | > ±7,5 |
| 1 | Work Process | Free to arrange | Search Principle | Free to arrange org | > ±7,5 |

| Production Type | Repeat frequency of similar order in a month x Average lot size |
|---|---|
| Series-mass production | >200 |
| Single-part small series | <200 |



Another way of showing the relationship between different MTM systems and the actuators is figured as in figure 4.10.

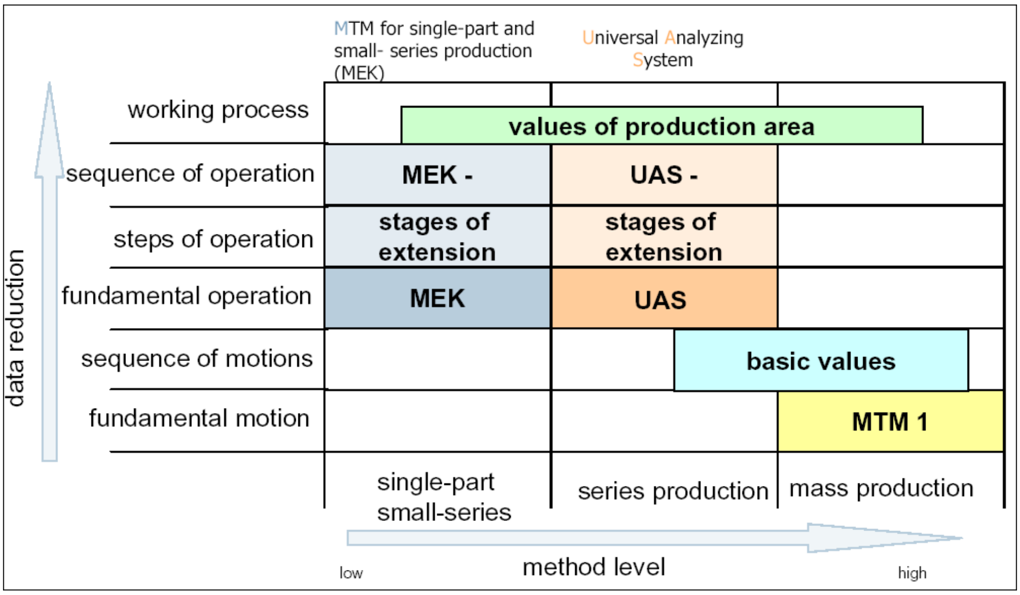



Figure 4.10 Relationship between different MTM systems and the actuators

Method level for single-part, small-series production is low relative to mass production. For mass production fundamental motions can be detected with high density of data collection which is compiled in MTM-1. As the new market forces the production environments from mass production to single-part production the method level begins to get lower thus the need for data reduction arises. Fundamental motions leaves their place to sequence of motions, then fundamental operations, steps of operations, sequence of operations and at last the working process which is the top level of data reduction for the availability to single-part production. This data reduction is exemplified in the figure 4.11.

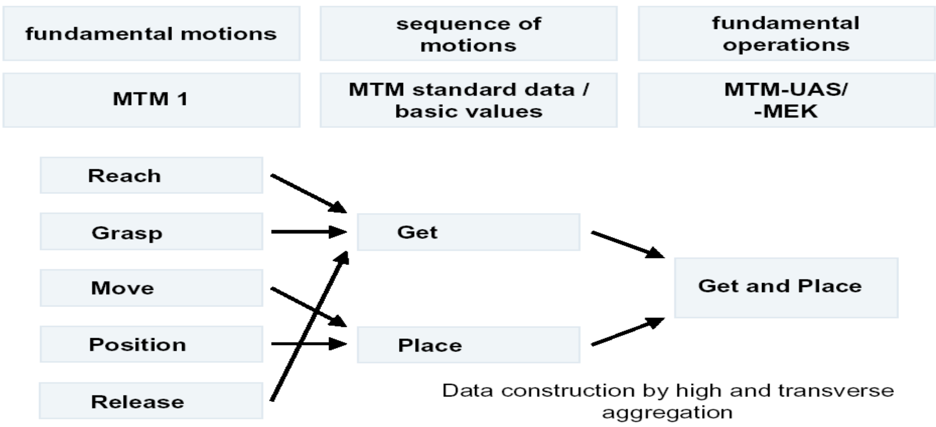



Figure 4.11 Data reduction for MTM systems

MTM-1, MTM standard data, MTM-UAS and MTM-MEK can also be organized as in figure 4.12 based on level of organization and the frequency of repetition of requests.

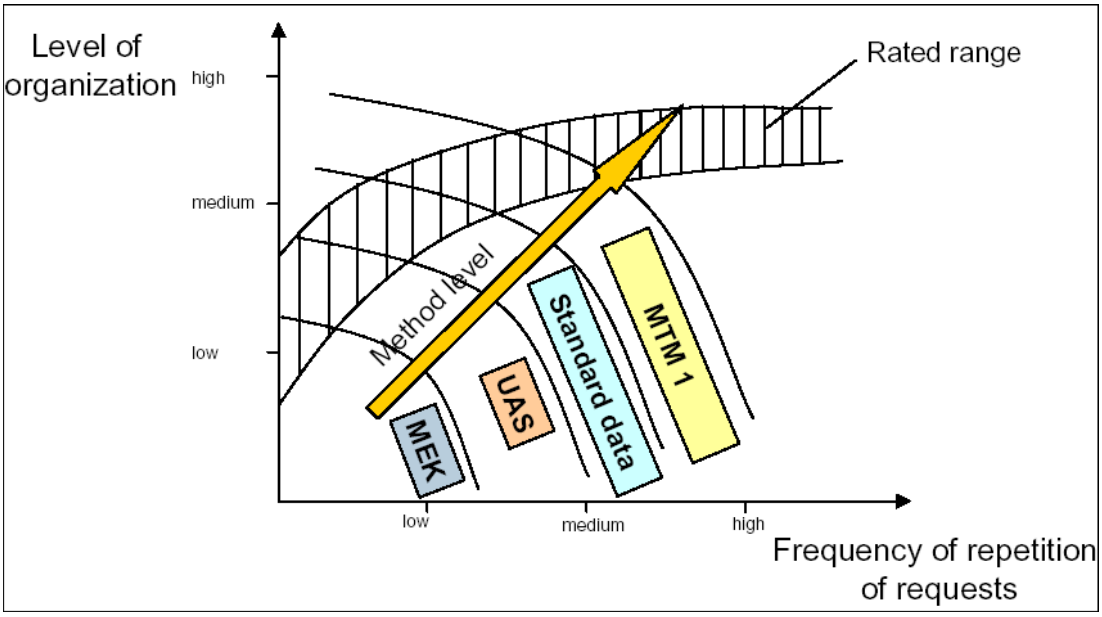



Figure 4.12 MTM systems in terms of level of organization and freq. of repetition (MTM-German Manuals, 1998)

The specialties of the actuators in system decision matrix and in other figures show that MTM-UAS is the most available method time measurement system for changeover operations. It would be very hard and unnecessary to analyze the setup operations by MTM-1 since the frequency of repetition of the motions (requests) are not enough and the level of organization is relatively low. Fundamental operation is best suited to describe the motions and the level of data reduction. The movements can be described within long cycle-middle change class. The working environment during changeover operation can be analyzed in universal organization and take principle is appropriate.

The details of MTM-UAS will be given in the following section and a case study will be reported using this new engineering technique.

# CHAPTER FIVE
# THE PRINCIPLES OF MTM-UAS APPLICATION

MTM-UAS is settled on 7 basic motions. Before the explanation of these motions the distance parameters are defined.

## 5.1 MTM-UAS Distance Parameters

There are three basic distance parameters used in MTM-UAS. These are;
Distance Parameter 1: ≤ 20 cm
Distance Parameter 2: >20 and ≤ 50 cm
Distance Parameter 2: >50 and ≤ 80 cm

## 5.2 Seven Basic Motions in MTM-UAS

### *5.2.1 Get and place (Symbol A)*

Description: Moving one or more object to a specified area via hands and/or fingers
Coding: Get & place symbol / placing status / distance parameter

***Scope of the motion***

Start: The motion starts with moving the hand through one or more object to get.
Scope: All finger, hand and arm actions which take time during the movement of one or more object to a specified area within 80 cm-distance.
End: The motion ends by releasing the objects.

***Description of the actuators:***

i) The weight of the object

a) ≤ 1 kg
b) > 1 kg and ≤ 8 kg
c) > 8 kg and ≤ 22 kg

ii) The size of the object

If one dimension of the object is more than 80 cm and the other two dimensions are more than 30x30 cm, the objects are regarded as “work compelling sizes” and handled in one level more difficult weight group. For example if one dimension of a Styrofoam is 85 cm and the weight is 0.6 kg, the weight class is rated in class b (> 1 kg and ≤ 8 kg)

iii) Status of get

a) Easy: Objects without anything nearby
b) Difficult: Objects mixed up with others
c) Handful: Objects collected together

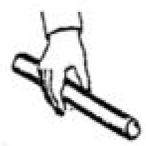
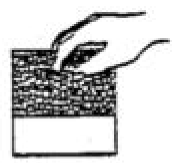
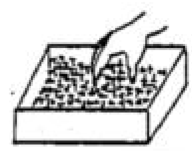
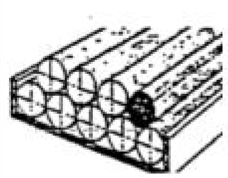
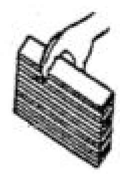
| Easy | Difficult | Handful |
|---|---|---|
| Objects without anything nearby | Objects mixed up with others | Objects collected together |
|  |  |  |
|  |  |  |

Figure 5.1 Status of get (MTM-UAS German Manuals, 1998)

iv) Status of place

- ❖ Example of approximate place is placing an object to a table.
- ❖ Example of loose place is placing a pin to the pin hole.
- ❖ Example of tight place is placing a key to key hole.

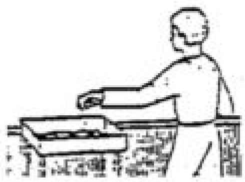
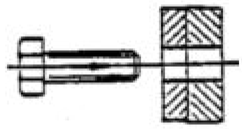
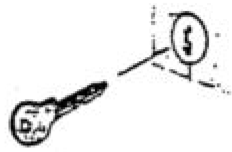
| | Approximate | Loose | Tight |
|---|---|---|---|
| |  |  |  |
| Telescope | Tolerance Limit<br>> 6 mm or lean | Tolerance Limit<br>≤ 6 mm without force | Tolerance Limit<br>≤ 6 mm with force |
| Adjoin | Tolerance Limit<br>> 6 mm | Tolerance Limit<br>> 1,5 ≤ 6 mm | Tolerance Limit<br>≤ 1,5 mm |

Figure 5.2 Status of place (MTM-UAS German Manuals, 1998)

In the table below the coding for, get & place motions using two hand is given.

Table 5.1 Get & place motions using two hand (MTM-UAS German Manuals, 1998)

| | | | ***Place*** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ***Approximate*** | | | ***Loose*** | | ***Tight*** |
| | ***Right Hand*** | ***Left Hand*** | ***App.*** | ***Loose*** | ***Tight*** | ***Loose*** | ***Tight*** | ***Tight*** |
| ***Get*** | *Easy* | *Easy* | AAX | ABX | ACX | ABX<br>AB1 | ACX<br>AB1 | ACX<br>AC1 |
| | *Easy* | *Easy* | ADX | AEX | AFX | AEX<br>AB1 | AFX<br>AB1 | AFX<br>AC1 |
| | *Difficult* | *Difficult* | ADX<br>AD1 | AD1 | AFX<br>AD1 | AEX<br>AE1 | AFX<br>AE1 | AFX<br>AF1 |
| | *Handful* | *Handful* | AGX<br>AG1 | | | | | |

***Application rules for get & place***

*Rule 1:* If there is a body motion between get and place motion, get and place is taken as one element. An additional place motion is not needed to analyze after that body motion.

*Example 1:* Getting an empty box from a 40 cm-height, walking 5 steps to work place and placing the box to a 45 cm-height. The coding is;

Get & place : AA2

Walking : KA 5x

*Rule 2:* If there is a solitary and defined work between get and place, an extra place motion is added.

*Example 2:* Getting a stand-alone object on a table (< 10N), taking to the sight area, checking the control label and placing back to the table. The coding is;

Get & place : AA2

Visual Control: VA

Place back : PA2

*Rule 3:* If the object requires more than one place motion, extra motions are added.

*Example 3:* A 1 meter-ruler is to be placed onto two points via two hands.

Get and place to point one : AK2

Place to point two : PC1

*Rule 4:* The bigger distance value of get or place is taken as the distance parameter.

*Rule 5:* If one dimension of the object is more than 80 cm and the other two dimensions are more than 30x30 cm, the objects are regarded as "work compelling sizes" and handled in one level more difficult weight group.

*Rule 6:* Placing more than one object after a handful get must be analyzed by extra motion element than AG.

<u>Rule 7:</u> The weight and the force value which define the weight class are independent from whether using one hand or two.

### *5.2.2 Place (Symbol P)*

<u>Description:</u> Placing one or more object which is currently taken under control to another place using fingers and/or hands.
<u>Coding:</u> Place symbol / placing status / distance parameter

***<u>Scope of the motion</u>***

<u>Start:</u> The motion starts with moving the hand which controls the object(s) to a defined area to place.
<u>Scope:</u> All finger, hand and arm actions which take time during the movement of one or more object which is currently under control to a specified area within 80 cm-distance.
<u>End:</u> The motion ends by releasing the objects.

***<u>Description of the actuators:</u>***

<u>i) Status of place</u>

Table 5.2 Status of place (MTM-UAS German Manuals, 1998)

| ***Place*** | ***Approximate*** | ***Loose*** | ***Tight*** |
|---|---|---|---|
| | ***Tolerance Limit*** | ***Tolerance Limit*** | ***Tolerance Limit*** |
| Telescope | > 6 mm or lean | ≤ 6 mm without force | ≤ 6 mm with force |
| Adjoin | > 6 mm | > 1,5 ≤ 6 mm | ≤ 1,5 mm |

- Example of approximate place is placing an object to a table.
- Example of loose place is placing a pin to the pin hole.
- Example of tight place is placing a key to key hole.

***<u>Application rule for place</u>***

<u>Rule:</u> The effect of object weight over the velocity of motion must be taken into consideration. (Follow up get & place data sheet)

### *5.2.3 Using handle tool – get & place and place aside (Symbol H)*

Description: One or more handle tool is got with fingers and hands, and used at the work area and placed back to their specified areas.

Coding: Handle tool symbol / placing status / distance parameter

***Scope of the motion***

Start: The motion starts with moving the hand through the tool.

Scope: All finger, hand and arm actions which take time during the movement of taking the tools under control via fingers and hands, using the tools, and placing the tools back within 80 cm-area. The time during hammering is not in scope of this motion.

End: The motion ends by placing the tools back.

***Description of the actuators:***

i) Status of handle tool

The same tolerance limits are used for handle tool with get and place.

***Application rules for handle tool***

*Rule 1:* The time values which are directly defined by the motions of the tool is given in data cards.

*Example 1:* Open-close of scissors.

*Rule 2:* Placing the tool to another place is analyzed by place motion.

*Example 2:* Getting screwdriver, placing onto the screw, turning the screw, placing the screwdriver onto the second screw over 10 cm height, screwing the second one and place the screwdriver back. The coding is;

| | |
|---|---|
| Get the screwdriver, place onto the screw and place back | : HC2 |
| Screwing the first screw | : Z?? |
| Placing on the second screw | : PC1 |
| Screwing the second screw | : Z?? |

*Rule 3:* If the handle tool is released when it is to be placed back to accomplish another motion the work flow is analyzed twice AXX (without using the handle tool)
*Example 3:* A water gauge is to be placed on an object, then the object is to be moved to get the balance and the water gauge is to be re-placed on the object to check whether it is ok or not. The coding is;

| | |
|---|---|
| Water gauge onto the object | : AA2 |
| Arrange the object | : PA1 |
| Water gauge onto the object | : AA2 |

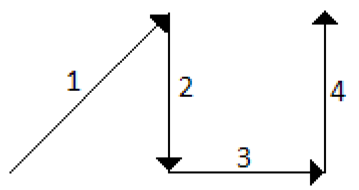
### *5.2.4 Operate (Symbol B)*

*Description:* Operation parts on a machine are gotten under control by hand or foot, a simple or simplified motion is performed to operate the machine. These operation parts on the equipments, machines, and tools are buttons, cranks, wheels, or tightener screws.
*Coding:* Operate Symbol / way of operation / distance parameter

**_Scope of the motion_**

*Start:* The motion starts with moving the hand or foot through the operation part.
*Scope:* All finger, hand, arm and foot actions to control the operation part and to perform one simple or a combination of simplified actions within 80 cm distance.
*End:* The motion ends by arranging the operation part and releases it.
*Example:* A drilling operation by a drill (BB3)

1 Hand to the drill cranck
2 The time to move drill bit to the part
3 Drilling time (PT)
4 Drill crank back (included in BB3)



***Description of the actuators:***

i) Status of operate

The number of required basic motions is described by this actuator. So, one simple operation and a combined-simplified operation are distinguished.

*Example:* A simple operation (BA)
Direct motion of an operation part
Turning a wheel by one turn
*Example:* Combined operation (BB)
Turning a wheel by one turn and arranging according to a scale
To change down the gear of a car
Back and forth motion of a bolt

***Application rules for operate***

*Rule 1:* The distance to the operation part is used to define the distance parameter.

*Rule 2:* Elements for operate motion contains only simple or combined-simplified motions. Other operations are handled in "motion cycles".

### *5.2.5 Motion Cycles (Symbol Z)*

*Description:* If an operation is performed continuously by fingers, hand and/or foot, this motion is analyzed as motion cycle.
*Coding:* Motion cycle symbol / way of motion cycle / distance parameter

***Scope of the motion***

*Start:* The motion starts with the first motion of the continuous motion cycle.
*Scope:* All finger, hand, arm and foot actions for a continuous motion(s).
*End:* The motion ends with the end of the last motion of the continuous motion cycle.

***Description of the actuators:***

i) Status of motion cycle

The number of required basic motions in a cycle is defined.

***One motion*** (ZA)

*Example:* Turning a wheel

***Back to back motions*** (ZB)

*Example:* Dual-piston motions

- Each motion of a manual screwdriver
- Rotating a step-switch
- Motion of hammer, scissor, file and windlass

***Rotation and one motion*** (ZC)

Piston motion with exact placing

*Example:* Placing a five headed-turn screw and screwing operation

***Fastening or loosening*** (ZD)

Applying pressure without placing.

*Example:* Hastening a screw after screwing.

***Application rules for operate***

*Rule 1:* The distance to the operation part is used to define the distance parameter.

*Rule 2:* The distance that hand or arm takes during a crank rotation determines the distance parameter instead of the radius of the crank.

*Rule 3:* Writing numbers, letters or drawing is analyzed by 2 ZBX for each.

***5.2.6 Body motions (Symbol K)***

*Description:* All the actions of foot and body that affect the time.

*Coding:* Body motion symbol / status of body motion

**a) *Walk*** (KA)

Walking one or more step and changing the body axis (front, back, sides, rotate)

***Scope of the motion***

*Start:* Walking over distance of 80 cm.

*Scope:* Stepping to walk over 80 cm.

*End:* The motion ends with reaching the target.

***Application rules for walk***

*Rule 1:* Each meter is analyzed by one KA.

*Rule 2:* If the body rotation angle exceeds 90 degree then the motion is analyzed by KA and one frequency.

*Example:* Body rotation (180 degree): KA 1x

Walking 2 meters : KA 2x

*Rule 3:* Ascend a stair is analyzed by KA and one frequency. (Assumed as level path)

**b) *Bend, stoop, kneel including arise*** (KB)

***Scope of the motion***

*Start:* Bending down of the body.

*Scope:* All body motions to bring down the hands at least to the level of knees.

*End:* Stand up.

***Application rule for bend, stoop, kneel including arise***

*Rule:* Kneeling on two knees and standing up is analyzed by KB and frequency parameter of two.

**c) *Sit and Stand*** (KC)

***<u>Scope of the motion</u>***

<u>*Start:*</u> Folding the knees to prepare for sit.

<u>*Scope:*</u> All body motions to arrange the place to sit, sitting, leaning back, preparation to stand, throw the body upright and pushing the chair to stand up.

<u>*End:*</u> Stand up.

***<u>Application rule for sit and stand</u>***

<u>*Rule:*</u> Sitting and standing up to/from the place of sit is analyzed KC and frequency parameter of two.

### *5.2.7 Visual Control (Symbol VA)*

<u>*Description:*</u> Checking an object to decide

<u>*Coding:*</u> Visual control symbol

***<u>Scope of the motion</u>***

<u>*Start:*</u> Looking at an object after a work is done or in the middle of a work

<u>*Scope:*</u> Turning the eyes to the object, making the decision (yes or no) and turning the eyes to the original position

<u>*End:*</u> The eyes are at their original position and the decision has already been made.

***<u>Description of the actuators:</u>***

<u>i) Status visual control</u>

Visual control is analyzed only if it takes time. Looking at the welding area, looking at the numbers or characters, or controlling the color of an object i.e.

***<u>Application rules for visual control</u>***

<u>*Rule 1:*</u> Visual control is analyzed only if it can be a unique motion.

# CHAPTER SIX
# IMPLEMENTATION OF NEW ANALYSIS SYSTEM

In this section, the steps of the new methodology introduced by Cakmakci and Karasu, (2006) will be exemplified step by step. The SMED steps are added to the figure 6.1 and given below. The changeover process under analysis is observed in a metal forming factory.

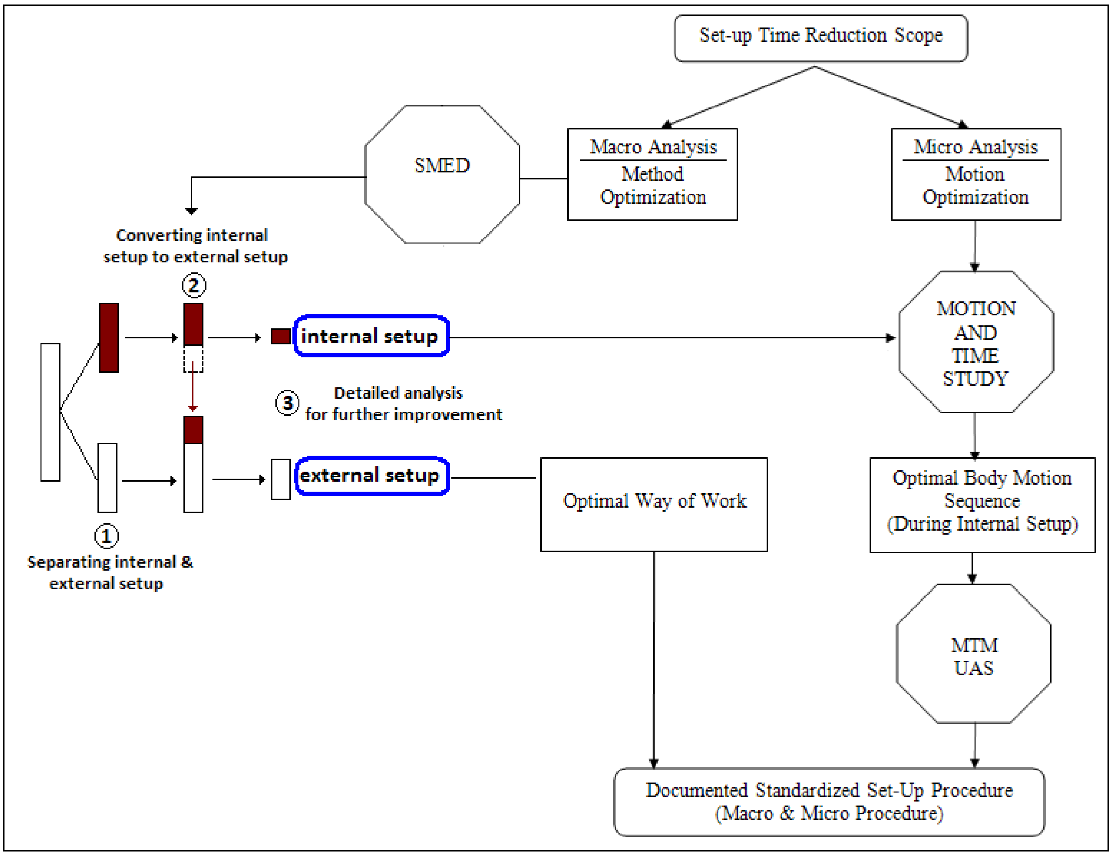



Figure 6.1 SMED steps added to macro and micro analysis (Cakmakci & Karasu, 2006)

## 6.1 First Step (Macro Analysis – Using SMED)

As the first stage of this first step internal and external setup operations are separated. The consequences of this first stage are;

- ✓ The changeover team is defined,
- ✓ The tools and equipments required for changeover are defined,
- ✓ These equipments are controlled whether they operate properly or not.

- ✓ Current die transportation method is changed. With the new method the new die are brought nearby the machine before the machine is stopped. Removed die is carried back to the die store after the machine is started to produce the new model.

With the second stage of the first step internal setup operations are tried to be converted to external setup operations. The operation conditions are prepared in advance. These attempt results in as;

- ✓ All the equipments, tools required for changeover are located in a portable changeover holder and are get ready before the machine is stopped for setup.
- ✓ The heights of the dies are standardized.
- ✓ The clamping devices are standardized.
- ✓ Die cassette system is used.
- ✓ Stopper studs are located on the stamping platform to make the centering easier and more accurate.

At the last stage of the first step internal & external operations are examined to find further improvements. The results for external operations are;

- ✓ Die storage area is re-designed to locate the most frequently used dies nearer to the production floor.
- ✓ Numerical and color coding is used to find the required die easily.
- ✓ A special transporter is used to take the heavy dies from the storage racks and to place the die onto the stamping platform safely.

After further examination of the internal operations;

- ✓ Two operators are assigned for each changeover operations; one is in front of the machine and the other at the back to make the setup 50% fast.
- ✓ Special fasteners are used instead of bolts. (with hydraulic fastening pistols)
- ✓ Adjustment parameters are defined and written documents are attached to the machines. These parameters are; the chap gaps and the exact coordinates of the stopper studs. So the first correct product from the new model can be produced in the first run and no need for extra adjustment.

## 6.2 The Resulting Macro Procedure After Step 1 / Optimal Way of Work

1) *Inform the die storage personal about the changeover operation 25 minutes before the machine is stopped for changeover. Use factory intranet-provide required information;*
    ***a.*** *The code of the current die*
    ***b.*** *The code of the die to be mounted for the next model production*
2) *Die storage personal arranges the special die transporter according to the information from changeover team*
3) *Die transporter gets the new die from the racks and carries to the die dock nearby the machine*
4) *Die transporter places the new die onto the dock platform*
5) *The machine is stopped for changeover*
6) *Die transporter gets the current die out of the machine and places down on the floor*
7) *Die transporter gets the new die from the dock platform*
8) *Die transporter places into the machine*
9) *Die transporter gets the old die and carries back to the die storage are while the internal setup starts*
10) *The machine is started after the internal operation is finished.*

## 6.3 Second Step (Micro Analysis - Using MTM UAS)

After the improvements in internal and external setup operations, internal operation are further analyzed to define the optimal body motion during the machine is stopped. The results of the first step provide the input for the second step.

- ✓ In the first step a portable holder is used to hold the changeover equipments and tools. In this step, the number of this holder duplicated for each operator.
- ✓ The best motion sequence for each operator is defined to complete the changeover operation safely, accurately and speedily. This sequence and regarding MTM-UAS analysis is given below. (Operator 1 is ready in front of the machine and operator 2 is ready at the back of the machine.)

## 6.4 The Resulting Micro Procedure After Step 2 / Optimal Body Motions via MTM

Table 6.1 MTM analysis

| Operator 1 | Code | TMU | F | Operator 2 | Code | TMU | F | MAX TOTAL |
|---|---|---|---|---|---|---|---|---|
| ***Stop the machine*** | BA2 | 25 | 1 | ***Wait*** | - | 0 | - | 25 |
| ***Visual Control*** | VA | 15 | 1 | ***Visual Control*** | VA | 15 | 1 | 15 |
| ***Turn to the equipment holder get the hydraulic pistol to unfasten the front clamps (2) and unfasten the clamps, place the pistol back to the equipment holder and clamps to clamp holder*** | KA | 25 | 1 | ***Turn to the equipment holder get the hydraulic pistol to unfasten the front clamps (2) and unfasten the clamps, place the pistol back to the equipment holder and clamps to clamp holder*** | KA | 25 | 1 | 25 |
| | AC2 | 55 | 1 | | AC2 | 55 | 1 | 55 |
| | HC2 | 70 | 1 | | HC2 | 70 | 1 | 70 |
| | PTC | 120 | 1 | | PTC | 120 | 1 | 120 |
| | PC1 | 30 | 1 | | PC1 | 30 | 1 | 30 |
| | PTC | 120 | 1 | | PTC | 120 | 1 | 120 |
| | KA | 25 | 1 | | KA | 25 | 1 | 25 |
| | PA2 | 20 | 1 | | PA2 | 20 | 1 | 20 |
| | KA | 25 | 1 | | KA | 25 | 1 | 25 |
| | AA1 | 20 | 2 | | AA1 | 20 | 2 | 40 |
| ***Give signal to op.2 to indicate it is OK*** | PTB | 50 | 1 | ***Give signal to op.1 to indicate it is OK*** | PTB | 50 | 1 | 50 |
| | VA | 15 | 1 | | VA | 15 | 1 | 15 |
| ***Open the chaps to the pre-defined gap using the pneumatic system*** | BA3 | 40 | 1 | ***Wait*** | | 0 | - | 40 |
| | PTC | 250 | 1 | ***Wait*** | - | 0 | - | 250 |
| ***Get the stopper studs and place onto the machine to center the die*** | AB3 | 60 | 2 | ***Wait*** | - | 0 | - | 120 |
| ***Give signal to op.1*** | PTB | 50 | 1 | ***Give signal to transporter*** | PTB | 50 | 1 | 50 |
| | VA | 15 | 1 | | VA | 15 | 1 | 15 |
| ***Special transporter get the die out and place the new one: Operators wait: 25000*** | | | | | | | | *25.000* |
| ***Remove the stopper studs*** | AA3 | 50 | 2 | ***Wait*** | - | 0 | - | 100 |
| ***Close the chaps using the pneumatic system*** | BA3 | 40 | 1 | ***Wait*** | | 0 | - | 40 |
| | PTC | 250 | 1 | ***Wait*** | - | 0 | - | 250 |
| ***Get and place the clamps to fasten*** | AC3 | 70 | 2 | ***Get and place the clamps to fasten*** | AC3 | 70 | 2 | 140 |
| ***Turn to the equipment holder get the hydraulic pistol to fasten the front clamps (2) and fasten the clamps, place the pistol back to the equipment holder*** | KA | 25 | 1 | ***Turn to the equipment holder get the hydraulic pistol to fasten the front clamps (2) and fasten the clamps, place the pistol back to the equipment holder*** | KA | 25 | 1 | 25 |
| | AC2 | 55 | 1 | | AC2 | 55 | 1 | 55 |
| | HC2 | 70 | 1 | | HC2 | 70 | 1 | 70 |
| | PTC | 120 | 1 | | PTC | 120 | 1 | 120 |
| | PC1 | 30 | 1 | | PC1 | 30 | 1 | 30 |
| | PTC | 120 | 1 | | PTC | 120 | 1 | 120 |
| | KA | 25 | 1 | | KA | 25 | 1 | 25 |
| | PA2 | 20 | 1 | | PA2 | 20 | 1 | 20 |
| | KA | 25 | 1 | | KA | 25 | 1 | 25 |
| ***Give signal to op.2 to indicate it is OK*** | PTB | 50 | 1 | ***Give signal to op.1 to indicate it is OK*** | PTB | 50 | 1 | 50 |
| | VA | 15 | 1 | | VA | 15 | 1 | 15 |
| ***Start the machine*** | BA2 | 25 | 1 | ***Wait*** | - | 0 | - | 25 |
| TOTAL (in terms of TMU) | | | | | | | | **27.220** |
| TOTAL (in terms of minute) | | | | | | | | **16,332** |

# CHAPTER SEVEN
# CONCLUSIONS

In this study a very important milestone of lean manufacturing; SMED is reviewed from method engineering perspective. Shingo's methodology is re-handled under macro and micro analysis to define not only the optimal way of work but also the optimum body motions during internal changeover operations to stabilize and optimize the process. What we got from this study is the optimized procedures for changeover operations which are prepared after very detailed discussions. Here MTM-UAS system is chosen for the analysis method for body motions during changeover.

MTM systems are becoming more popular in the world. German MTM team has been developing various MTM-Systems for different needs. For healthcare activities MTM-HC, for clerical activities MTM-C, for electronic tests MTM-TE and for the operations performed under microscopes MTM-M (www.mtm.org).

Like these examples this study proposes a new MTM system for changeover operations which uses the advantage of SMED and pre-defined and pre-measurable motion study techniques. Also the results of this new approach provide the firms the best way of changeover. Documented procedures make the rules and the successes sustainable.

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