# EXPERIMENT - 1

**Stop Watch Time Study Method:**

**4.2.1 Meaning of Time Study:**

Time study is the technique of establishing an allowed time standard to perform a given task, based upon measurement of work content of the prescribed method, with due allowance for fatigue and personal and unavoidable delays[1]. ILO defines time study as a work measurement technique for recording the times and rates of working for the elements of specified job carried out under specified conditions, and for analyzing the data so as to obtain the time necessary for carrying out the job at a defined level of performance[2]. According to Meyers (2002)[3], time standards can be defined as “the time required to produce a product at a work station with the three conditions: (1) a qualified, well-trained operator, (2) working at a normal pace, and (3) doing a specific task."

**4.2.2 Time Study Techniques/Types:**

Time study is usually referred to as work measurement and it involves the technique of establishing an allowed time standard to perform a given task, based on measurement of the work content of the prescribed method and with due allowance for fatigue, personal or unavoidable delays. Establishes time values are a step in systematic procedure of developing new work centers and improving methods in existing work centers. Chart 4.1 presents time study techniques.

**Chart 4.1 Time Study Techniques by Source**

| Sr.No | Source | Time Study Techniques |
|---|---|---|
| 1 | Barnes, (1980) | • Standard Data<br>• Work Sampling<br>• Predetermined Time Standard System (PTS)<br>• Stopwatch Time Study |
| 2 | Niebel, (1993) | • Stopwatch Time Study<br>• Computerized Data Collection<br>• Standard Data<br>• Fundamental Motion Data<br>• Work Sampling and Historical Data |
| 3 | Lawrences, (2000) | • Time Study<br>• Standard Data Systems<br>• Predetermined Time Systems (PTS)<br>• Work Sampling<br>• Physiological Work Measurement<br>• Labor Reporting |
| 4 | Meyers and Stewart, (2002) | • Predetermined Time Standard System(PTSS)<br>• Stopwatch Time Study<br>• Work Sampling<br>• Standard Data<br>• Expert Opinion and Historical Data |
| 5 | Niebel and Freivalds, (2003) | • Time Study<br>• Standard Data and Formulas<br>• Predetermine Time Systems<br>• Work Sampling<br>• Indirect and Expense Labor Standards |

*Source: Nor Diana Hashim, 'Time Study Method Implementation in Manufacturing Industry', A B.E Report, Universiti Technikal Malaysia, Melaka, 2008, P.10.*

To do time study various experts provided with the various techniques of time study which are summarized in chart 4.1. The time technique is discussed by five different sources. Most of the technique had a same method but differ by name. The detail descriptions on the techniques are shown as below:

### 4.2.3 Stopwatch Time Study Method:

Work study is divided in two groups in order to gain higher productivity. First group is a group of method studies which are used to simplify the job and develop more ergonomic methods of doing it. Second group is a group of work measurements which are used to find the time required to carry out the operation at a defined level of activity (Russell, Taylor, 2005a)[4].

Stopwatch time study measures how long it takes an average worker to complete a task at a normal pace. A "normal" operator is defined as a qualified, thoroughly experienced operator who is working under conditions as they customarily prevail at the work station, at a pace that is neither fast nor slow, but representative of an average. The actual time taken by the above-average operation must be increased, and the time taken by the below-average must be reduced to the value representative of normal performance. Performance rating is a technique for equitably determining the time required to perform a task by the normal operator after the observed values of the operation under study have been recorded (Nakayama, 2002)[5]. Hence, when a work is measured with the stop watch device it is known as stop watch time study method. Stop watch time study method is a technique of establishing an allowed time standard to perform a given task with the help of stop watch along with due allowance. When a stop watch is used as a work measurement technique to record times and rates of working for the element of specified job carried out under specified conditions and for analyzing the data so as to obtain the time necessary to carry a specified job at specified level of performance is referred to as stop watch time study method.

Frederick W. Taylor started to develop time study in 1881 when he started measuring time at a machine shop at home with stopwatch and clipboard. That was the beginning of time study. Even Taylor used stopwatch, as basic tool for recording time, present tools hasn‟t changed much. Today besides standard tools of time study, stopwatch and clipboard, we use digital stopwatches, computers, barcodes and accustudy software (Izetbegovic, 2007)[6].

**4.2.3.1 Evolution of Stop Watch Time Study Method:**

The Chart 4.2 showed the major evolution milestone of time study in the industry. This is given according to year and the person that contribute to the evolution of the time study technique.

## Chart 4.2

## Major Evolution Milestones of Time Study

| Sr.No | Year | Person | Contribution |
|---|---|---|---|
| 1 | 1760 | Jean Rodolphe Perronet- French engineer | Extensive time studies on the manufacture of No. 6 common pins and arrived at a standard of 494 per hour (2.0243 hrs/1000). |
| 2 | 1820 | Charles W. Babbage- an English economist | Conducted time studies on manufacture of No. 11 common pins. It has determined that one pound (5,546 pins) should be produced in 7, 6892 hours (1.3864 hrs. /1000). |
| 3 | 1856-1915 | Frederick W Taylor | The first person to use a stopwatch to study work content and as such is called the father of time study. He accomplishes the four Principles of Scientific Management. Responsible for the following innovations stopwatch time study, high-speed steel tools, tool grinders, slide riles and functional-type organization. He emphasized the analytical and organizational aspect of work. |
| 4 | 1853-1931 | Harrington Emerson | He was the expert that was needed to make Scientific Management, the Taylor system, a household name and his experience proved that the use of efficient methods would lead to tremendous savings. Accounts of his work were never extensively published and no comprehensive biography exists but his work is best remembered as an example of how the creative engineer can find the tools to improve any operation. |
| 5 | 1861-1919 | Henry Laurence Gantt | He invented the task and bonus system or earned-hour plan. He also developed a technique for scheduling work and performance control system. Rather than penalizing the less proficient worker, he advocated a livable wage with a sizable bonus for performance over 100 percents. He also designed the antisubmarine tactics known as convoy zigzagging that permitted escort ships to protect the slow freighters. |
| 6 | 1868-1924 and 18781972 | Frank and Lilian Gilbreth | Develop method study technique like cyclograph, chronocyclographs, movie cameras, motion picture camera and a special clock called a microchronometer. They also study fatigue, monotony, transfer of skills and assisted the handicapped in becoming more mobile. Their systematic study of motion reduced costs greatly and founded a new profession of method analysis. The Gilbreths also developed flow diagrams, process chart, and operation chart. Also the apprentice on the 17 elementary subdivisions of motion, later engineers coined a short word therblig. |
| 7 | 1900-1984 | Ralph M. Barnes | His achievements included writing the longest published text on work measurement, a through description of the Gilbreths micro motion study, time study and the procedure for work sampling. |
| 8 | 1993-2003 | Niebel, Lawrences, Meyers and Stewart, Niebel and Freivalds | Their contribution includes Stopwatch time study, Computerized data collection, Standard data, PTS, Work Sampling, Physiological work measurement, Expert opinion and Historical data and Labour Reporting. |

*Source: Nor Diana Hashim, 'Time Study Method Implementation in Manufacturing Industry', A B.E Report, Universiti Technikal Malaysia, Melaka, 2008,P. 5-6.*

#### 4.2.3.2 Importance and Uses of Stop Watch Time Study:

Generally this technique is used to determine the time required by a qualified and well trained person working at a normal pace to do a specified task. The result of time study is the time that a person suited to the job and fully trained in the specific method. The job needs to be performed if he or she works at a normal or standard tempo. This time is called the standard time for operation. This means the principle objectives of stop watch time study are to increase productivity and product reliability and lower unit cost, thus allowing more quality goods or services to be produced for more people. The importance and uses of stop watch time study can be stated as under:

(i) Determining schedules and planning work

(ii) Determining standard costs and as an aid in preparing budgets

(iii) Estimating the costs of a product before manufacturing it. Such information is of value in preparing bids and determining selling price.

(iv) Determining machine effectiveness, the number of machines which one person can operate, and as an aid in balancing assembly lines and work done on a conveyor.

(v) Determining time standards to be used as a basis for labor cost control.

(vi) Helps to know the Labour productivity, Labour efficiency, Labour Performance and overall time required to perform the task.

(vii) Helps to improve the process of operation.

#### 4.2.3.3 Procedure for conducting stop watch time study:

Generally, the following procedure is followed in conducting stop watch time study:

**1. Selection of task to be timed:**

Select the task or job that needs to be timed for study purpose. There are various priorities on the basis of which task or job to be studied is selected such as bottleneck or repetitive jobs, jobs with longer cycle time, to check correctness of existing time, comparison of two methods etc.

**2. Standardize the Method of Working:**

To achieve performance standard accuracy it is necessary to record the correct method of working.

**3. Select the operator for study:**

Select the consistent worker whose performance should be average or close to average so that observed times are close to normal times.

**4. Record the details:**

The following information is recorded on observation sheet: Name of labour, task/job performed, department, section of work activity, general information about activity performed etc.

**5. Break the task into element:**

Each operation is divided into a number of elements. This is done for easy observation and accurate measurement.

**6. Determine number of cycles to be measured:**

It is important to determine and measure the number of cycles that needs to be observed to arrive at accurate average time. A guide for the number of cycles to be timed based on total number of minutes per cycle is shown below in Chart 4.3.

**Chart 4.3**

**Number of recommended cycles for time study**

| Minutes Per Cycle | To 0.10 | To 0.25 | To 0.50 | To 0.75 | To 1.0 | To 2.0 | To 5.0 | To 10.0 | To 20.0 | To 40.0 | Over 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Cycles Recommended | 200 | 100 | 60 | 40 | 30 | 20 | 15 | 10 | 8 | 5 | 3 |

*Source: A.E.Shaw:"stopwatch time study", in H.B.Maynard (ed): Industrial Engineering Handbook, op.cit.Reproduced by kindpermission of the McGraw Hill Book Company.*

**7. Measure the time of each element using stop watch:**

The time taken for each element is measured using a stop watch. There are two methods of measuring. *viz*., Fly back method and Cumulative method. The time measured from the stop watch is known as observed time.

**8. Determine standard rating:**

Rating is the measure of efficiency of a worker. The operator„s rating is found out by comparing his speed of work with standard performance. The rating of an operator is decided by the work study man in consultation with the supervisor. Various rating methods used are speed rating, synthetic rating and objective rating.

**9. Calculate the Normal time:**

The observed time cannot be the actual time required to perform the work for a worker. Therefore, Normal time needs to be calculated. Normal time is the time that a worker takes when working at normal pace. It is calculated as below:

**Normal Time = Observed time * Rating**

**10. Determine the allowance:**

A worker cannot work all the day continuously. He will require time for rest going for toilet, drinking water etc. Unavoidable delays may occur because of tool breakage etc. So some extra time is added to the normal time. The extra time is known as allowance. It is generally allotted as per the company policy.

**11. Determine the standard time:**

The standard time is the sum of Normal time and allowances. Thus it is calculated as below:

**Standard Time = Normal Time + Allowances**

### 4.2.3.4 Methods of timing using Stopwatch:

There are two methods of timing using a stop watch. They are: Fly back or Snap back method and Continuous or Cumulative method.

**1. Fly back Method:**

Here the stop watch is started at the beginning of the first element. At the end of the element the reading is noted in the study sheet. At the same time, the stop watch hand is snapped back to zero. This is done by pressing down the knob, immediately the knob is released. The hand starts moving from zero for timing the next element. Thus the timing for each element found is called observed time.

**2. Continuous method:**

Here the stop watch is started at the beginning of the first element. The watch runs Continuously throughout the study. At the end of each element the watch readings are recorded on the study sheet. The time for each element is calculated by successive subtraction. The final reading of the stop watch gives the total time known as observed time.

### 4.2.3.5 Equipments used to measure time using Stop watch:

Following equipments are used to measure time using Stop watch time study method:

1. Digital or electronics stop watch
2. Electronic data collector and computer
3. Observation board
4. Observation sheet
5. Stationary – Pen, Pencil, Eraser, Calculator.

#### 4.2.3.6 Major Companies using Stop watch time study method:

Majority of the manufacturing industries use stop watch time study method as tool for work measurement. Following are some of the manufacturing industries those apply stop watch time study method for work measurement as shown in Chart 4.4.

**Chart 4.4**

**List of Major Companies using Stop Watch time study Method**

| **Sr.No** | **List of Major Companies using Stop Watch Time Study method** |
|---|---|
| 1 | Mahindra and Mahindra (Automobile) |
| 2 | Tata Motors (Automobile) |
| 3 | Honda Motors (Automobile) |
| 4 | Bajaj Motors (Automobile) |
| 5 | Ford Motors Company |
| 6 | General Motors |

*Source: www.wikipedia.com*

The above list is indicative and not exhaustive.

# EXPERIMENT - 2

**AIM: To Study & Prepare Operation Process Chart (OPC) for given assembly.**

**OBJECTIVES: After completing this experiment, you will be able to:**

- **Identify operations and inspections.**
- **List the operations and inspections involved in manufacturing process of each part of an assembly or processes.**
- **Note down details about materials, machines and equipment used for each component of an assembly.**
- **To understand sub assembly and assembly procedure.**
  **Construct Operation (Outline) Process Chart.**

## Introduction: -

**Work Study: - It is a generic term for those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead systematically to the investigation of all the factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement.**

**Method Study: - Method study is the systematic recording and critical examination of existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs.**

**Work Measurement: - Work measurement is the application of techniques designed to establish the time for a qualified worker to carry out a specified job at defined level of performance. [Work Study by ILO page no; 28, 29]**

**Thus work study is a management technique to increase productivity and is divided into two broader concepts Method Study and Work Measurement.**

**As per the definition of method study the main objective, is to improve the existing method of doing work and to develop more effective and economical method. Method study uses different methods to record the data.**

**The most commonly used method study charts and diagrams are as follows:**

**A. Charts: Indicating process SEQUENCE**
- **Outline Process Chart,**
- **Flow Process Charts (Man, Material & Equipment type)**
- **Two Handed Process Chart.**

**B. Charts: using a Time Scale**
- **Multiple Activity Chart (Man-Machine Chart)**
- **SIMO Chart**

**C. Diagrams: Indicating movement**

**Flow Diagram**

**String Diagram**

**Cycle graph**

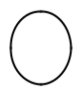
**Chrono cycle graph Travel Chart.**

**In this experiment we are going to study about Operation (Outline) Process Chart.**

**Operation (Outline) Process Chart: It is a process chart giving an overall picture by recording in sequence only the main operations and inspections.**

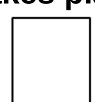
**In an outline process chart, only the principal operations are carried out and the inspections made to ensure their effectiveness are recorded, irrespective of who does them and where they are** performed. In preparing such a chart, only the symbols for 'operation' and 'inspection' are **necessary.**

**Symbols used for Operation (Outline) Process Chart.**

**Operation: - The symbol for operation is as shown:** 

**Operation indicates the main steps in a process, method or procedure. Usually the part, material or product concerned is modified or changed during the operation i.e. physical / chemical e.g. changing shape in machining, chemical change during chemical process; adding or subtracting during assembly or disassembly.**

**When man type charts are produced operation is indicated when any activity or work is done by the man who is used for that particular scenario, for e.g. a clerical routine, an operation is said to take place when information is given or received, or when planning or calculating takes place.**

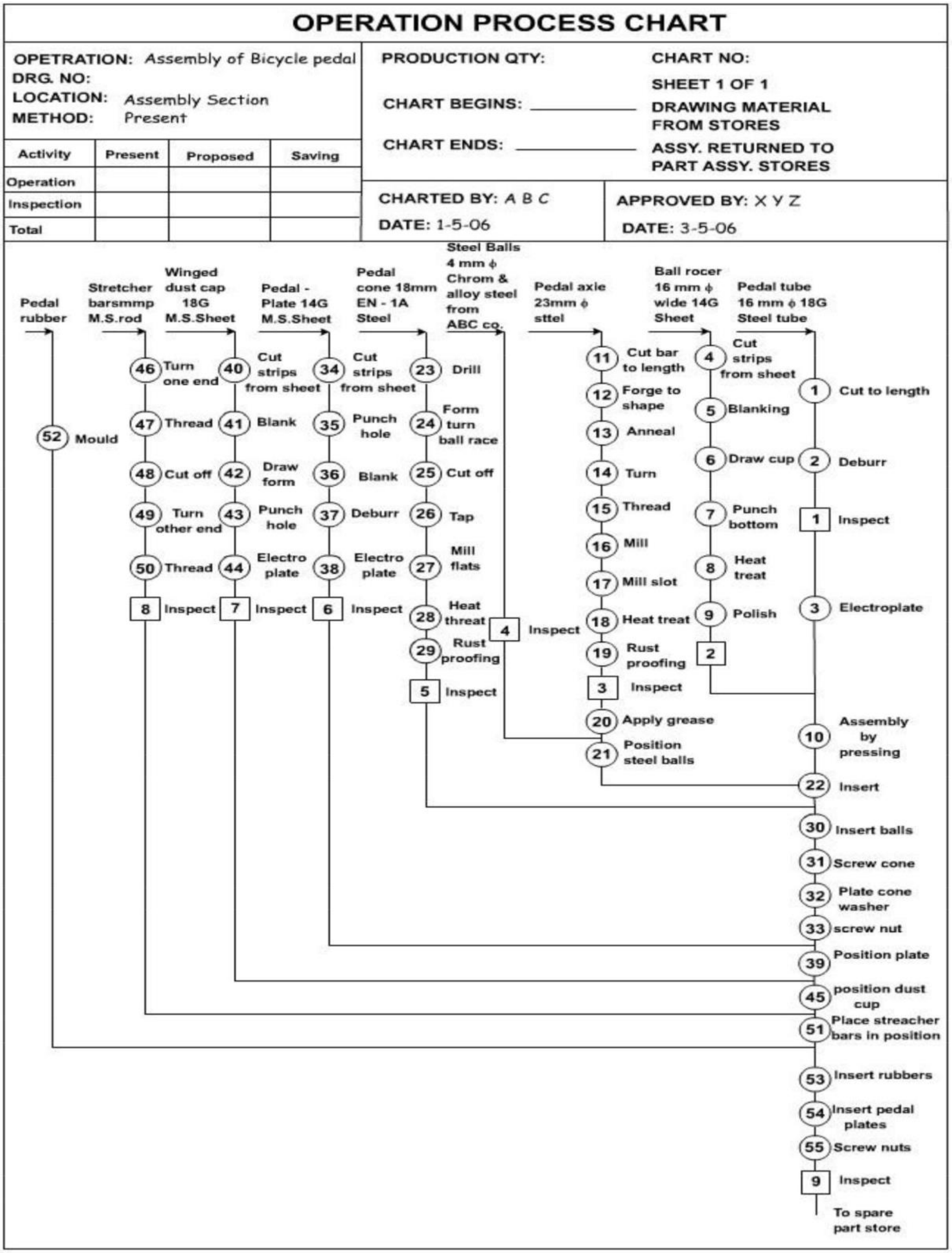
**Inspection: - The symbol for inspection is as shown:** 

**Inspection indicates an inspection for quality and / or a check for quantity. e.g. measurement of dimension/values, etc., counting number of components etc.,**

**An inspection does not take place the material any nearer too becoming a completed product. It merely verifies that an operation has been carried out correctly as to quality and/or quantity, were it not for human shortcomings, most inspections could be done away with.**

**[Work Study by ILO page no: 70-72]**

**Example of OPC: - The following is the example of OPC**




Operation process chart for assembly of bicycle pedal

Figure 1.1: Example of OPC for an assembly of bicycle pedal

**Exercise: Construct OPC for the given assembly and situations.**

**(viii) Manufacturing blade assembly of table fan. Each blade consists of the following components:**

**(i) Blade. (ii)Fixing plate. (iii)Three pieces of bolt and nut pairs. (iv) Six pieces of washers**

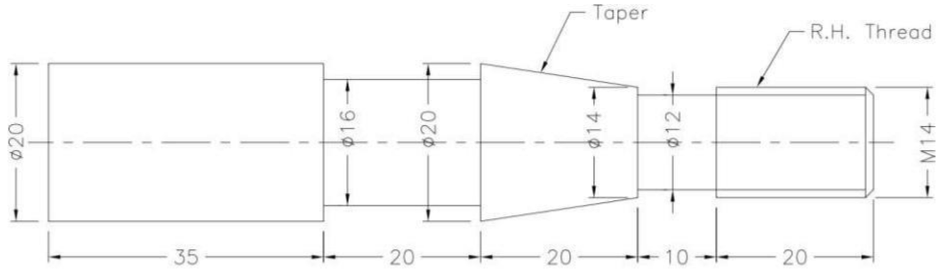
**(ix) Assembly of Nut Bolt and Washer**

**(x) Writing a letter using a short hand typist. :**

**Chart Begins: Short Hand typist in his office awaiting for dictation.**

**Chart Ends: Short Hand typist put typed letter and its copies in Dispatch Tray.**

**(xi) For manufacturing the job given in figure. Construct for both material and machine tool used.**




All Dimensions Are In M.M.

**10. Repair of Car punctured tyre.**

# EXPERIMENT - 3

## AIM: To Study & Prepare Flow Process Chart (FPC) for given assembly.

**OBJECTIVES: After completing this experiment, you will be able to:**

- **Identify operations, inspections, transportations, delays and storage.**
- **List the various activities involved in manufacturing process of each part of an assembly or processes.**
- **Decide the type of flow process chart to be constructed.**
- **To construct flow process chart to be constructed.**
  **Proposed improved flow process chart.**

## Introduction: -

**Flow Process Chart: A flow process chart is a process chart setting out the sequence of the flow of a product or a procedure by recording all events under review using the appropriate process chart symbols.**

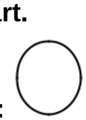
**Flow process chart is prepared in a manner similar to that in which the Outline Process** chart is made, but using, in addition to the symbols for 'operation' and 'inspection', those for 'transport', 'delay' and 'storage'. Whichever the type of flow process charts is being constructed, **the same symbols are always used and the charting procedure is very similar. In fact have only one printed form of chart for all the types of flow process charts.**

**Flow process charts contain more information than outline process chart because they indicate additionally, storage, delay and transportation also which represent a major portion of the product cost.**

**Types of Flow Process Charts: The following are the types of flow process chart:**

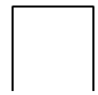
**(xii) Man Type: A flow process chart which records what the worker does.**
**(xiii) Material Type: A flow process chart which records how material is handled or treated.**
**(xiv) Equipment Type: A flow process chart which records how the equipment is used.**

**Symbols used for Operation (Outline) Process Chart.**

**Operation: - The symbol for operation is as shown:** 

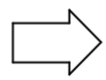
**Operation indicates the main steps in a process, method or procedure. Usually the part, material or product concerned is modified or changed during the operation i.e. physical / chemical e.g. changing shape in machining, chemical change during chemical process; adding or subtracting during assembly or disassembly.**

**When man type charts are produced operation is indicated when any activity or work is done by the man who is used for that particular scenario, for e.g. a clerical routine, an operation is said to take place when information is given or received, or when planning or calculating takes place.**

**Inspection: - The symbol for inspection is as shown:** 

**Inspection indicates an inspection for quality and / or a check for quantity. e.g. measurement of dimension/values, etc., counting number of components etc.,**

**An inspection does not take place the material any nearer too becoming a completed product. It merely verifies that an operation has been carried out correctly as to quality and/or quantity, were it not for human shortcomings, most inspections could be done away with.**

**Transport: - The symbol for transport is as shown:** 

**Transport indicates the movement of workers, materials or** equipment's **from place to place.**

**A transport thus occurs when an object if moved from one place to another, except when such movements are part of an operation or are caused by the operations at the work station during an operation or an inspection.**

**Delay: - The symbol for delay is as shown:** 

**Delay indicates a delay in the sequence of events: for example, work waiting between consecutive operations, or any object laid aside temporarily without record until required.**

**Examples are worked stacked on the floor of a shop between operations, cases awaiting unpacking, parts waiting to be put into storage bins or a letter waiting to be signed.**

**Storage: - The symbol for storage is as shown:** 

**Storage indicates a controlled storage in which material is received into or issued from a store under some form of authorization; or an item is retained for reference purposes.**

**[Work Study by ILO page no: 70-72]**

**Example of Flow Process Chart: -**

| FLOW PROCESS CHART | MATERIAL TYPE | | | |
|---|---|---|---|---|
| CHART NO:- 5 SHEET NO:- 5 | S U M M A R Y | | | |
| Subject charted:-P.C.M. | ACTIVITY | PRESENT | PROPOSED | SAVING |
| | OPERATION ○ | 7 | | |
| ACTIVITY:-FLOW OF MELT IN PIG IRON CASTING MACHINE | TRANSPORT ⇨ | 6 | | |
| | DELAY D | 1 | | |
| | INSPECTION □ | | | |
| | STORAGE ▽ | | | |
| METHOD:- PRESENT | TOTAL ACTIVITY | 14 | | |
| LOCATION:-BLAST FURNACE,SAMAGHOGHA | TIME (man-min) | | | |
| :GUIDE BY:- KULDEEP BHATNAGAR | COST | | | |
| | LABOUR | | | |
| CHARTED BY:-Vimal Makwana | MATERIAL | | | |
| APPROVED BY:- | TOTAL | | | |

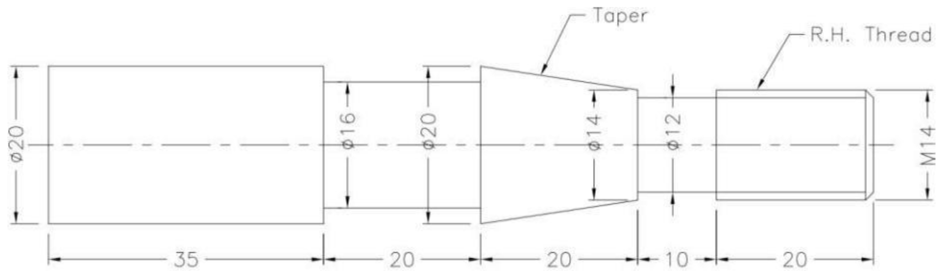
| DESCRIPTION | QTY | DIST-ANCE | TIME (min) | SYMBOL ○ | ⇨ | D | □ | ▽ |
|---|---|---|---|---|---|---|---|---|
| POURING METAL FROM LADDLE | | | | ● | | | | |
| FORWARD THE MELT TO MAIN RUNNER | | | | | ● | | | |
| FORWARD THE MELT MAIN RUNNER TO SLAG CHUTE | | | | | ● | | | |
| SLAG ARE COLLECTED BY SLAG CHUTE | | | | ● | | | | |
| FORWARD THE MELT TO APRON PLATE | | | | | ● | | | |
| OVERFLOW MELT WILL BE COLLECTED IN APRON PLATE [ TWO STAND ] | | | | ● | | | | |
| TWO STAND PRODUCED CASTING FOR ROTATION | | | | ● | | | | |
| CAST IS COOLED BY WATER | | | | ● | | | | |
| SPRAY THE LIME ON CAST | | | | ● | | | | |
| FORWARD THE CAST FOR DISCHARGE | | | | | ● | | | |
| DISCHARE THE CAST | | | | | ● | | | |
| WAITING FOR CRANE | | | | | | ● | | |
| LOADING THE CAST BY MAGNETIC CRANE | | | | ● | | | | |
| TRANSPORT THE CAST | | | | | ● | | | |
| | | | | | | | | |
| Total | | | | 7 | 6 | 1 | | |

**Figure 2.1: Example of Flow Process Chart (Material Type)**

**Exercise: Construct Flow Process for the given assembly and situations in the following format**

11. **Manufacturing blade assembly of table fan. Each blade consists of the following components:**
    **(i) Blade. (ii)Fixing plate. (iii)Three pieces of bolt and nut pairs. (iv) Six pieces of washers**
12. **Assembly of Nut Bolt and Washer**

13. **Writing a letter using a short hand typist.:**
    **Chart Begins: Short Hand typist in his office awaiting for dictation.**
    **Chart Ends: Short Hand typist put typed letter and its copies in Dispatch Tray.**
14. **For manufacturing the job given in figure. Construct for both material and machine tool used.**




All Dimensions Are In M.M.

6. **Repair of Car punctured tyre.**
7. **Construct a Flow Process Chart for the following:**
    - **i. Move bar stock from store to hacksaw** — **Dist. 8 meter**
    - **ii. Cutting of bar stock** — **Time 4 min**
    - **iii. Move to lathe machine** — **Dist. 6-meter**
    - **iv. Turning Process** — **Time 5 min**
    - **v. Move to milling machine** — **Dist. 7-meter**
    - **vi. Wait for milling machine** — **Time 2 min**
    - **vii. Milling keyway** — **Time 10 min**

# FLOW PROCESS CHART ____________ TYPE

| CHART NO:- SHEET NO:- OF:- | S U M M A R Y | | | |
|---|---|---|---|---|
| Subject charted:- | ACTIVITY | PRESENT | PROPOSE | SAVING |
| | OPERATION ○ | | | |
| ACTIVITY:- | TRANSPORT ⇨ | | | |
| | DELAY D | | | |
| | INSPECTION □ | | | |
| | STORAGE ▽ | | | |
| METHOD:- | DISTANCE (m) | | | |
| LOCATION:- | TIME (man-min) | | | |
| OPERATIVE(S):- CLOCK Nos:- | COST:- | | | |
| | LABOUR | | | |
| CHARTED BY:- | MATERIAL | | | |
| APPROVED BY:- DATE:- | TOTAL | | | |

| DESCRIPTION | TIME (min) | SYMBOL ○ | ⇨ | D | □ | ▽ | |
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| TOTAL | | | | | | | |

# EXPERIMENT - 4

## AIM: To study & Prepare Man-Machine (Multiple Activity) Chart for the given situation

**OBJECTIVES: After completing this experiment, you will be able to:**

- **Record the activities performed by the operator and machine.**
- **Identify independent, combined and idle activities.**
- **Construct man and machine chart.**
- **Calculate utilization for man and machine.**
- **Analyze the chart with a view to increase utilization.**

## Introduction: -

**Man-Machine (Multiple Activity) Chart: A man-machine (multiple activity) chart is a chart on which the activities of more than one subject (worker, machine or item of equipment) are each recorded on a common on a common time scale to show their interrelationship.**

**Man-Machine chart or multiple activity chart is a useful recording tool for situations where the work involves interactions of different subjects. One or more workers looking after different machines or a group of workers on loading materials at one point and dumping the same at a different point are some examples where this type of chart can be used effectively. The fundamental difference between this tool and the other charts described in the previous section are as follows:**

**(xv) In man-machine (multiple activity) chart a time scale is used. No such time scale is used in the other charts.**

**(xvi) Man-machine (multiple activity) charts can be used equally effectively even if there is no movement of workers involved in the work under consideration. The primary focus of this chart, for situations where the workers are moving as a part of their work, is to identify the idle time on the part of either the workers or the machines. The focus of other charts described so far were primarily to identify excess distances traversed by the workers, which is only indirectly related to the time.**

**By using separate vertical columns, or bars, to represent the activities of different operatives or machines against a common time scale, the chart shows very clearly periods of idleness on the part of any of the subjects during the process. A study of the chart often makes it possible to rearrange these activities so that such ineffective time is reduced. The man- machine (multiple activity) chart is extremely useful in work involving repetitive operations. For a situation involving a worker handling different machines, this chart can be used to find the number of machines the worker can look after so as to minimize the cost.**

**[Work Study by ILO page no: 125-126]**

## Example of Man-Machine (Multiple Activity) Chart: -

Operator Name : Ram Dyal Sharma
Department : Machine Shop
Activity : Drill hole in casting
Drg.No : C25
Method : Present

**Summary**

| | Man | Machine |
|---|---|---|
| Idle time | 2.50 minutes | 1.25 minutes |
| Working time | 1.25 | 2.50 |
| Total cycle time | 3.75 | 3.75 |
| Utilization | Operator utilization = $\frac{1.25}{3.75}$ = 33% | Machine utilization = $\frac{2.50}{3.75}$ = 67% |

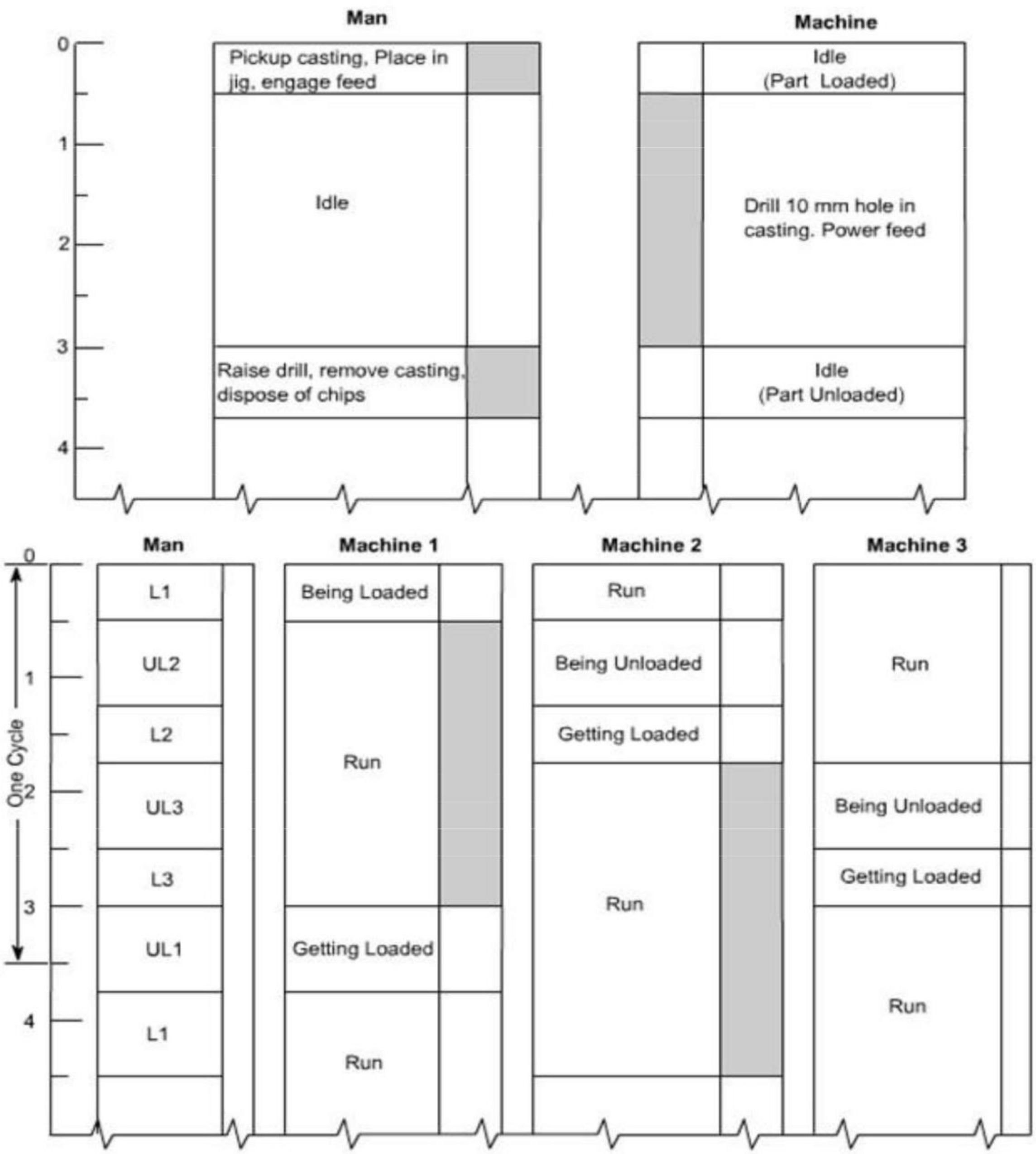



**Figure 3.1: Example of Man- Machine (Multiple) Chart**

**The activities involved during the operations are classified as: -**

15. **Independent Activity:**
    **Man: Operator working independently.**
    **Machine: Auto feed, m/c working independently.**
16. **Combined Activity:**
    **Man: Operator working with other operator or handling machine (hand feed).**
    **Machine: Machine loaded or unloaded, servicing of machine.**
17. **Idle:**
    **Man: Waiting for machine to complete operation.**
    **Machine: Operator engaged in inspection, etc.**

**The color used to show various activities on man and machine chart are:**

8. **Green: For independent activity.**
9. **Orange: For combined activity.**
10. **Red: For idle time.**

**Exercise: Construct Man-Machine (Multiple Activity) Chart for the situations**

7 **Each of the two sides of a hand-operated toaster can be operated independently of the other. A spring holds each side of the toaster shut, and each side must be held open in order to insert bread. Assume that the toaster is hot and ready to toast bread. The following are the elemental times necessary to perform the operations. Assume also that both hands can perform their tasks with the same degree of efficiency.**

- **Place slice of bread in either side of toaster: 4 seconds.**
- **Toast either side of bread: 30 seconds.**
- **Turn slice of bread on either side of toaster: 2 seconds.**
- **Remove toast from either side of toaster: 4 seconds.**

**By using an activity chart for toasting 3 slices of bread, what method would you recommend to obtain the best equipment utilization that is, the very shortest over-all time?**

2. **A chamfering, turning and threading operation is done on a job on lathe machine. Information of that operation is recorded as under. Show this information on man and machine chart.**

i. Carry bar stock from the store. 1 min
ii. To fix the job in lathe chuck. 2 min
iii.To carryout manual turning of the job. 1.5 min
iv. To carryout chamfering operation on job 1 min
v. To carryout threading operation on job. 2 min
vi. To bring the saddle back and rearrange it 0.5 min
vii. To carryout threading work on the job. 1.5 min
viii. Inspection of the job. 1 min
ix. To remove the job from the lathe chuck. 0.5 min
x. Carrying completed work piece to store 1 min

# EXPERIMENT - 5

## 1. Introduction

Workplace design deals with the shape, the dimensions and the layout (i.e. the placement and orientation) of the different material elements that surround one or more working per-sons. Examples of such elements are the seat, the working surfaces, the desk, the equip-ment, the tools, the controls and displays used during the work, but also the passages, the windows, the heating/cooling equipment, etc.

The ergonomic workplace design aims at improving work performance (both in quantity and quality), through:

(xvii) minimizing the physical strain and workload of the working person,

(xviii) facilitating task execution, i.e. ensuring effortless information exchange with the en-vironment, minimization of the physical constraints, etc.,

(xix) ensuring occupational health and safety,

(xx) achieving ease of use of the various workplace elements.

Designing a workplace meeting ergonomics principles is a difficult problem, as one should consider an important number of interacting and variable elements, and try to meet an important number of requirements, some of which may be contradictory. In fact, there is interdependence between the workplace components, the working person, the task require-ments, the environment and the habitual body movements and postures the working person will adopt (Figure 1).

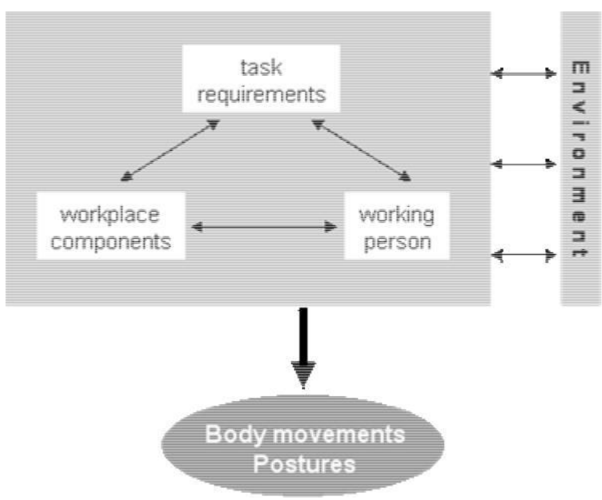



*Figure 1: There is interdependence between working person, task requirements, workplace ele-ments, environment and body movements and postures.*

Consider for example a person working in a computerized office (task requirement: work with a computer). If the desk (workplace component 1) is too low and the seat (work-place component 2) too high for the anthropometric characteristics of the worker (character-istic of the working person), the worker will lean forward (awkward posture), with negative effects on his physical workload, his health (particularly if he should work for a long period in this workplace), and finally on his overall performance. Furthermore, if behind the worker there is a window causing glare on the computer's screen (characteristic of the environ-ment), he will probably bend sideways (awkward posture), in order to be able to see what is presented on the screen (task requirement), causing similar effects. Consequently, when de-signing a workplace, one has to adopt a systemic view, considering the characteristics of the working person, the task requirements as well as the environment in which the task will be performed.

Furthermore, the elements of the work system are variable. In fact, the working per-son may be short or tall, massively built or slim; s/he may be young or elderly; with specific needs, etc. Finally, s/he may be refreshed or tired, depending on time of the day. The task requirements may also be multiple and variable. For example, at a secretarial workstation, the task may require exclusive use of the computer for a period of time, then the secretary may enter data from paper forms to the computer, and then she may serve a customer. At the same time, the workstation should be oriented is such a way that the secretary be able to watch both the entry and the director's doors. Finally, the workplace environment may be noisy or quiet, warm or cool, with annoying air streams, illuminated by natural or artificial light, and all the above changing during the working day.

If to the complexity of the work system and the multiplicity of ergonomic criteria one adds the financial and aesthetic issues, successful design of a workplace becomes extremely difficult. Hence, some people maintain that designing a good workplace is rather an "art" than a "discipline", as there is no standard theory or method that ensures a successful result, the output depending heavily on the designer's "inspiration". Although this is true to a cer-tain extent, good knowledge of the characteristics of the working persons who will occupy the workplace, of their tasks, as well as of the broader environment, combined with an effort for rigueur during the design process, contribute decisively to a successful design.

The present chapter is mainly methodological; it presents and discusses a number of methods, techniques, guidelines and design solutions which aim to support the decisions to be taken during the workplace design process. The next section discusses the problem of working postures and stresses the fact that there is no *one best posture* which can be as-sumed for long periods of time. Consequently, the effort should be put on designing the components of the workplace in such a way as to form a "malleable envelop" that permits the worker to adopt various healthy postures. The two other sections deal with the design of individual workstations and with the layout of groups of workstations in a given space.

## 2. The problem of working postures

A central issue of the ergonomic workplace design is the postures the working person will adopt. In fact, the decisions that will be taken during the workplace design, will affect to a great extent the postures that the working person will be able to adopt or not. The two most common working postures are sitting and standing. Between the two, sitting posture is of course more comfortable. However, there is research evidence that sitting adopted for pro-longed periods of time results in discomfort, aches or even irreversible injuries. For example,

Figure 2 shows the most common musculoskeletal disorders encountered at office worksta-tions.

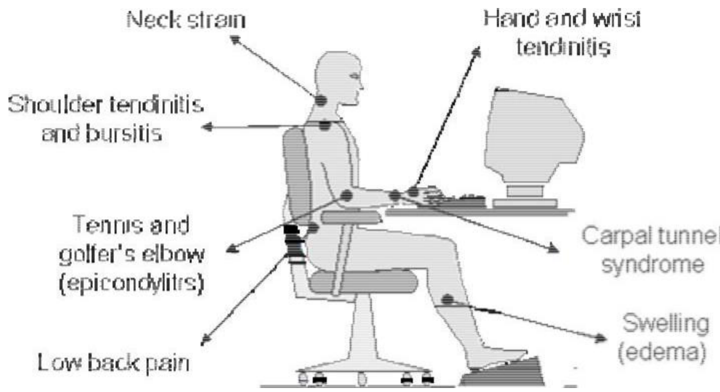



*Figure 2: Common musculoskeletal disorders encountered at office workstations.*

Studying the effects of “postural fixity” while sitting, Griego (1986) found that it causes among others: (i) reduction of nutritional exchanges at the spine disks and in the long term may promote their degeneration, (ii) static loading of the back and shoulder mus-cles, which can result in aches and cramping, (iii) restriction in blood flow to the legs, which can cause swelling (edema) and discomfort. Consequently, the following conclusion can be drawn: The workplace should permit the alteration between various postures, because there is no “ideal” posture which can be adopted for a long period of time.

Based on this conclusion, the standing-sitting workstation has been proposed, espe-cially for cases where the task requires long periods of continuous work (e.g. bank tellers or assembly workstations). This workstation (Figure 3) permits to perform a job alternating the standing with the sitting posture.

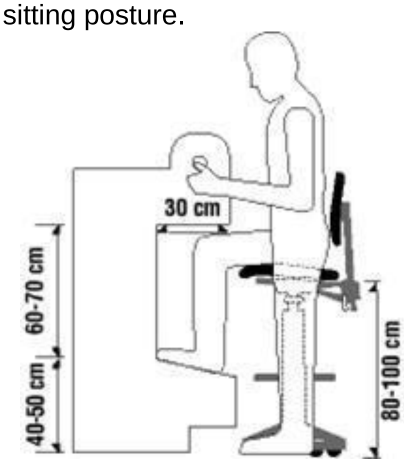



*Figure 3: An example of standing-sitting workstation.*

Despite the absence of an ideal posture, there are however postures which are more comfortable and healthy than others. The ergonomic research aims at identifying these pos-tures and formulating requirements and principles which should be considered during the design of the components of a workplace. In this way the resulting design will promote healthy work postures and constrain the prolonged adoption of unhealthy postures.

2.1. Sitting posture and seats

The problem of designing seats that are appropriate for work is far from solved. In recent decades the sitting posture and the design of seats have attracted the interest of research-ers, designers and manufactures, due to the ever increasing number of clerical workers and the importance of musculoskeletal problems encountered by them. This has resulted in the emergence of a proper science, the *science of seat*, and subsequently to a plethora of publi-cations and design solutions (see for example Lueder & Noro 1994, Mandal, 1985).

Sitting posture poses a number of problems at a musculoskeletal level. The most im-portant of them is the *lumbar kyphosis*. When one is sitting, the lumbar region of the back flattens out and may even assume an outward bend. This shape of the spine is called *ky-photic*, and is somewhat the opposite to the *lordotic* shape of the spine when someone is standing erect (Figure 4). The more the angle between the thighs and the body is smaller, the more the kyphosis is greater. This occurs because of the restrained rotation of the hip joint, which forces the pelvis to rotate backward. Kyphosis provokes increased pressure on the spine disks at the lumbar portion. Nachemson & Elfstrom (1970), for example, found that unsupported sitting in upright posture resulted in a 40% increase in the disks' pressure com-pared to the pressure when standing. There are three complementary ways to minimize lumbar kyphosis: (i) by using a thick lumbar support; (ii) by reclining the backrest; and (iii) by providing a forward-tilting seat. Andersson et al. (1979) found that the use of a 4 cm thick lumbar support, combined with a backrest recline of $110^{o}$ resulted in a lumbar curve resembling closely to the lumbar curve of a standing person. Another finding of Andersson et al. (1979) was that the exact location of the support within the lumbar region did not signifi-cantly influence any of the angles measured in the lumbar region. The studies of Bendix (1986) and Bridger (1988) support the proposition of Mandal (1985), for the forward-tilting seat.

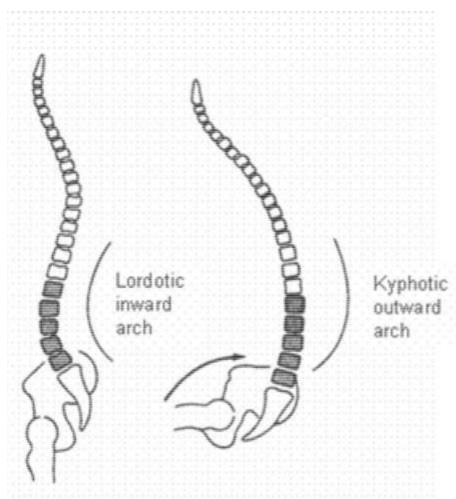



*Figure 4: Lordotic and kyphotic postures of the spine (source: Grandjean, 1988).*

Considering the above, the following ergonomic requirements should be met:

18. The seats should dispose a backrest which can recline. ii The backrest should provide a lumbar support.
iiiThe seat should provide a forward-titling seat.

However, as Dainoff (1994) observes, when tasks require close attention to the objects on the working surface or the computer screen, people usually bend forward, and the backrest support becomes useless.

A design solution which aims to minimize the lumbar kyphosis is the *kneeling* or *balance chair* (figure 5), where the seat is inclined more than $20^0$ from the horizontal plane. Be-sides the somewhat unusual way of sitting, this chair has also the drawbacks of loading the area of knees as they receive a great part of the body's load, and of constraining the legs' movements. On the other hand it enforces a lumbar lordosis very close to the one adopted while standing and does not constrain the torso to move freely forwards, backwards or side-ways.

*Figure 5: Example of a kneeling chair (source: www.comcare.gov.au/officewise.html).*

There are quite a lot of detailed ergonomic requirements concerning the design of seats used at work. For example:

11. The seat should be adjustable in order to fit to the various anthropometric character-istics of their users, as well as to different working heights.
12. The seat should offer stability to the user.
13. The seat should offer freedom of movement to the user.
14. The seat should be equipped with armrests.
15. The seat lining material should be water absorbent, to absorb body perspiration. The detailed requirements will not be presented extensively here, as the interested reader can find them easily in any specialized handbook. Furthermore, these requirements became "classical", and have been transformed into regulatory documents such as health and safety or design standards, legislation, etc. (see for example EN 1335, ISO 9241, ANSI/HFS 100-1988 and DIN 4543 standards for office work, or EN 1729 for chairs and tables for educa-tional institutions and ISO/DIS 16121 for the driver's workplace in line-service buses).

Although most of the modern seats for office work meet the basic ergonomic require-ments, the design of their controls does not meet the usability principles. This fact, combined with the poor users' knowledge on healthy sitting, results in the non use of the adjustment possibilities offered by the seats (Vitalis et al 2000). Lueder (1986) provides the following guidelines for increasing the usability of controls:

8 Controls should be easy to find and interpret.
9 Controls should be easily reached and adjusted form the standard seated work posi-tion.
10 Controls should provide immediate feedback (for example, seats that adjust in height by rotating pan delay feedback because user must get up and down repeatedly to de-termine the correct position).
11 The direction of operation of controls should be logical and consistent with their ef-fect.
12 Few motions should be required to use the controls.
13 Adjustments should require the use of only one hand.
14 Special tools should not be necessary for the adjustment.

3. Labels and instructions on the furniture should be easy to understand.

### 2.2. Sitting posture and work-surface height

Besides the problem of the lumbar kyphosis, sitting working posture may also provoke excessive muscle strain at the level of the back and the shoulders. For example, if the working surface is too low, the person will bend forward too far; if it is too high, he will be forced to raise his shoulders.

To minimize these problems, appropriate design of the workplace is required. More specifically, the working surface should be at a height that permits a person to work with the shoulders at the relaxed posture. It should be noticed here that the working height does not always equate to the work-surface height. The former depends on what one is working on (e.g. the keyboard of a computer), while the later is the height of the upper surface of the table, desk, bench, etc. Furthermore, to define the appropriate work-surface height, one should consider the angles between the upper arms and the elbows, and the angle between the elbows and the wrists. To increase comfort and minimize the occupational risks, the first of the two angles should be about $90^{o}$ if no force is required, and a little bit broader, if appli-cation of force is required. The wrists should be straight as far as possible, in order to avoid the carpal tunnel syndrome.

Two other common problems encountered by people working in sitting posture are the neck aches and the Dry Eye Syndrome. These problems are related to the prolonged gazing at objects placed too high; for example, when the Visual Display Terminal of a com-puter workstation is placed too high (Ankrum, 1997). The research which aims at determin-ing the optimal placement of such objects, considering the mechanisms of both the visual and musculoskeletal systems, is still active (see for a review Ankrum & Nemeth 2000). How-ever, most research findings agree that: (i) neck flexion is more comfortable than extension, with the zero point (dividing flexion from extension) described as the posture of the head/neck when standing erect and looking at a visual target 15° below eye level, and (ii) the visual system prefers downward gaze angles. Furthermore, there is evidence that when assuming an erect posture, people prefer to tilt their head, with the Ear-Eye Line (i.e. the line which crosses by the cartilaginous protrusion in front of the ear hole and the outer slit in the eyelid), being about $15^{0}$ below the horizontal plane (Grey et al.1966; Jampel & Shi 1992). Based on these findings many authors propose the following rule of thumb for the placement of the VDU: the center of the monitor should be placed at a minimum of 15° be-low the eye level, with the top and the bottom at an equal distance from the eyes. (i.e. the screen plane should be facing slightly upwards).

Sanders & McCormick (1992) propose in addition the following general ergonomic recom-mendations for work-surfaces:

- If at all possible the work-surface height should be adjustable to fit individual physical dimensions and preferences.
- The work-surface should be at a level that places the working height at elbow height, with shoulders at relaxed posture.
- The work-surface should provide adequate clearance for a person’s thighs under the work-surface.

### 2.3. Spatial arrangement of work artifacts

While working one uses a number of artifacts; for example the controls and displays on a control panel, the different parts of an assembled object at an assembly workstation, or the keyboard, the mouse, the visual display terminal, the hard-copy documents and the telephone at an office workstation. Application of the following ergonomic recommendations for the arrangement of these artifacts helps to decrease workload, facilitate the work flow and improve overall performance:

- *Frequency of use* and *criticality*: artifacts that are frequently used, or are of special importance, should be placed in prominent positions, for example in the center of the work surface or near to the right hand for right-hand people, and vice versa for left-hand peo-ple.
- *Sequential consistency*: when a particular procedure is always executed in a sequential order, the artifacts involved should be arranged according this order.
- *Topological consistency*: where the physical location of controlled elements is important for the work, the layout of the controlling artifacts should reflect the geographical arrangement of the former.
- *Functional grouping*: artifacts (e.g. dials, controls, visual displays) that are related to a particular function should be grouped together.

Application of the above recommendations requires knowledge of the work activities to be performed at the workplace designed. Task analysis provides enough data to appropri-ately apply these recommendations, as well as to solve eventual contradictions between them, by deciding which arrangement fits best to the situation at hand.

# 3 Designing individual workstations

Figure 6 presents a generic process for the ergonomic design of individual workstations, with the different phases, the data or sources of data that have to be considered at each phase, and methods that could be applied. It has to be noted that certain phases of the process may carried out concurrently, or in a different order, depending on the particularities of the workstation to design, or the preferences and experience of the designers.

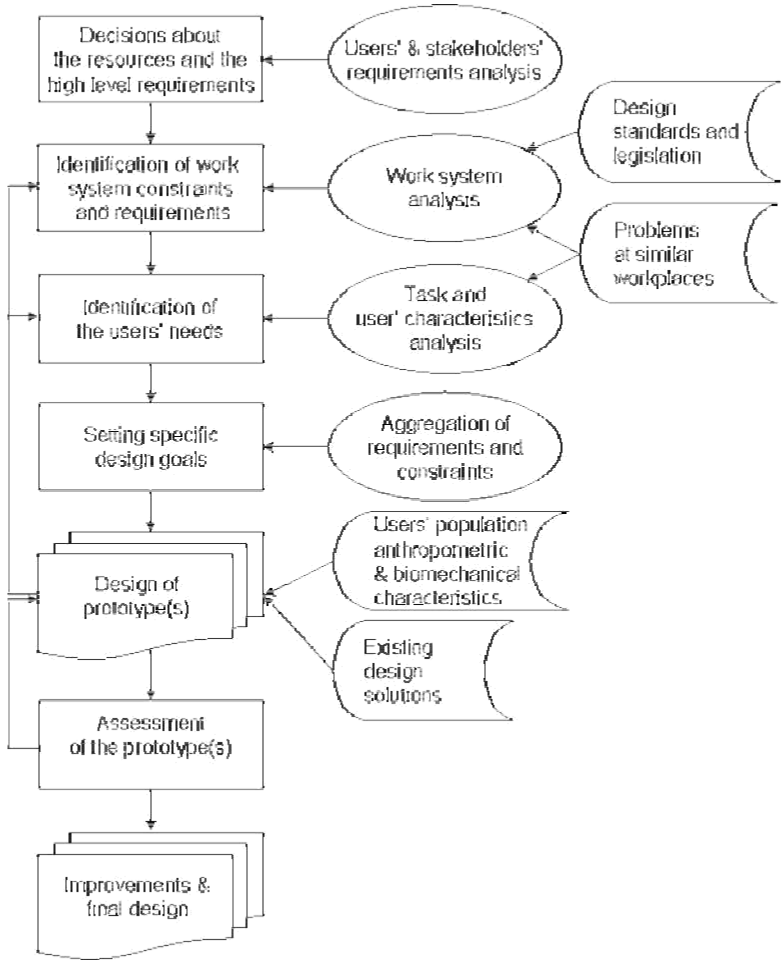



*Figure 6: A generic process for the ergonomic design of individual workstations.*

*1st phase: Decisions about the resources and the high level requirements*

The first phase of the design process is to decide about the time to spend and the people who will participate in it (the design team). These decisions depend on the high level requirements of the stakeholders (e.g., improvement of working conditions, increase of productivity, innovation, occupational safety and health protection, as well as the money they are ready to spend), and the importance of the project (e.g., number of identical worksta-tions, significance of the tasks carried out, particularities of the working persons). An addi-tional issue that has to be dealt at this phase is to ensure the participation to the design process of the people who will occupy the future workstations. The access to workstations where similar jobs are being performed is also advisable.

The rest of the design process will be significantly influenced by the decisions taken at this phase.

*2nd phase: Identification of the work system constraints and requirements*

The aim of this phase is to identify the different constraints and requirements posed by the work system which have to be considered during the design of the workstation. More specifi-cally, during this phase one has to collect data about:

- the types of tasks to be carried out at the workstation designed;

- the work organization i.e. the interdependency between the tasks to be carried out in the workstation and others in the proximal environment;
- the various technological equipment and tools that will be used, their functions, user interfaces, shape and dimensions;
- the environmental conditions of the broader area in which the workstation will be placed (e.g. illumination and sources of light, level of noise and noise sources, ther-mal conditions and sources of warm or cold draughts, etc.);
- the normal as well exceptional situations in which the working persons could be found (e.g. electricity breakdowns, fire, etc);
- any other element or situation of the work system that may directly or indirectly inter-fere with the workstation designed.

These data can be collected by questioning the appropriate people, as well as by obser-vation and analysis of similar work situations.

Specific design standards (e.g. ANSI, EC, DIN or ISO) as well as legislation related to the type of the workstation designed, should also be collected and studied during this phase.

*3rd phase: Identification of the users' needs*

The needs of the future workstation occupants are identified during this phase, considering the tasks to be performed at the workstation designed, as well as the characteristics of per-sons who will occupy it. Consequently, task analysis (see chapter XX) and users' characteris-tics analysis should be carried out at this phase.

Of particular importance are the characteristics of the users' population which depend on their gender, age, nationality or particular disabilities, and concern:

- the size of the body parts (anthropometry, see chapter XX);
- the ability and limits of their movements (biomechanics see chapter XX);
- the visual and auditory perception abilities and limitations;
- previous experiences and work practices;
- cultural or religious obligations (e.g. women at certain countries are obliged to wear particular costumes).

The task analysis aims at identifying mainly:

- the work processes that will take place and the workstation elements implicated in them;
- the physical actions that will be carried out, e.g. fine manipulations, whole body movement, force exertion, etc;
- the required information exchange (visual, auditory, kinesthetic, etc) and the informa-tion sources;
- the required privacy;
- the required proximity with other workstations, equipments or elements of the broader working environment.

The more the design team has the possibility to analyze work situations similar to the workstation designed, the more the results of the task analysis will be valuable.

At this phase, data about performance and health problems of persons working in similar work situations should also be collected. Ergonomic and occupational safety and health lit-erature may be used as the main source for the collection of such data.

Finally, as in the previous phase, the users' needs should be identified not only for nor-mal, but also for exceptional situations in which the workstation occupants may be found (e.g. electricity blackout, fire, etc).

*4th phase: Setting specific design goals*

Considering the outputs of the previous phases, the design team is now able to transform the generic ergonomic requirements of workstation design into a set of specific goals. These specific design goals will guide the choices and the decisions to be made at the next phase. Furthermore, they will be used as criteria for assessment of the designed prototype, and will guide its improvement.

The specific goals are an aggregation of *shoulds*, and consist of:

- the requirements of the stakeholders (e.g. the workstation should be convenient for the 95% of the user population, should cost maximum $ X, increase productivity at least 10%, etc);
- the constraints and requirements posed by the work system in which the designed workstation(s) will be installed (e.g. the workstation(s) should not exceed X cm of length and Y cm of width, should offer working conditions not exceeding X dB of noise, and Y $^0$ of Wet Bulb Globe Temperature, etc);
- the users' needs (e.g. the workstation should accommodate elderly people, should be appropriate for prolonged computer work, should facilitate cooperation with the neighboring workstations, etc);
- requirements to avoid common health problems associated with similar situations (e.g. the workstation should minimize upper limbs musculoskeletal problems);
- design standards and related legislation (e.g. the workstation should ensure absence of glare, or cold draughts, etc).

The systematic record of all specific design goals is very helpful for the next phases. It is important to note that agreement on these specific goals between the design team, the management and users representatives, is indispensable.

*5th phase: Design of prototype(s)*

This phase is the most demanding of the design process. In fact, the design team has to generate design solutions meeting all the specific design goals identified at the previous phase. Given the large number of design goals, as well the fact that some of them may be conflicting, the design team has to make appropriate compromises, considering some goals as more important than others and eventually passing by some of them. Good knowledge of the particularities of the task that will be performed at the workstation designed, as well as the specific users' characteristics, is the only way to set the right priorities and avoid serious mistakes.

A first decision to make is the working posture(s) that will assume the users of the workstation designed. Table I provides some recommendations for this.

*Table I: Recommendations for choosing the working posture (Corlett & Clark 1995)*

| Working posture | Task requirements |
|---|---|
| Working person's choice | It is preferable to arrange for both sitting and standing (see figure 3) |
| Sitting | Where a stable body is needed:<br>- for accurate control, fine manipulation;<br>- for light manipulation work (continuous);<br>- for close visual work – with prolonged attention;<br>- for limited headroom, low work heights.<br>Where foot controls are necessary (unless of infrequent or short duration).<br>Where a large proportion of the working day requires standing. |
| Standing | For heavy, bulky loads.<br>Where there are frequent moves from the workplace.<br>Where there is no knee room under the equipment.<br>Where there is limited front – rear space.<br>Where there is a large number of controls and displays.<br>Where a large proportion of the working day requires sitting. |
| Support seat (see figure 7) | Where there is no room for a normal seat but a support is desirable. |

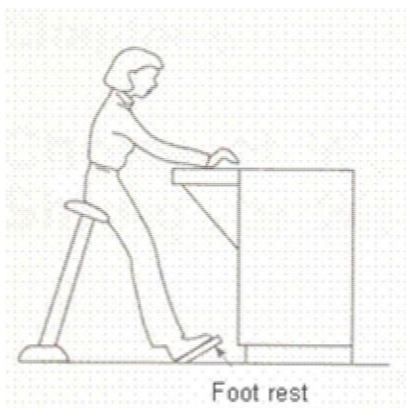



*Figure 7: Where there is no room for a normal seat a support is desirable (source: Helander, 1995).*

Once the working posture has been decided, the design may continue to define the shape, the dimensions and the arrangement of the various elements of the workstation. To do so, one has to consider the anthropometric and biomechanical characteristics of the users' population, as well as the working actions that will be performed. Besides the ergonomic recommendations presented at previous sections, some additional recommendations for the design of the workstation are the following:

- To define the *clearance*, i.e. the minimum required free space for placement of the body, one has to consider the largest user (usually the anthropometric dimensions corre-sponding to the 97.5 percentile). In fact, providing free space for these users, all shorter users will also have enough space to place their body. For example, if the vertical, lateral and forward clearance below the working desk are designed considering the height of the thigh upper surface for a sitting person, the hip width and the thigh length corresponding to the 97.5 percentile of the users' population (plus one or two centimeters for allowance), 97.5% of the users of this desk will be able to approach easily the desk while sit-ting.

- To position the different elements of the workplace that have to be *reached* by the users, consider the smaller user. In fact, if the smaller users reach easily the various work-station elements, i.e. without leaning forward or bending sideways, all the larger users will also reach them easily.
- Draw the common kinetospheres or comfort zones for the larger and smaller users, and put in there the various elements of the workstation that have to be manipulated (e.g. controls). (Figure 8).
- When necessary, provide the various elements of the workstation with appropriate adjustability, in order to fit with the anthropometric characteristics of the users' population. (Care should be given to the usability of the adjustability controls).
- While envisioning design solutions continuously check to ensure that the workstation ele-ments do not obstruct the users' courses of action (e.g. perception of necessary visual in-formation, manipulation of controls, etc).

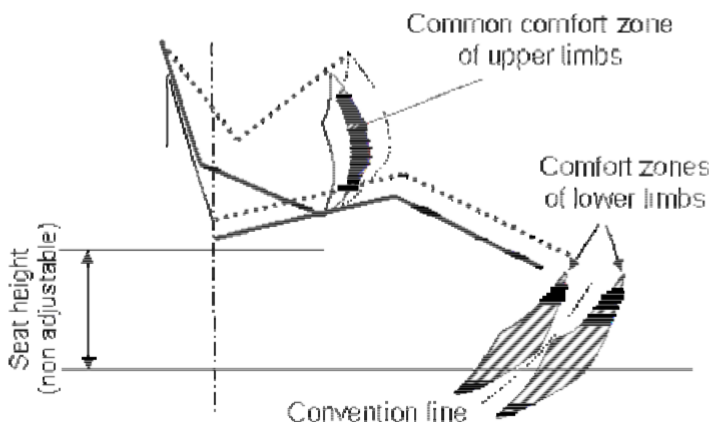



*Figure 8: Drawing the common comfort zones of hands and legs for the large and small users of a driving workplace with non adjustable chair.*

It should be stressed that at least some iterations between the 2nd, 3rd and the present phase of the design process are unavoidable. In fact it is almost impossible to identify from the start all the constraints and requirements of the work system, the users' characteristics or the task requirements that intertwine with the elements of the anticipated workstation.

Another issue to deal with during this phase is designing for protection of the working person from possible annoying or hazardous environmental factors. If the workstation has to be installed in a harsh environment (noisy, cold or warm, with hazardous atmosphere, etc.), one has to provide it with appropriate protection. Again, attention should be paid to the de-sign of such protective elements. These should take into consideration the anthropometric characteristics of the users' population and the special requirements of the task, in order not to obstruct the processes involved both in normal and degraded operation (e.g. mainte-nance, breakdowns etc.).

Other important issues that have to be resolved at this phase are the workstation main-tainability, its unrestricted evacuation, its stability and robustness, as well as other safety issues such as rough corners, etc.

The search for already existing design ideas and solutions is quite useful. However, they should be carefully examined before their adoption. In fact, such design ideas although valu-able for anticipation may not be readily applicable for the specific users' population, the par-ticularities of their tasks or the environment in which the workplace designed will be in-stalled. Furthermore, many existing design solutions may disregard important ergonomic is-sues. Finally, although the adoption of already existing design solutions exploits the design community' s experience and saves time, it deprives the design team from generating inno-vative solutions.

The use of computer aided design (CAD) applications with human models is very helpful at this phase (see chapter XX). If such software is not available, appropriate drawings and mock-ups should be developed for the generation of design solutions, as well as for their as-sessment (see next phase).

Given the complexity of generating good design solutions, the search for alternatives is valuable. The members of the design team should not be anchored at the first design solu-tion that comes to their minds. They should try to generate as many alternative ideas as possible, gradually converging to the one or ones that better satisfy the design goals.

*6th phase: Assessment of the prototype(s)*

Assessment of the designed prototype(s) is required in order to check how well the specific design goals, set at the fourth phase, have been met, as well as to uncover possible omis-sions during the identification of the work system constraints and requirements, and the us-ers' needs analysis (second and third design phases).

The assessment can be performed analytically or/and experimentally, depending on the importance of the project. At the analytical assessment the design team assesses the designed workplace considering exhaustively the specific design goals, using the drawings and mock-ups as support. Applying a multi-criteria method, the design team may rank the degree to which the design goals have been met. This ranking may be used as a basis for the next phase of the design process (improvement of the prototype), as well as a means to chose among alternative design solutions.

The experimental assessment (or user testing) is performed with the participation of a sample of future users, simulating the work with a full-scale mock-up of the designed workstation prototype(s). The assessment should be made in conditions as close as possible to the real work. Development of use scenarios of both normal and exceptional work situa-tions is useful for this reason. Experimental assessment is indispensable for the identification of problematic aspects that are difficult, if not impossible, to realize before having a real workplace with real users. Furthermore, this type of assessment provides valuable insights for eventual needs during implementation (e.g. the training needed, the eventual need for a users' manual etc).

*7th phase: Improvements and final design*

In this phase, considering the outputs of the assessment, the design team proceeds in the necessary modifications of the designed prototype. The opinions of other specialists such as architects and decorators which have more to do with the aesthetics, or production engi-neers and industrial designers which have more to do with production or materials and ro-bustness matters, should be considered at this phase – in the case such specialists do not participate in the design team.

The final design should be complemented with:

- drawings for production and appropriate documentation including the rationale behind the adopted solutions,
- cost estimation for the production of the workstation(s) designed,
- implementation requirements such as the training needed and the users' manual, if required.

*Final remark*

The reason for conducting the users' needs and requirements analysis is to anticipate the future work situation, in order to design a workstation that fits to its users, their tasks and the surrounding environment. However, it is impossible to completely anticipate a future work situation in all its specificity, as work situations are complex, dynamic and evolving. Furthermore, if the workstation designed is destined to form part of an already existing work system, it might affect the overall work ecology, something which is also very difficult to anticipate. Therefore, a number of modifications will eventually be needed some time after its installation and use. Thus it is strongly suggested to conduct a new assessment of the designed workstation once the users have been familiarized with the new work situation.

# 4. Ergonomic layout of workstations

Ergonomic layout deals with the placement and orientation of individual workstations at a given space (building). The main ergonomic requirements to meet concern the tasks per-formed, the work organization and the environmental factors. More specifically, such re-quirements are:

- the layout of the workstations should facilitate the work flow;
- the layout of the workstations should facilitate the cooperation (both of the personnel and external persons);
- the layout of the workstations should conform to the organizational structure;
- the layout should ensure the required privacy;
- there should be appropriate lighting, conforming to the task's needs;
- the lighting should be uniform throughout the working person's visual field;
- there should be no annoying reflections or glare in the working area;
- there should be no annoying hot or cold draughts in the workplace;
- the access to the workstations should be unobstructed and safe.

In this section we will focus on the ergonomic layout of workplaces for office work. The choice to focus on the ergonomic layout of workstations in offices has been made for the following reasons: First, office layout is an exemplar case for the arrangement of a number of individual workstations in a given space, encompassing all major ergonomic requirements found in most types of workplaces (with the exception of workplaces where the technology involved determines to a large extent the layout, e.g. workstations in front of machinery). Second, office workplaces concern a growing percentage of the working population world-wide. For example, during the 20$^{th}$ century the percentage of office workers increased form 17% to over 50% of the work-force in USA, while the rest were working in agriculture, sales, industrial production and transportation (Czaja 1987). With the spread of information tech-nologies, the proportion of office workers is expected to further increase. Third, because cur-rent health problems encountered by office workers are to a great extent related to the in-appropriate layout of their workplaces (Marmaras & Papadopoulos 2003).

### 4.1. Generic types of office layouts

There is a number of generic types of office layouts (Shoshkes 1976, Zelensky 1998). The two extremes are on the one side the “private office”, where each worker has his personal closed space/room, and on the other the “open-plan”, where all the workstations are placed in a common open space. In between there is a multitude of combinations of private offices with open-plans. Workstation arrangements in open-plans can be either orthogonal, with single, double or fourfold desks forming parallel rows, or with the workstations arranged in groups, matching the organizational or functional structure of the work. A recent layout phi-losophy is the “flexible office”, where the furniture and the equipment are designed to be easily movable in order to be able to modify the workstations arrangement depending on the number of the people present at the office, as well as the running projects or work schemes (Brunnberg 2000). Finally, in order to respond to the current needs for flexibility in the or-ganization and structuring of the enterprises, as well as to reduce costs, a new trend in of-fice management is the “free address office” or “nonterritorial offices”, where workers do not have their proper workstation, but whenever at the office, they use the workstation they find free.

Each type of layout has its strengths and weaknesses. Private offices offer increased pri-vacy and better control of environmental conditions, fitting to the particular preferences and needs of their users. On the other hand, they are more expensive both in construction and maintenance, not easily modifiable to match changing organizational needs, and render co-operation and supervision difficult. Open-plan offices offer flexibility in changing organiza-tional needs and facilitate cooperation between co-workers but tend to suffer from environ-mental annoyances such as noise and suboptimum climatic conditions as well as lack of pri-vacy. To minimize the noise level as well as to create some sense of privacy in the open-plans, movable barriers may be used. To be effective, the barriers have to be at least 1.5 meters high and 2.5 meters wide. Furthermore, Wichman (1984) proposes the following spe-cific design recommendations to enhance the working conditions in an open-plan office:

- Use sound-absorbing materials on all major surfaces wherever possible. Noise is often more of a problem than expected.
- Equip the workstations with technological devices of low noise (printers, photocopy machines, telephones, etc). For example, provide telephones that flash a light for the first two “rings” before emitting an auditory signal.
- Leave some elements of design for the workstation user. People need to have control over their environments; so leave some opportunities for changing or rearranging things.
- Provide both vertical and horizontal surfaces for the display of personal belongings. People like to personalize their workstations.
- Provide several easily accessible islands of privacy. This would include small rooms with full walls and doors that can be used for conferences and private or long-distance telephone calls.
- Provide all private work areas with a way to signal willingness of the occupant to be disturbed.
- Have clearly marked flow paths for visitors. For example, hang signs from the ceiling showing where secretaries and department boundaries are located.
- Design workstations so it is easy for drop-in visitors to sit down while speaking. This will tend to reduce disturbances to other workers.
- Plan for ventilation air flow. Most traditional offices have ventilation ducting. This is usually not the case with open-plan cubicles, so they become dead-air cul-de-sacs that are extremely resistant to post hoc resolution.
- Over plan for storage space. Open-plan systems with their emphasis on tidiness seem to chronically underestimate the storage needs of people.

The decision about the generic type of layout should be taken by the stakeholders. The role of the ergonomist here is to indicate the strengths and weaknesses of each alternative, in order to facilitate the adoption of the most appropriate type of layout for the specific situation. After this decision has been taken, the design team should proceed to the detailed layout of the workstations. The next section describes a systematic method for this purpose.

### 4.2. An ergonomic method for office layout

This method proposes a systematic way to design workplaces for office work. The method aims at alleviating the design process for arranging the workstations, by decomposing the whole problem to a number of stages, during which only a limited number of ergonomic re-quirements are considered. Another characteristic of the method is that the ergonomic re-quirements to be considered have been converted to design guidelines (Margaritis & Mar-maras, 2003). Figure 9 presents the main stages of the method.

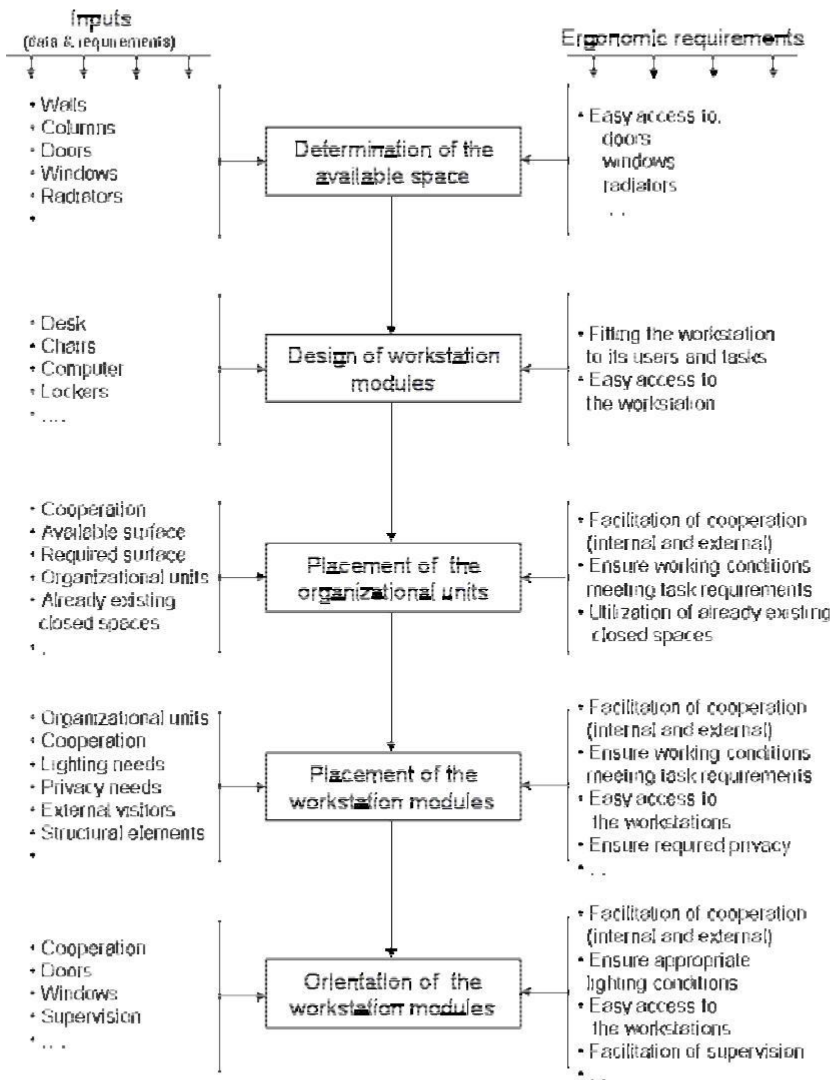



*Figure 9: The main stages of a method for office layout meeting the ergonomic requirements.*

Before starting the layout design, the design team should collect data concerning the ac-tivities that will be performed in the workplace designed and the needs of the workers. More specifically, the following information should be gathered:

- The number of people that will work permanently or occasionally.
- The organizational structure and the organizational units it comprises.
- The activities carried out by each organizational unit. Of particular interest are the needs for cooperation between the different units (and consequently the desired rela-tive proximity between them), the need for reception of external visitors (and conse-quently the need to provide easy access to them), as well as any other need related to the particularities of the unit (e.g. security requirements).
- The activities carried out by each worker. Of particular interest are the needs for co-operation with other workers, the privacy needs, the reception of external visitors, the specific needs for lighting, etc.
- The equipment required for each work activity (e.g. computer, printer, storage).

At this stage the design team should also get the detailed ground plan drawings of the space concerned including all elements which should be considered as fixed (e.g. structural walls, heating systems).

*1st stage: Determination of the available space*

The aim of this stage is to determine the space where no furniture should be placed, in order to ensure free passage by the doors and to allow the necessary room for elements such as windows and radiators, for manipulation and maintenance purposes.

To determine the free of furniture spaces the following suggestions can be used (Fig-ure 10):

Allow for

- an area of 50 cm in front of any window;
- an area of 3 m in front and 1 m at both sides of the main entrance door;
- an area of 1.50 m in front and 50 cm at both sides of any other door;
- an area of 50 cm around any radiator.

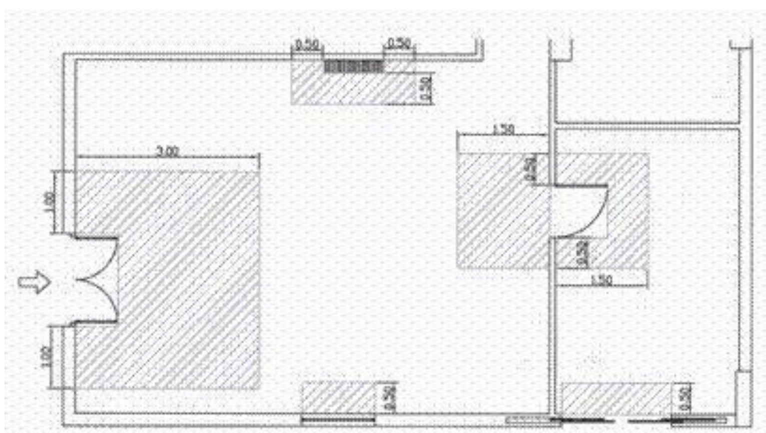



*Figure 10: Determining the available space.*

*2nd stage: Design of workstation modules*

The aim of this stage is to design workstation modules meeting the needs of the workers. Each module is composed by the appropriate elements for the working activities, i.e. desk, seat, storage cabinets, visitors' seats, and any other equipment required for the work. A free space should be provided around the furniture for passages between the workstations, as well as for unobstructed sitting and get up from the seat. This free space may be delimited in the following way (minimum areas):

Allow for:

- an area of 55 cm along the front side of the desk, or the outer edge of the visitor's seat;
- an area of 50 cm along the entry side of the workstation;
- an area of 75 cm along the back side of the desk (seat side)
- an area of 100 cm along the back side of the desk, if there are storage cabinets be-hind the desk.

A number of different modules will result from this stage, depending on particular work requirements (e.g. secretarial module, head of unit module, client service module) (Figure 11).

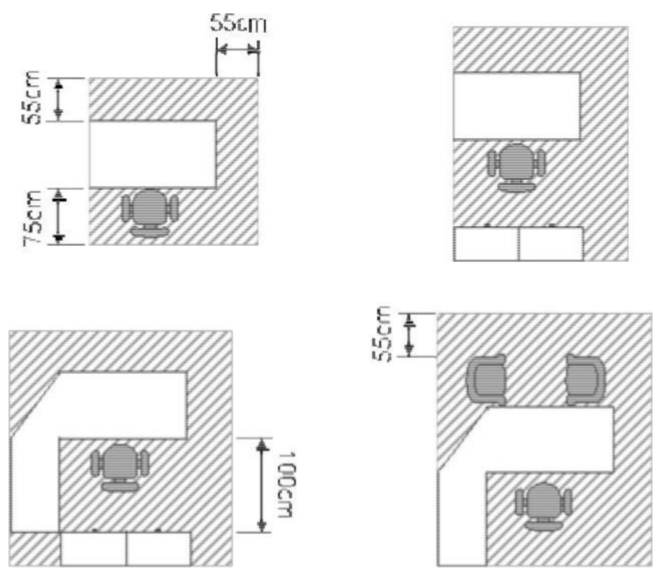



*Figure 11: Examples of workstation modules.*

Laying out by workstation modules instead of by individual elements such as desks, seats, etc, permits the designer to focus on the requirements related to the overall layout of the workplace, ensuring at the same time the compliance with the requirements related to the individual workstations.

*3rd stage: Placement of the organizational units*

The aim of this stage is to decide about the placement of the different organizational units (i.e. departments, working teams, etc) within the various free spaces of the building. There are five main issues to be considered here: (i) the shape of each space, (ii) the exploitable area of each space i.e. the area where workstations can be placed, (iii) the required area for each unit, (iii) the desired proximity between the different units, and (iv) eventual particular requirements of each unit which may determine their absolute placement within the building (e.g. the reception should be placed right next to the main entrance).

The exploitable area of each space, is an approximation of the "free of furniture spaces" defined at the first stage considering also narrow shapes where modules cannot fit. Specifically, this area can be calculated as follows:

$$A_{exploitable} = A_{total} - A_{where\ no\ modules\ can\ be\ placed}$$

Where:

$A_{total}$ is the total area of each space, and

$A_{where\ no\ modules\ can\ be\ placed}$ is the non exploitable area, where workstation modules should not or cannot be placed.

The required area for each organizational unit can be estimated considering the number of workstation modules needed and the area required for each module. Specifically, in order to estimate the required area for each organizational unit, $A_{required}$, one has to calcu-late the sum of the areas of the different workstation modules of the unit.

Comparing the exploitable area of the different spaces with the required area for each unit, the candidate spaces for placing the different units can be defined. Specifically, the candidate spaces for the placement of a particular unit are the spaces where:

$$A_{exoloitable} \geq A_{required}$$

Once the candidate spaces for each unit have been defined, the final decisions about the placement of organizational units can be taken. This is done in to steps. In the first step the designer designates spaces for eventual units which present particular placement re-quirements (i.e. reception etc.). In the second step he positions the remaining units consid-ering their desirable relative proximity plus additional criteria such as the need for natural lighting or the reception of external visitors. To facilitate the placement of the organizational units according to their proximity requirements, a *proximity table* as well as *proximity dia-grams* may be drawn.

The *proximity table* represents the desired proximity of each unit with any other one, rated by using the following scale:

*9*: The two units cooperate firmly, and should be placed close together.

*3*: The two units cooperate from time to time, and it would be desirable to be placed in proximity.

*1*: The two units do not cooperate frequently, and it is indifferent if they will be placed in proximity.

Figure 12 presents the proximity table of a hypothetical firm consisting of nine organiza-tional units. At the right bottom of the table, the Total Proximity Rate (TPR) has been calcu-lated for each unit, as a sum of its individual proximity rates. The TPR is an indication of the cooperation needs of each unit with all the others. Consequently, the designer should try to place the units with high TPRs at a central position.

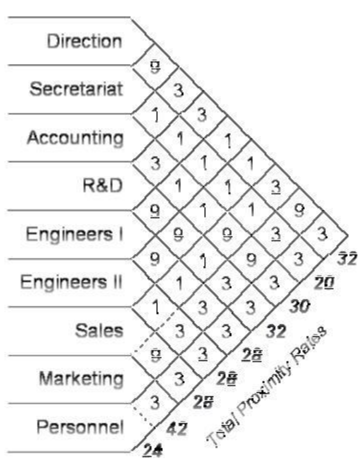



*Figure 12: The proximity table of a hypothetical firm.*

*Proximity diagrams* are a graphical method for the relative placement of organizational units. They facilitate the heuristic search for configurations which minimize the distance be-tween units with close cooperation. *Proximity diagrams* are drawn on a sheet of paper with equidistant points, like the one shown at Figure 13. The different units are alternated at the different points, trying to find out arrangements where the units with close cooperation will be as close as possible to each other. The following rules may be applied to obtain a first configuration:

- Place the unit with the highest TPR at the central point.
- If there are more that one units with the same TPR, place first the unit which has the most close proximity rates (9s).
- Go on by placing the units having the higher proximity rates with the ones that are al-ready positioned.
- In cases where more than one units have equal proximity rates with the one already positioned, place first the unit with the higher TPR.
- Go on in the same manner, until all the units have been positioned.

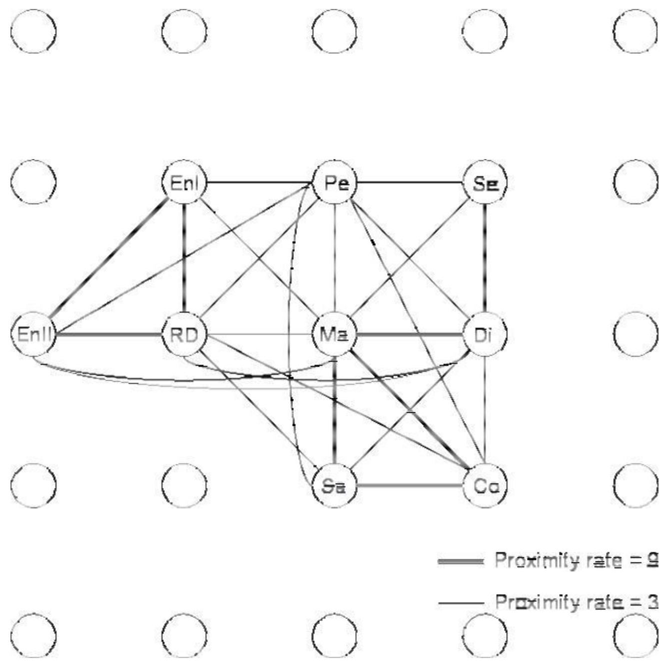



*Figure 13: Example of a proximity diagram.*

More than one alternative arrangements may be obtained in this way. It should be stressed that the proximity diagrams are drawn without taking into account the required area for each unit and the exploitable area of the spaces at which the units may be placed. Consequently, the arrangements drawn cannot be directly transposed to the ground plan of the building without modifications. Drawing the proximity diagrams is a means to facilitate the decision concerning the relative positioning between organizational units. As a method, it becomes useful in cases where the number of units is important.

*4th stage: Placement of the workstation modules*

Once the areas where the different organizational units will be placed have been determined (third stage), the placement of the workstations modules of each unit can start. The follow-ing guidelines provide help to meet the ergonomic requirements:

i. Place the workstations in a way that facilitates cooperation between co-workers. In other words, workers who cooperate tightly should be placed near each other.
ii. Place the workstations which receive external visitors near the entrance doors.
iii. Place as many workstations as possible near the windows. Windows may provide bene-fits besides variety in lighting and a view (Hall, 1966). They permit fine adjustment of light through curtains or venetian blinds and provide distant points of visual focus, which can relieve eye fatigue. Furthermore, related research has found that people strongly prefer the workstations placed near windows (Manning 1965, Sanders & McCormick 1970).
iv. Avoid placing the working persons in airstreams created by air-conditioners, open win-dows and doors.
v. Place the workstation modules in a way that forms straight corridors leading to the doors. The corridors width allowing for one person passage should be at least 60cm and for two persons passage at least 120cm (Alder, 1999).
vi. Leave the required space in front and to the sides of electric switches and wall plugs.
vii. Leave the required space for waiting visitors. In cases where waiting queues are ex-pected, provide at least a free space of 120cm width and *n* x 45cm length, where *n* is the maximum expected number of waiting people. Add to this length another 50cm in front of the queue.

*5$^{th}$ stage: Orientation of the workstation modules*

The aim of this stage is to define the direction of the workstations modules of each unit in a way to meet the ergonomic requirements. This stage can be carried out either concurrently with or after the previous phase. The following guidelines support this phase and should be applied judiciously as it may not always be possible to satisfy to all of them:

i. Orientate the workstations in such a way that there are no windows directly in front or behind the workers when they are looking towards a visual display terminal (VDT). In offices, windows play a role similar to lights: a window right in front of a worker dis-turbs through direct glare, while directly behind him, produces reflected glare. For this reason VDT workstations ideally should be placed at right angles to the windows. (Grandjean, 1997). (Figure 14)
ii. Orientate the workstations in such a way that there are no direct lighting sources within ± 40° in the vertical and horizontal direction from the line-of-sight, in order to avoid direct glare (Kroemer et al. 1994).
iii. Orientate the workstations in a way that allows workers to observe entrance doors.
iv. Orientate the workstations so as to facilitate the cooperation between members of work teams. Figure (15) shows alternative orientations of workstations, depending on the number of team members and the presence or not of a leader (Cummings et al. 1974).

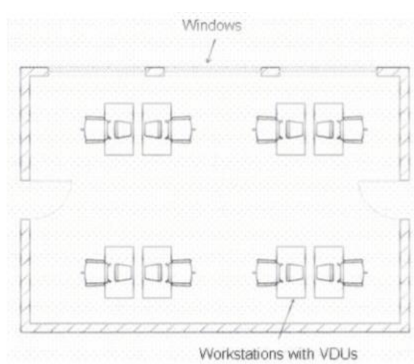



*Figure 14: Workstations with VDT ideally should be placed at right angles to the windows.*

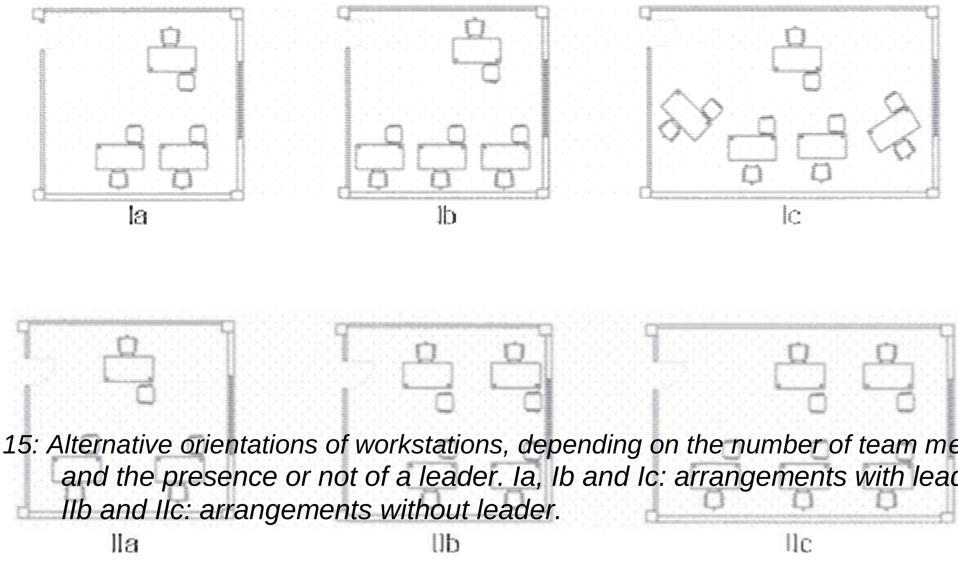



*Figure 15: Alternative orientations of workstations, depending on the number of team members and the presence or not of a leader. Ia, Ib and Ic: arrangements with leader; IIa, IIb and IIc: arrangements without leader.*

# EXPERIMENT - 6

## Aim: To conduct process capability study for a machine in the workshop.

## 1. Introduction

Machining is a general purpose manufacturing process for the manufacture of machine components and the performance evaluation of metal cutting machine tools is often based on their capability in machining work piece to specified details. The ISO standards had described the statistical methods of managing the machining process of

Sample work piece on machine tools. Process capability is the long-term performance level of a process brought under statistical control. Statistical process control is an excellent quality assurance tool to improve the quality of manufacture and ultimately scores on end-customer satisfaction. The process capability is the ability of the combination of the equipment to produce a product that will consistently meet the design requirements and the customer expectation. The analysis ensures that processes are fit for industrial specification and limiting the process variation is important in achieving product quality characteristics. A computational framework for control of machining system capability was discussed in. Process capability indices are effective tools for the continuous improvement of quality, productivity and managerial decisions. The indices form complementary system of measurement of process performance. The turning operation process capability indices could be evaluated towards measuring the performance of the process. The capability indices could be used to compare con-trolled process output to the specification limit desired. Process capability studies indicate if a process is capable of producing virtually all-conforming product.

Process capability indices performance measure of the machine operation has become very popular in assessing the capability of manufacturing processes hence determining the machine tool performance. More and more efforts have been devoted to studies and applications of process capability indices. A process capability index is a numerical summary that compares the behaviour of a product or process characteristic to engineering specifications. These measures are also often called capability or performance indices or ratios; we use capability index as the generic term. A capability index relates the voice of the customer (specification limits) to the voice of the process. A large value of the index indicates that the current process is capable of producing parts that, in all likelihood, will meet or exceed the customer's requirements. A capability index is convenient because it reduces complex information about the process to a single number. Capability indices have several applications, though the use of the indices is driven mostly by monitoring requirements specified by customers. Many customers ask their suppliers to record capability indices for all special product characteristics on a regular basis. The indices are used to communicate how well the process has performed. For stable or predictable processes, it is assumed that these indices also indicate expected future performance. Suppliers may also use capability in-dices for different characteristics to establish priorities for improvement activities. Similarly, the effect of a process change can be assessed by comparing capability indices calculated before and after the change. Designers had to deal with this by specifying tolerances, which are allowable variation from the normal values. Conceptual tolerance limits are designed requirements while the control limit depends on how the process actually operates. Process capability allows one to quantify by how well a process can produce acceptable product. The importance of tolerance and the control of manufacturing variation received increased strive to improve productivity and in the quality of the products. There is a realization that it is no longer acceptable to arbitrarily select the tolerances in engineering drawings, as the effects of tolerance assignment are better tolerated. The variation constrained or bounded by the tolerances also directly affect product performance and robustness of the design and poorly performing products will eventually lose their place in the market. The possibility of minimizing failure cost of electronic production processes by adjusting acceptance limits of such resulting product of the operation was analysed through simulation in.

The concept of the influence of the process parameters had also been focused. Revealed that the influence of the machine feed, diameter of the work piece, and diameter of the hole being bored on in a machining operation significantly influenced the tool wear rate. The effect of the machining parameter on the tool life for machining process was investigated by where the spindle speed was found to have an inverse influence on tool life and was more dominant than the effect of feed rate. Showed that the combined effect of cutting speed at it's lower level, feed rate and depth of cut at their higher values, and larger work piece diameter can result into increasing chip micro hardness during formation in machining. Attempt to study the effect of machining parameters on the surface characteristics and quality of machined part with respect to the specific cut-ting pressure, microstructural alteration and micro hardness of high speed dry turning of super alloy Inconel 718. Specific cutting pressure was discussed to have affected the machining process and tool capability. The effects cutting speed and feed rate on main cutting force and surface roughness were experimentally investigated by in which optimal and critical cutting parameters were determined. Cutting speed limit was determined to avoid formation of built up edge and layer during machining of AA6351 (T6) alloy with uncoated carbide inserts. The results of their study showed that the feed rate considerably affect the main cutting force and surface roughness of the product. In the investigation by, the surface roughness of a machined piece tends to decrease with in-creasing cutting speed during turning operation up to a specified limit while the roughness decreases with decreasing feed rate of the machine tool. Turning tests performed on nickel-based alloy show that the cutting speed during turning of the material had significant influence on the surface roughness and chip formation.

The ability to predict the accuracy of machine parts in a machining operation could provide possibility of obtaining optimal machining process and the ability to design a robust optimal performing machining system. The focus of this study is to investigate the process capability of turning on the general purpose AJL180-325VS Gap Bed Lathes machine installed for student training for purpose of industrial application. The machine was investigated to determine its suitability for machining operation at specified tolerance limit as may be required by the industrial clients.

## 2. Experimental Procedure

The experimental procedure includes the selection of the specific materials, machine and the machining operation required for the capability study.

### 2.1. Materials

The work materials used for the study was the annealed cold drawn SAE 1050 high carbon steel material of 50 (xxi) Diameter cut to length of 300 mm for each work piece. The typical properties of the steel include the elastic modulus of 210 GPa, tensile strength of 636 MPa, yield strength of 369.4 MPa, hardness of 187 HB with impact strength of 16.9 J annealed at 790˚C. The general purpose AJL180-325VS Gap Bed Lathes machine of 300 mm turning length capacity installed with 250 mm chuck diameter was used with a High Speed Steel (HSS) single point cutting tool of 5˚ rake angle and 8˚ relief angle with nose radius of 0.5 mm was used for the cutting process. The work-piece measurements were taken using the digital Vanier Calliper and the statistical process control (SPC) software was used for the analysis of the data which were recorded on statistical data sheet.

### 2.2. Methods

The process capability study involve the generation of data from the shaft turning. The procedure for the study include Selection of the candidate material, evaluating the measurement system, preparing the control plan, analysing data samples, estimating the process capability and establishing a plan for continuous turning process improvement.

The key parameters considered for purpose of viewing the machine tool capability are the cutting speed, the feed rate and the depth of cut. The straight turning operation shown schematically in **Figure 1 was done for ninety (90) test piece at spindle speed of 300 rpm - 500 rpm, with feed rate 0.25 - 0.5 mm/rev at a depth of cut of 0.01 mm for nominal diameter of 40 mm with specification limit of 40f7 (tolerance of 0.025 ± 0.050). Roughly drilled hole are finished to specification H8 on each test piece to exact size by using a reamer which was mounted on the lathe tailstock. The cutting operation for the steel was performed at room temperature of 25˚C.**

The Spindle speed, $N$, for the cutting process was obtained from Equation (1)

$$N = \frac{v \times 1000}{\pi D} \quad (1)$$

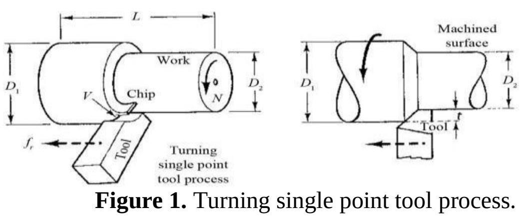



**Figure 1.** Turning single point tool process.

Where: $v$ is the cutting speed measured "*m*/min" and $D$ is the work-piece diameter measured in "mm". Moving range of two successive observations was used to determine the variability employed in deriving the control limits for the process. The variability of the process was measured in terms of the distribution of the absolute value of the difference of every two of the successive observations. The control limit were obtained from Equations (2)-(8)

$$\bar{x} = \frac{\sum_{j=1}^{n} x_j}{n}$$

Where x the process mean, *j* is the number of observation ranging *n* observation, and *n* is the subgroup size.

Moving range: $R = \sum_{j=1}^{n} x_i - x_{j-1}$

Average moving range : $\bar{R} = \frac{\sum_{j=1}^{n} \left| x_i - x_{j-1} \right|}{N}$

Upper Control Limit, UCL = $\bar{x} + A_2\bar{R}$ for x-bar chart

Lower Control Limit, LCL = $\bar{x} - A_2\bar{R}$ for x bar chart

Upper Control Limit, UCL = $D_4\bar{R}$ for R-bar chart

Lower Control Limit, LCL = $D_3\bar{R}$ for R bar chart

Where A2, D3, D4 are control chart constants which depends upon the size of the subgroup of the data.

The process capability indices, process average, and the standard deviation were obtained from the process data assuming that the data is normally distributed. The capability indices are obtained from the following expressions.

$$C_p = \frac{UCL - LCL}{6\sigma} \quad (9)$$

$$C_{pk} = \min\left(\frac{UCL - \bar{x}}{3\sigma}, \frac{\bar{x} - LCL}{3\sigma}\right) \quad (10)$$

where $C_p$ is the process capability for two-sided specification limit, irrespective of process centre, $C_{pk}$ is the process capability for two-sided specification limits accounting for process centring and $\sigma$ is the standard deviation. The statistical process control (SPC) technique was used to assure that the process remains stable. The output of the turning process was compared with the specification limit using the capability indices.

## 3. Results

**Table 1** shows the data obtained for three attempt of the turning process at various speed and feed rate of the operation.

**Figure 2** shows the control chart for the machining operation. The Process Control Chart shows that the data points fell within the control limits. The moving range chart also indicates that all the data points are within the control limits indicating that the process is in statistical control and hence is under control and stable. Consequent upon this premise, the process capability evaluated by the use of capability indices via the SPC software is shown in **Figure 2(b)**.

For the subgroup size of $n = 3$, the control chart constants are obtained as, $A_2 = 1.023$, $D_3 = 0$, $D_4 = 2.574$, $d_2 = 1.693$

The control limits are thus obtained as shown in **Table 2**.

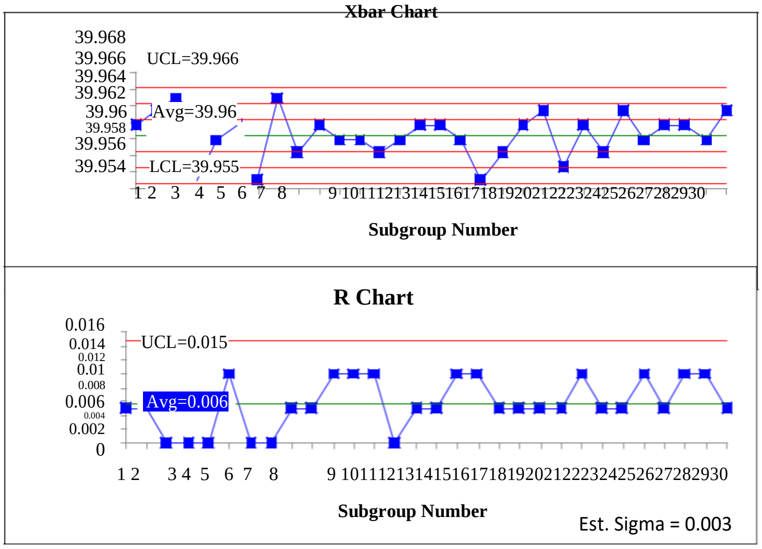
The process capability indices were obtained for the process data as $C_p = 0.58$ and $C_{pk} = 0.58$. This implied that the process is placed exactly at the centre of the specification limits. And since $C_p < 1$ the process is considered not adequate. The machine capability for industrial application is therefore not adequate and the proce

**Table 1.** Influence of cutting speed and feed rate on the machining tolerance limit of the center lathe.

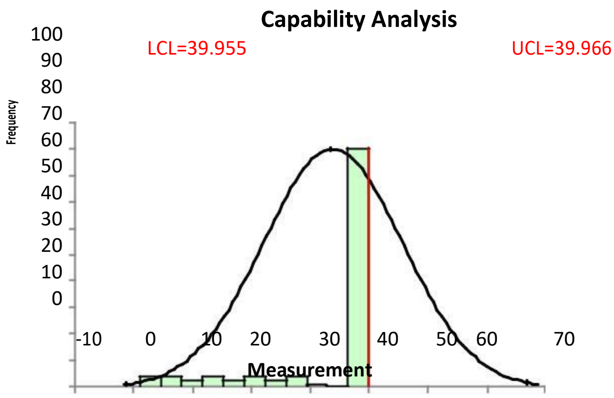
| Sub-group/No. | Speed (rpm) | Feed/rev. (mm) | Shaft diameter (mm) Attempt 1 | Attempt 2 | Attempt 3 | Ave. dia. (mm) |
|---|---|---|---|---|---|---|
| 1 | 300 | 0.25 | 39.960 | 39.965 | 39.960 | 39.962 |
| 2 | 400 | 0.30 | 39.965 | 39.960 | 39.965 | 39.963 |
| 3 | 500 | 0.50 | 39.965 | 39.965 | 39.965 | 39.965 |
| 4 | 300 | 0.25 | 39.955 | 39.955 | 39.955 | 39.955 |
| 5 | 400 | 0.30 | 39.960 | 39.960 | 39.960 | 39.960 |
| 6 | 500 | 0.50 | 39.965 | 39.965 | 39.955 | 39.962 |
| 7 | 300 | 0.25 | 39.955 | 39.955 | 39.955 | 39.955 |
| 8 | 400 | 0.30 | 39.965 | 39.965 | 39.965 | 39.965 |
| 9 | 500 | 0.50 | 39.960 | 39.955 | 39.960 | 39.958 |
| 10 | 300 | 0.25 | 39.960 | 39.965 | 39.960 | 39.962 |
| 11 | 400 | 0.30 | 39.955 | 39.965 | 39.960 | 39.960 |
| 12 | 500 | 0.50 | 39.960 | 39.965 | 39.955 | 39.960 |
| 13 | 300 | 0.25 | 39.965 | 39.955 | 39.955 | 39.958 |
| 14 | 400 | 0.30 | 39.960 | 39.960 | 39.960 | 39.960 |
| 15 | 500 | 0.50 | 39.960 | 39.960 | 39.965 | 39.962 |
| 16 | 300 | 0.25 | 39.960 | 39.965 | 39.960 | 39.962 |
| 17 | 400 | 0.30 | 39.965 | 39.960 | 39.955 | 39.960 |
| 18 | 500 | 0.50 | 39.960 | 39.950 | 39.955 | 39.955 |
| 19 | 300 | 0.25 | 39.955 | 39.960 | 39.960 | 39.958 |
| 20 | 400 | 0.30 | 39.960 | 39.960 | 39.965 | 39.962 |
| 21 | 500 | 0.50 | 39.960 | 39.965 | 39.965 | 39.963 |
| 22 | 300 | 0.25 | 39.955 | 39.955 | 39.960 | 39.957 |
| 23 | 400 | 0.30 | 39.965 | 39.955 | 39.965 | 39.962 |
| 24 | 500 | 0.50 | 39.960 | 39.960 | 39.955 | 39.958 |
| 25 | 300 | 0.25 | 39.960 | 39.965 | 39.965 | 39.963 |
| 26 | 400 | 0.30 | 39.955 | 39.960 | 39.965 | 39.960 |
| 27 | 500 | 0.50 | 39.960 | 39.965 | 39.960 | 39.962 |
| 28 | 300 | 0.25 | 39.965 | 39.955 | 39.965 | 39.962 |
| 29 | 400 | 0.30 | 39.965 | 39.960 | 39.955 | 39.960 |
| 30 | 500 | 0.50 | 39.960 | 39.965 | 39.965 | 39.963 |

**Table 2**. Control limit values or turned shaft data.

| | Center line | Control limits *UCL* | *LCL* | Std. dev. |
|---|---|---|---|---|
| x bar chart | 39.96 | 39.966 | 39.955 | 0.003 |
| R chart | 0.006 | 0.015 | 0 | |




(a)




(b)

Figure 2. (a) Turning process control chart; (b) Process capability plot for the shaft turning process.

centring is also considered inadequate. In this circumstance, the $C_{pk}$ index is used to interpret the capability of the process. It therefore could be deduced that the process at varying feed rate and spindle speed is not capable of producing the quality required for the specified shaft. The machine settings are therefore not favourable and the process need be revisited to take the mean back towards the centre.

## 4. Conclusion

The result of analysis of the data collected indicates that, the process is not capable of consistently bringing out shafts with diameter falling well within the customer's expectation, even though it remained in statistical control. Also, the process is not acceptable. The process owner cannot claim that the customer will not experience difficulty in the use of products which translate into losses. The reliability of such product resulting from the process cannot therefore be guaranteed.

# EXPERIMENT - 7

**Aim**: To design a sampling scheme based on OC curve.

## 1 Introduction

Acceptance sampling is an inspecting procedure applied in statistical quality control. It is a method of measuring random samples of populations called "lots" of materials or products against predetermined standards. Acceptance sampling is a part of operations management or of accounting auditing and services quality supervision. It is important for industrial, but also for business purposes helping decision-making process for the purpose of quality management.

Sampling plans are hypothesis tests regarding product that has been submitted for an appraisal and subsequent acceptance or rejection. The products may be grouped into batches or lots or may be single pieces from a continuous operation. A random sample is selected and could be checked for various characteristics. For lots, the entire lot is accepted or rejected in the whole. The decision is based on the pre-specified criteria and the amount of defects or defective units found in the sample. Accepting or rejecting a lot is analogous to not rejecting or rejecting the null hypothesis in a hypothesis test. In the case of continuous production process, a decision may be made to continue sampling or to check subsequent product 100%.

The hypotheses for acceptance sampling plan as a kind of statistical test are:

$H_0$ *...The lot is of acceptable quality*

(1)

$H_1$*...The lot is not of acceptable quality*.

Rejecting the lot is the same as rejecting the null hypotheses $H_0$.

If the quality controls have broken down, the sampling will prevent defective products from passing any farther. There are a number of different methods widely used for selecting a product for checking quality characteristics:

(xxii) No checking;
(xxiii) 100% checking;
(xxiv) Constant percentage sampling;
(xxv) Random spot checking;
(xxvi) Audit sampling (with no acceptance and rejection criteria); and
(xxvii) Acceptance sampling.

Acceptance sampling is based on probability and is the most widely used sampling technique all through industry. Many sampling plans are tabled and published and can be used with little guidance. The Dodge-Romig Sampling Inspection Tables are an example of published tables. Some applications require special unique sampling plans, so an understanding of how a sampling plan is developed is important. In acceptance sampling, the risks of making a wrong decision are known.

In some previous research findings in from studying an audit sampling based on acceptance sampling applications using other software are showed considering $\alpha$ - the management risk, and $\beta$ - the risk of audit results users. The paper

Presents the author's research results achieved using sampling methods and methods of statistical quality control in the analysis of audit risks that are caused by sampling. Using the audit hypothesis testing model and substantive test based on hypothetical examples, the following relationships were recognized: inverse proportionality between the risk $\alpha$ and the risk $\beta$ ; inverse proportionality

between $\beta$ risk and specific audit risks called

inherent, control and analytical procedures risks. The sample size was inversely proportionate to: the levels of the risk $\alpha$ , and of the acceptable precision (A), and to the size of tolerable misstatement (TM), as well. The value of precision *A* would increase if the risk $\beta$ would increase.

When analysing OC curves of an acceptance sampling plan selected, the conclusion arose that, with fixed values of other relevant factors ( $\alpha$ , AQL and LTPD), an inverse proportionality between the risk of incorrect acceptance of an audit population, which is the risk $\beta$ of audit resultsusers, and the needed sample size n existed. When changing on low levels the management risk $\alpha$ , which is the risk of incorrect rejection of an audit population, with unchanged values of other relevant factors ( $\beta$ , AQL and LTPD), the needed sample size n does not change visibly.

# 2 Problem Formulation

## 2.1 Types of Risks in Acceptance Sampling

Because an entire lot of material is not being inspected, not everything is known, so, sampling will always incur certain risks. Only the sample is known.

This incurs the risk of making two types of errors in «the accept : not accept» decision.

A lot may be rejected that should be accepted and the risk of doing this is the producer's risk.

The second error is that a lot may be accepted that should have been rejected and the risk of doing this is called the consumer's risk.

But, it is a good thing that these two risks could be measured.

The Type I Error, called significance level, is preset on with quite low level, most at 5% (or 1% or 10%), to protect of this type of error. It is true that:

19. $= P\{Type\ I\ Error\}$

$$\alpha = P\{rejected\ H_0 \mid H_0\ is\ true\}, \qquad (2)$$

and

16. $= P\{not\ rejected \mid H_0\ \ H_0\ is\ false\}$

$$\beta = P\{Type\ II\ Error\}. \qquad (3)$$

The power of the test is equal to:

$$Power = 1 - \beta = P\{rejected\ H_0 \mid H_0\ is\ false\}. \quad (4)$$

Because the probability of committing a Type I Error ($\alpha$ ) and the probability of committing Type II Error ( $\beta$ ) have an inverse relationship and the letter is the complement of the power of the test (1-

15 ), then $\alpha$ and the power of the test vary directly.

An increase in the value of the level of significance ($\alpha$ ) results in and increase in power, and a decrease in $\alpha$ results in a decrease in power. An increase in the size of the sample *n* chosen results in an increase in power and vice versa.

## 2.2. Designing an Acceptance Sampling Plan

Acceptance sampling is defined as an inspection procedure used to determine whether to accept or reject a specific quantity of goods or materials.

The best sample plan minimizes producer's risk of rejecting an acceptable lot and customer's risk of receiving bad product. There are many possibilities to solve this problem, e.g. see computerized solutions in.

Nowadays, as more companies start to apply quality programs, such as Total Quality Management (TQM) approach, they work closely with suppliers to ensure high levels of quality and the need for acceptance sampling plans is decreasing. The goal is that no defect items should be entered into the production process, passed from a producer to a customer, which could be an external or an internal customer. In reality many firms must check their materials inputs.

The basic procedure for acceptance sampling is quite simple: (1) A random sample is taken from a large quantity of items and tested or measured relative to the quality characteristic of interest. (2) If the sample passes the test, the entire quantity called a lot of items is accepted. (3) If the sample fails the test, two scenarios are possible: either the entire quantity of items is subjected to 100 percent inspection and all defective items would be repaired or replaced, or the whole quantity is returned to the supplier. Designing an acceptance sampling plan is making a decision about quality and risk. Acceptance sampling involves both the producer or supplier of materials, and the consumer or buyer. Consumers need acceptance sampling to limit the risk of rejecting good-quality materials or accepting bad-quality materials. Consequently, the consumer, sometimes in conjunction with the producer through contract specifications, determines the parameters of the plan. Any firm can be in a production chain, so can be both a producer of goods purchased by another firm and a consumer of goods or raw materials supplied by another firm.

When designing an acceptance sampling plan two levels of quality are considered: first, acceptable quality level, and, second, the unacceptable or worst quality level.

The first is the quality level desired by the consumer and is called the limit quality or the acceptable quality level (AQL). The producer's risk

is the risk that the sampling plan will fail to verify an acceptable lot's quality AQL and, thus, reject it. This kind of risk is also called a Type I Error of the plan. Most often the producer's risk is preset at $\alpha$ =0.05, or 5%. Both, producers and consumers also are interested in a low producer's risk, because of the high costs of sending back good materials or products, which could cause interruption and delay of a production process or make poor relations with the partners.

The second, unacceptable level of quality is the worst level of quality that the consumer can tolerate and it is called the lot tolerance proportion (or percent) defective (LTPD). The probability of accepting a lot with LTPD quality is the

consumer's risk $\beta$ , or the Type II Error of the

plan. In the praxis a common value for the consumer's risk is set as LTPD=0.10, or 10%.

Three often used attribute sampling plans are the single-sampling plan, the double-sampling plan, and the sequential sampling plan. Analogous variable sampling plans also have been devised for variable measures of quality. Different types of acceptance sampling plans are designed to provide a specified producer's and consumer's risk. It is in the consumer's interest to keep the Average Number of Items Inspected (ANI) to a minimum because that keeps the cost of inspection low.

The single-sampling plan is a decision rule to accept or reject a lot based on the results of one random sample from the lot. The procedure is to take a random sample of size n and inspect each item. If the number of defects does not exceed a specified acceptance number c, the consumer accepts the entire lot. Any defects found in the sample are either repaired or returned to the producer. If the number of defects in the sample is greater than c, the consumer subjects the entire lot to 100 percent inspection or rejects the entire lot and returns it to the producer.

Accepted lots and screened rejected lots are sent to their destination. The rejected lots may be submitted for repeated inspection.

In a double-sampling plan: (1) management specifies two sample sizes ($n_1$ and $n_2$) and two acceptance numbers ($c_1$ and $c_2$); (2) If the quality of the lot is very good or very bad, the consumer can make a decision to accept or reject the lot on the basis of the first sample, which is smaller than in the single-sampling plan. To use the plan, the consumer takes a random sample of size $n_1$; (3) If the number of defects is less than or equal to $c_1$, the consumer accepts the lot; (4) If the number of defects is greater than $c_2$, the consumer would reject the lot; (5) If the number of defects is between $c_1$ and $c_2$, the consumer would take a second sample of size $n_2$; (6) If the combined number of defects in the two samples is less than or equal to $c_2$, the consumer would accept the lot. Otherwise, it is rejected. This plan is also called a «lot by lot double-sampling». Rejected lots are detailed or scrapped and accepted lots and detailed rejected lots are sent to their destination.

The sequential sampling plan is a further refinement of the double- and multiple-sampling concept. The inspector will select one part from the lot and check for the specified requirements.

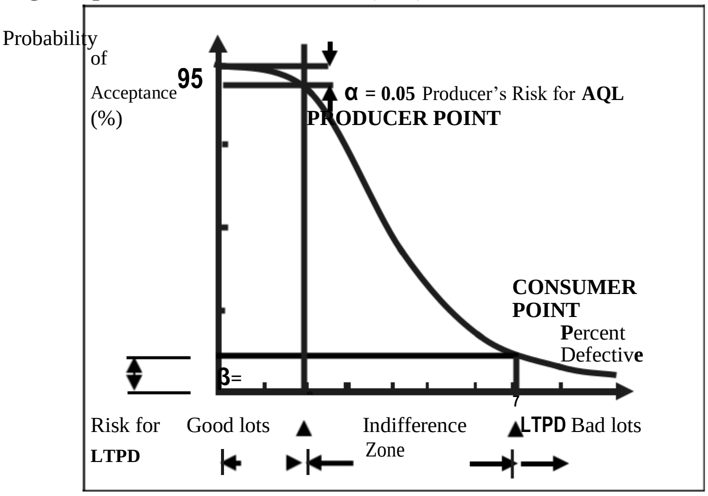
So called continuous sampling is used where product flow is continuous and not feasible to be formed into lots, described in.

## 2.3 Operating Characteristic (OC) Curve

Analysts create a graphic display of the performance of a sampling plan by plotting the probability of accepting the lot for a range of proportions of defective units. This graph, called an OC curve, describes how well a sampling plan discriminates between good and bad lots.

Undoubtedly, every manager wants a plan that accepts lots with a quality level better than the AQL 100 percent of the time and accepts lots with a quality level worse than the AQL zero percent of the time. An OC curve is developed by determining the probability of acceptance for several values of incoming quality. An OC curve showing producer's risk $\alpha$ and consumer's risk $\beta$ is given in Fig.1.

Fig.1 Operation Characteristic (OC) Curve




On the vertical axis is the probability of acceptance and this is the probability that the number of defects or defective units in the sample is equal to or less than the acceptance number c of the sampling plan.

The units on the abscissa are in terms of percent defective. The AQL is the acceptable quality level in percentages and the LTPD is lot tolerance percent defective. The producer's risk $\alpha$ is the probability of rejecting a lot of AQL quality, i.e. Type I Error. The consumer's risk $\beta$ is the probability of accepting a lot of LTPD quality, i.e. Type II Error.

Although the hypergeometric may be used when the lot sizes are small (finite), the binomial and Poisson are by far the most popular distributions to use when constructing sampling plans (for infinite lots from processes), compare to.

# 3 Problem Solution

The sampling distribution for the single-sampling plan is the binomial distribution because each item inspected is either defective or not. The probability of accepting the lot equals the probability of taking a sample of size n from a lot.

How can management change the sampling plan to reduce the probability of rejecting good lots and accepting bad lots? To answer this question, let us see how n and c affect the shape of the OC curves. A better single-sampling plan would have a lower producer's risk $\alpha$ and a lower consumer's risk $\beta$ .

Sampling plans may be constructed to meet certain criteria and to insure that the specified outgoing quality levels are met. In the construction of a lot by lot single-sampling plan, four parameters must be determined prior to determining the sample size n and acceptance number c. The parameters are: the acceptable quality level AQL; the risk $\alpha$ ; the lot tolerance percent defective LTPD; and the risk $\beta$ .

In most situations the objective is to find a sample size n and acceptance number c whose OC curve meets the above parameters. In this paper, first, the effect of sample size n and then the effect of acceptance number c on the shape of the OC curve will be discussed. After that, the effect of changing AQL and LTPD will be briefly overviewed.

### 3.1 Sample Size Effect on OC Curve

The question is what would happen if the sample size n would increase with the acceptance number left unchanged at c=1?

Different values of the producer’s and consumer’s risks are shown in the Table 1,

Table 1 The Producer's Risk and the Consumer's Risk in OC Curve for Given AQL and LTPD with Fixed c=1 and Changing Sample Size n

| | Acceptance level c=1 | |
|---|---|---|
| Sample Size n | Producer's Risk $\alpha$ (for a given AQL=1%) | Consumer's Risk $\beta$ (for a given LTPD=5%) |
| 30 | 0,0361 | 0,5535 |
| 40 | 0,0607 | 0,3991 |
| 50 | 0,0894 | 0,2794 |
| 60 | 0,1212 | 0,1916 |
| 70 | 0,1553 | 0,1292 |
| 80 | 0,1908 | 0,0861 |
| 90 | 0,2273 | 0,0567 |
| 100 | 0,2642 | 0,0371 |
| 110 | 0,3012 | 0,0241 |
| 120 | 0,3377 | 0,0155 |
| 130 | 0,3737 | 0,0100 |
| 140 | 0,4089 | 0,0064 |
| 150 | 0,4430 | 0,0041 |

Fig.2 OC Curve for n=30, c=1, AQL=1%, LTPD=5%, $\alpha$ =0,0361, $\beta$ =0,5535, and Probability of Acceptance =(1-$\alpha$ )=0,9639.

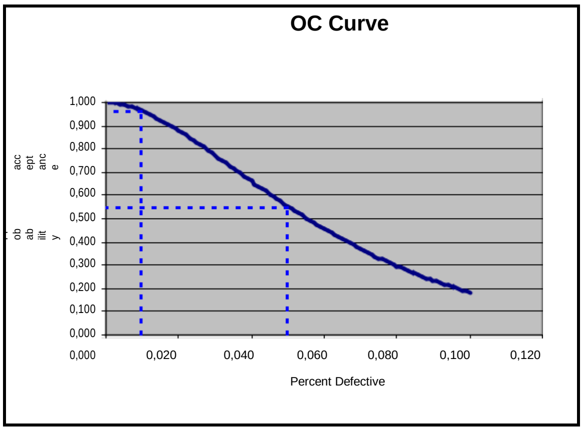



Fig.3 OC Curve for n=80, c=1, AQL=1%, LTPD=5%, $\alpha$ =0,1908, $\beta$ =0,0861, and Probability of Acceptance =(1-$\alpha$ )=0,8092.

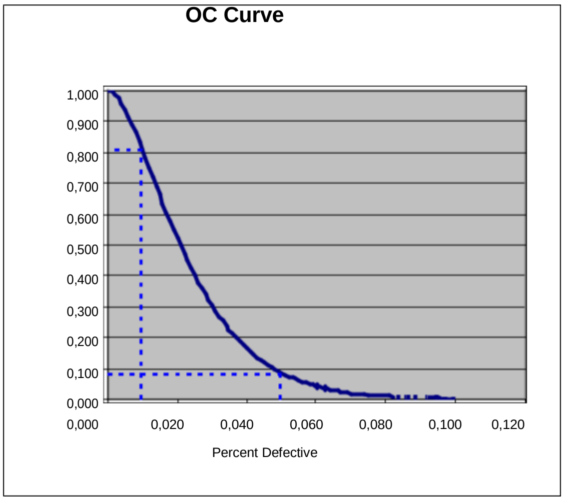



Fig.4 OC Curve for n=150, c=1, AQL=1%, LTPD=5%, $\alpha$ =0,4430, $\beta$ =0,0041, and Probability of Acceptance = (1-$\alpha$ )=0,557.

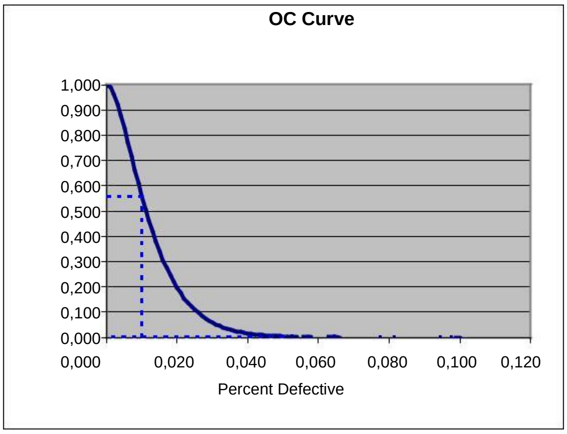



Table 1 presents an OC curve results for producer's risk $\alpha$ and consumer's risk $\beta$ with desired values of AQL=1%, LTPD=5%. The sample size n is changing, while c=1. It could be seen how the OC curve responds. Effects of increasing sample size on the OC curve while holding acceptance number c=1 constant could be noticed in Fig.2, Fig.3 and Fig.4., created using ExcelOM2 software. Increasing n while holding c constant increases the risk $\alpha$ and reduces the risk

4..

### 3.2 Acceptance Number Effect on OC Curve

The results of increasing acceptance number from c=1 to c=2, while holding sample size n on the same levels as in Table 1, are showed in Table 2.

Increases in the acceptance number from one to two lowers the probability of finding more than two defects and, consequently, lowers the producer's risk $\alpha$ .

Table 2 The Producer's Risk and the Consumer's Risk in OC Curve for Given AQL and LTPD with Fixed c=2 and Changing Sample Size n

| | Acceptance level c=2 | |
|---|---|---|
| Sample Size n | Producer's Risk $\alpha$ (for a given AQL=1%) | Consumer's Risk $\beta$ (for a given LTPD=5%) |
| 30 | 0,0033 | 0,8122 |
| 40 | 0,0075 | 0,6767 |
| 50 | 0,0138 | 0,5405 |
| 60 | 0,0224 | 0,4740 |
| 70 | 0,0333 | 0,3137 |
| 80 | 0,0466 | 0,2306 |
| 90 | 0,0619 | 0,1664 |
| 100 | 0,0794 | 0,1183 |
| 110 | 0,0987 | 0,0829 |
| 120 | 0,1196 | 0,0575 |
| 130 | 0,1421 | 0,0395 |
| 140 | 0,1658 | 0,0269 |
| 150 | 0,1905 | 0,0182 |

However, raising the acceptance number for a given sample size increases the risk of accepting a bad lot $\beta$ . An increase in the acceptance number from c=1 to c=2 increases the probability of getting a sample with two or less defects and, therefore, increases the risk $\beta$ . Thus, to improve single-sampling acceptance plan, management should increase the sample size n, which reduces the risk $\beta$ , and increase the acceptance number c, which reduces the risk $\alpha$ .

Comparison of Fig.2 with Fig.5 and Fig.3 with Fig.6, shows the following principle: Increasing the critical value for an acceptance number c, while holding the sample size n constant, decreases the producer's risk $\alpha$ , and increases the consumer's risk $\beta$ . The results for risks in Table 1 and Table 2 support the respective images.

Fig.5 OC Curve for n=30, c=2, AQL=1%, LTPD=5%, $\alpha$ =0,0033, $\beta$ =0,8122, and Probability of Acceptance =(1-$\alpha$ )=0,9967.

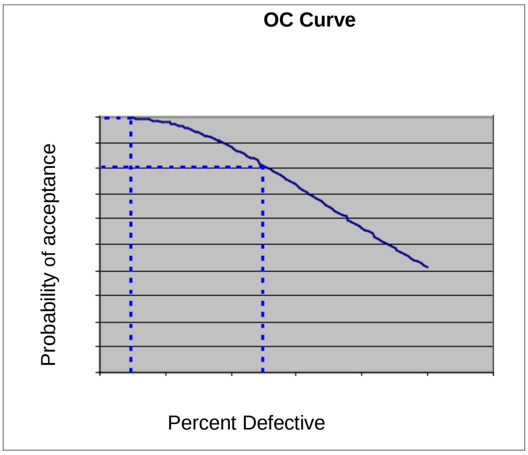
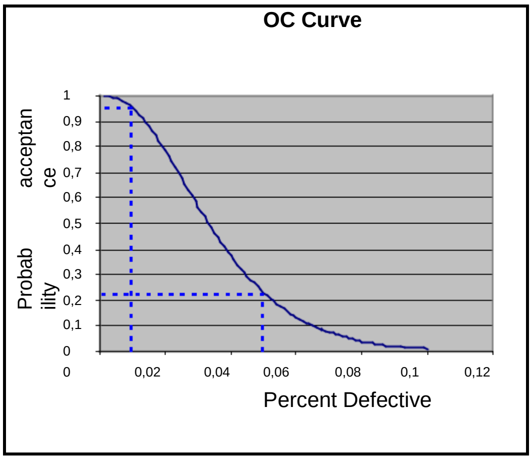


Fig.6 OC Curve for n=80, c=2, AQL=1%, LTPD=5%, $\alpha$ =0,0466, $\beta$ =0,2306, and Probability of Acceptance =(1-$\alpha$ )=0,9534.




## 4 Conclusions

Acceptance sampling is concerned with the decision to accept or reject a lot (or batch) of goods. The design of the acceptance sampling process includes decisions about sampling versus complete inspection, attribute versus variable measures, AQL, $\alpha$ , LTPD, $\beta$ , and sample size.

Management can select the best plan (choosing sample size n and acceptance number c) by using an operating characteristic (OC) curve.

If the sample size n is increased, with c, AQL and LTPD fixed, the OC curve would change so that the producer's risk $\alpha$ increases while consumer's risk $\beta$ decreases. Further, with increasing the critical value c, and with n, AQL and LTPD fixed, the probability being the producer's risk − would decrease, but the probability for consumer's risk $\beta$ would increase.