# REVERSE ENGINEERING OF LEGO CUBE (EXERCISE A)

PROF. ALBERTO BOSCHETTO

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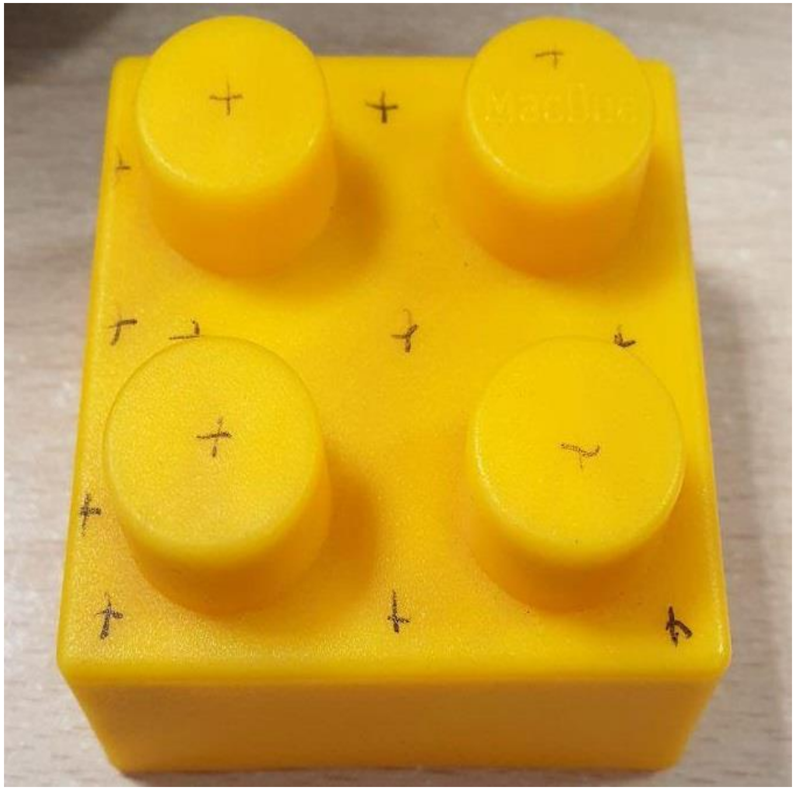
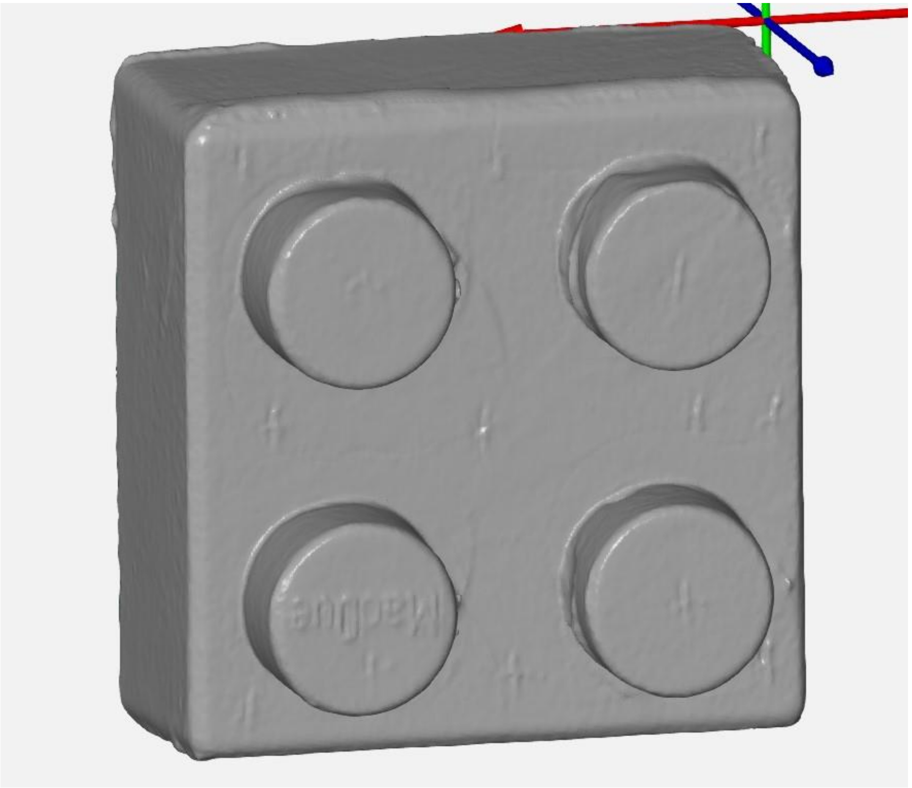
# OBJECTIVE

Observations describing how and where the measured object is different from modeled one:





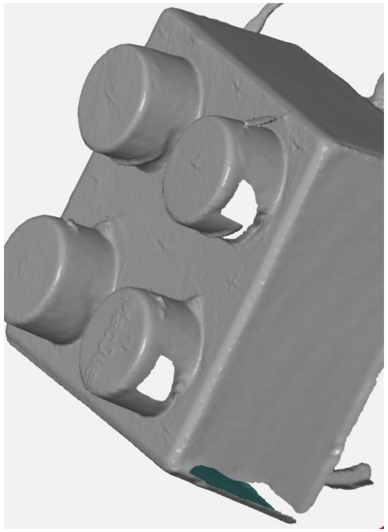
# SCANNING METHODOLOGY

- This is Reverse Engineering where we want to detect planes by giving a special wavelength (of laser) that gets return to our eyes. We want to couple this wavelength by sub diving during the assessment with color.
- Parameters used for the setup: Resolution: 4.4k points square inch and the focus: 6.5 inches.
- We took 3 scans to develop the STL model of the object.
- After the first scan: Texturing or the aesthetics: even if we do not need the color, the texture is used by the algorithm in order to have a coherent retrieving of x, y, z of a point. This scan was taken on a fixed platform.
- We ensured the surface of the object to be scanned is orthogonal.
- For the second scan we gave 15 degrees rotation to the platform.
- For the third scan we rotated the platform by a large angle.

# ANALYSIS OF THE STL MODEL

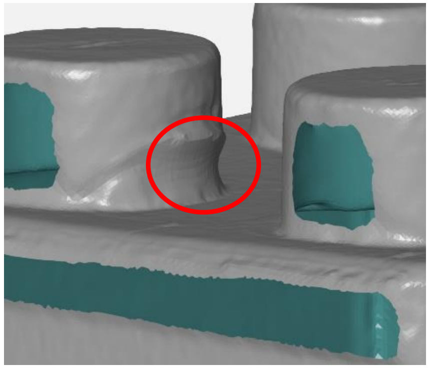
- During visual analysis we observe following defects which are listed below :

  1) Holes



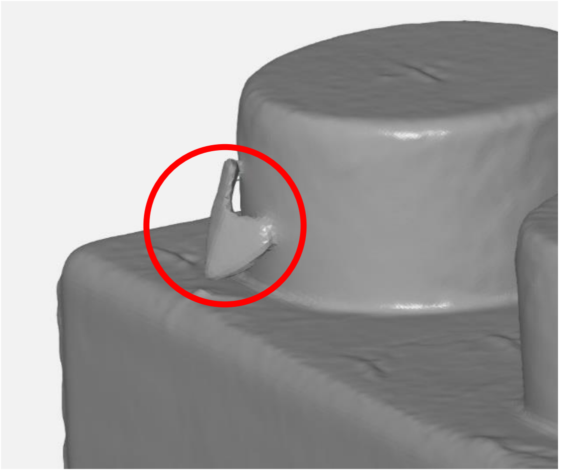
  2) Additional Elements

  3) Craters



# ANALYSIS OF THE STL MODEL

4) Surface Extrusions



- This defects are due to scanning process:
- To differentiate the inside and outside surfaces of our MODEL, we have considered the Right-Hand Thumb Rule.
- Surface was characterize by small angle that is quite parallel to the light , in this condition the retrieving was affected by large scattering of the results.
- We could recognize the resolution as used in a way which we see the surface orthogonally, if the surface is not orthogonal , the density of the point is reduced along with projection.
- If the object is not completely opaque to the wavelength , we have a diffusion inside the object. Even if the object is opaque but a part of the energy still trespasses and go to the substrates of the surface so this result in some diffusion and hence inaccuracy. This results in improper triangulation and hence causes to discontinuous of surface.

# ANALYSIS OF CAD MODEL

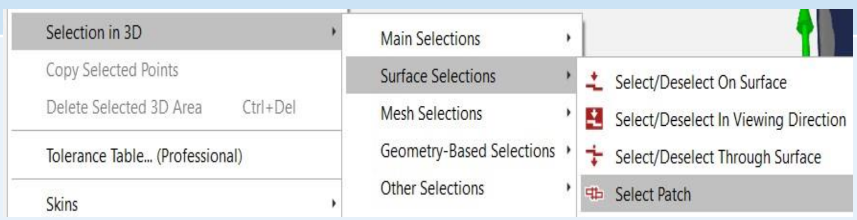
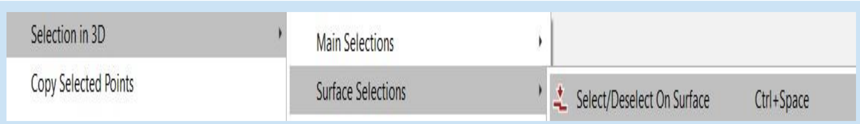
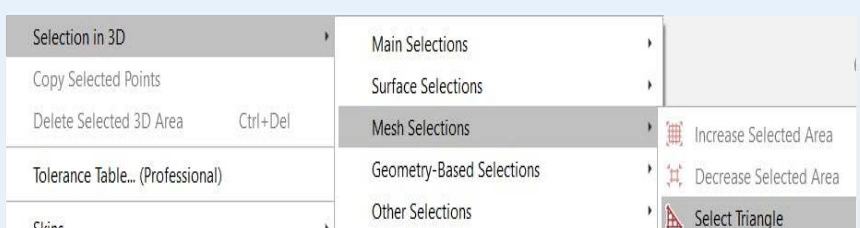
We have to know the way to study the geometrical properties of this processed scan like cylindricity, conicity , measurements against the real object to compare tolerances and relative accuracy.Surface roughness was not provided.

In CAD model dimension was not provided and to measure these dimension we used 3D tool free.

# MESH REPAIRING METHOD

- We used GOM inspect tool to study the defects in the STL model and used different commands to repair the model.
- Holes of different shapes and sizes:
- Additional Elements:
- Craters:
- Surface Extrusions:

# MESH REPAIRING PROCESS

| DEFECTS | REPAIR COMMAND | OBSERVATION |
|---|---|---|
| Holes |  | Deviation in the case of cylinder material thickness was found to be -0.71mm |
| Additional Elements |  | Most of the additional elements have been eliminated. |
| Craters |  | Deviation in the case of cylinder material thickness was found to be -0.70 mm |
| Surface Extrusions |  | Most of the surface extrusions have been eliminated. |

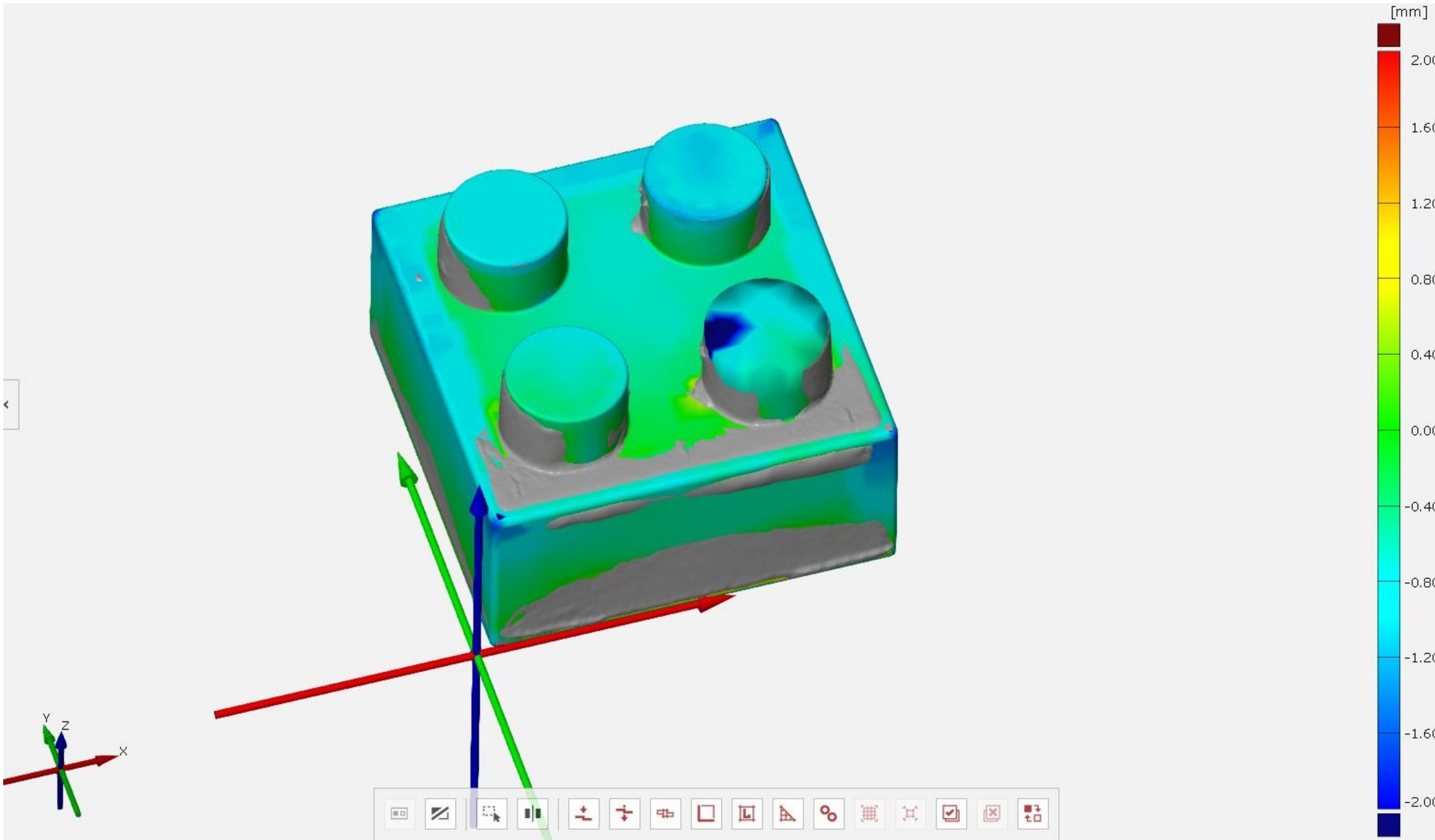
# SURFACE COMPARISON

Surface comparison tool in the inspection models of GOM software enables us to compare the surface of STL MODEL with that of the CAD BODY.

Here we observe the surface deviation in terms of colour scale where,

- Degree of Green indicates marginal deviation between the two surfaces.
- Degree of Red indicates positive deviation(i.e. STL MODEL surface is above the CAD BODY).
- Degree of Blue indicates negative deviation(i.e. STL MODEL surface is below the CAD BODY).

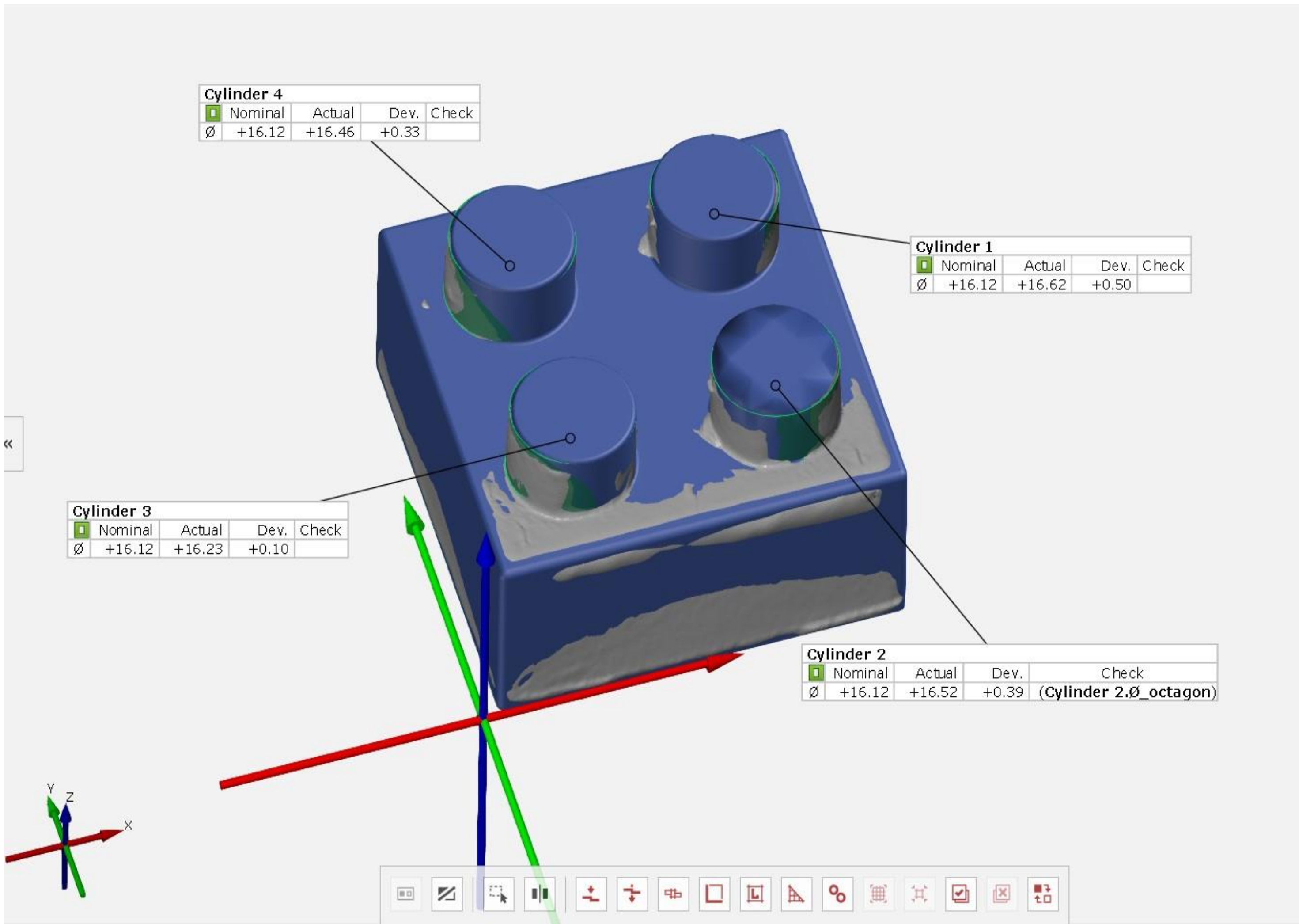
# SURFACE COMPARISON: THE COLOR SCALE



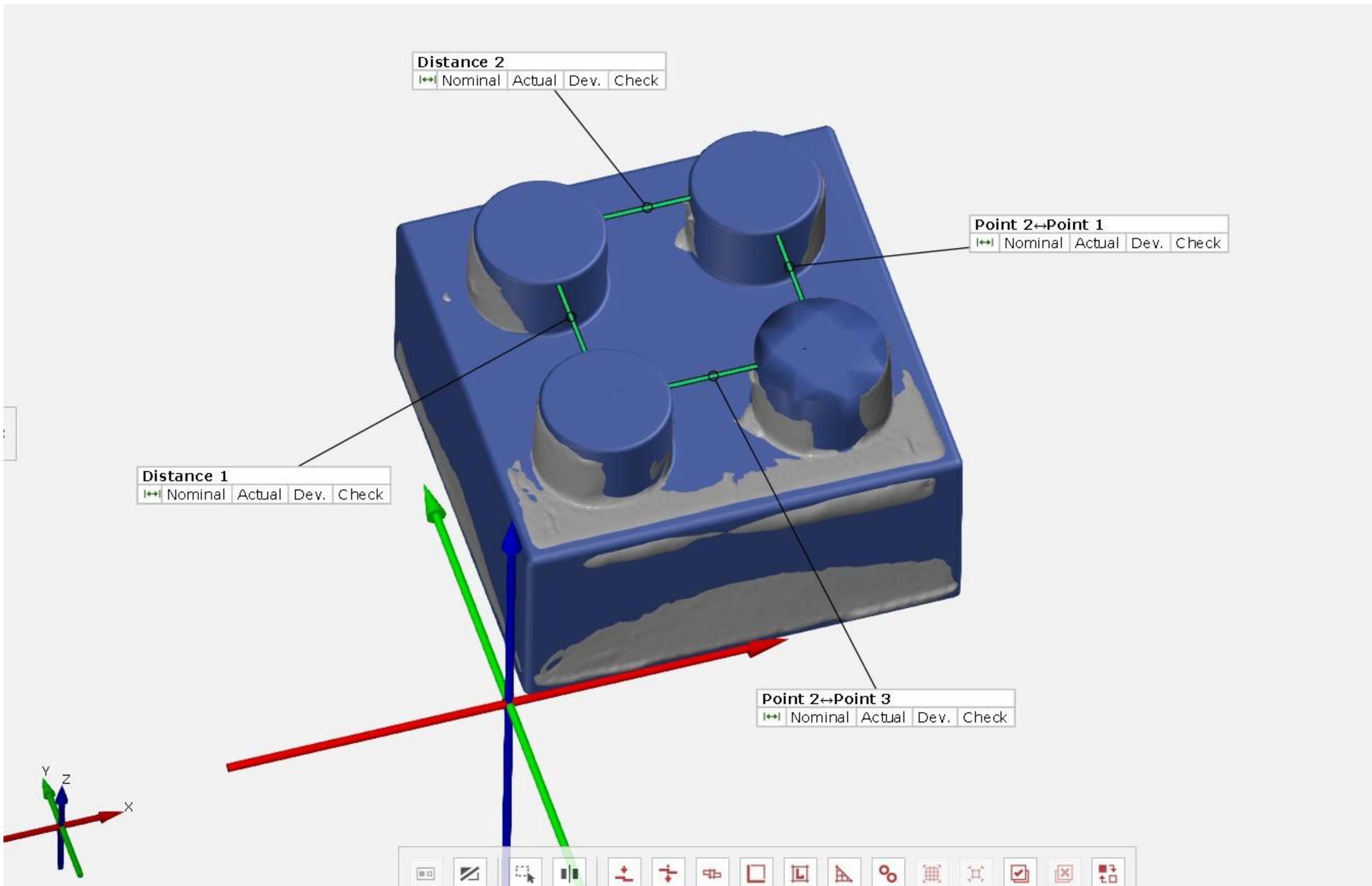
# OBSERVATIONS:

- The inside and outside volume of the matter is decided by the process of slicing. In this step the STL virtual model is mathematically cut in thin cross sections perpendicularly to z axis (a normal vector) and in this way the curves discriminate between outside (gray) and inside (indigo) elements with different colors. We can also use the right-hand rule to understand this concept where we have the entrance normal (in CW direction) and the exiting normal (in CCW direction) respectively.
- Different colors in elements of the STL MODEL are because of additional lighting, so this tells us that the plastic material of the object is not uniform. So we should coat it for example with talcum powder.
- Different surface skins are fused with different angle of viewing. In the fusing process, the algorithm tries to describe in a common skin.

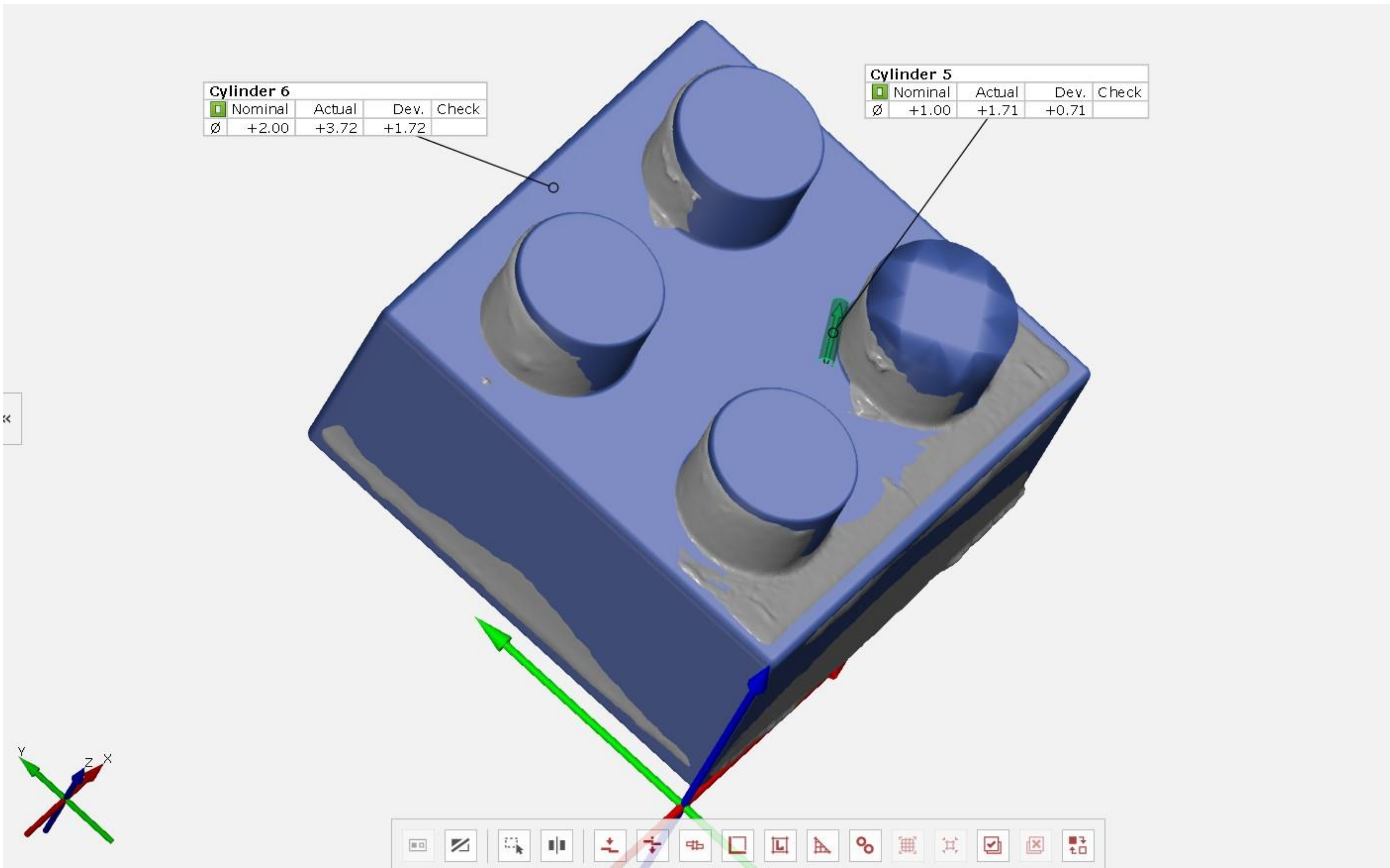
# OBSERVATIONS: DEVIATION IN CYLINDERS



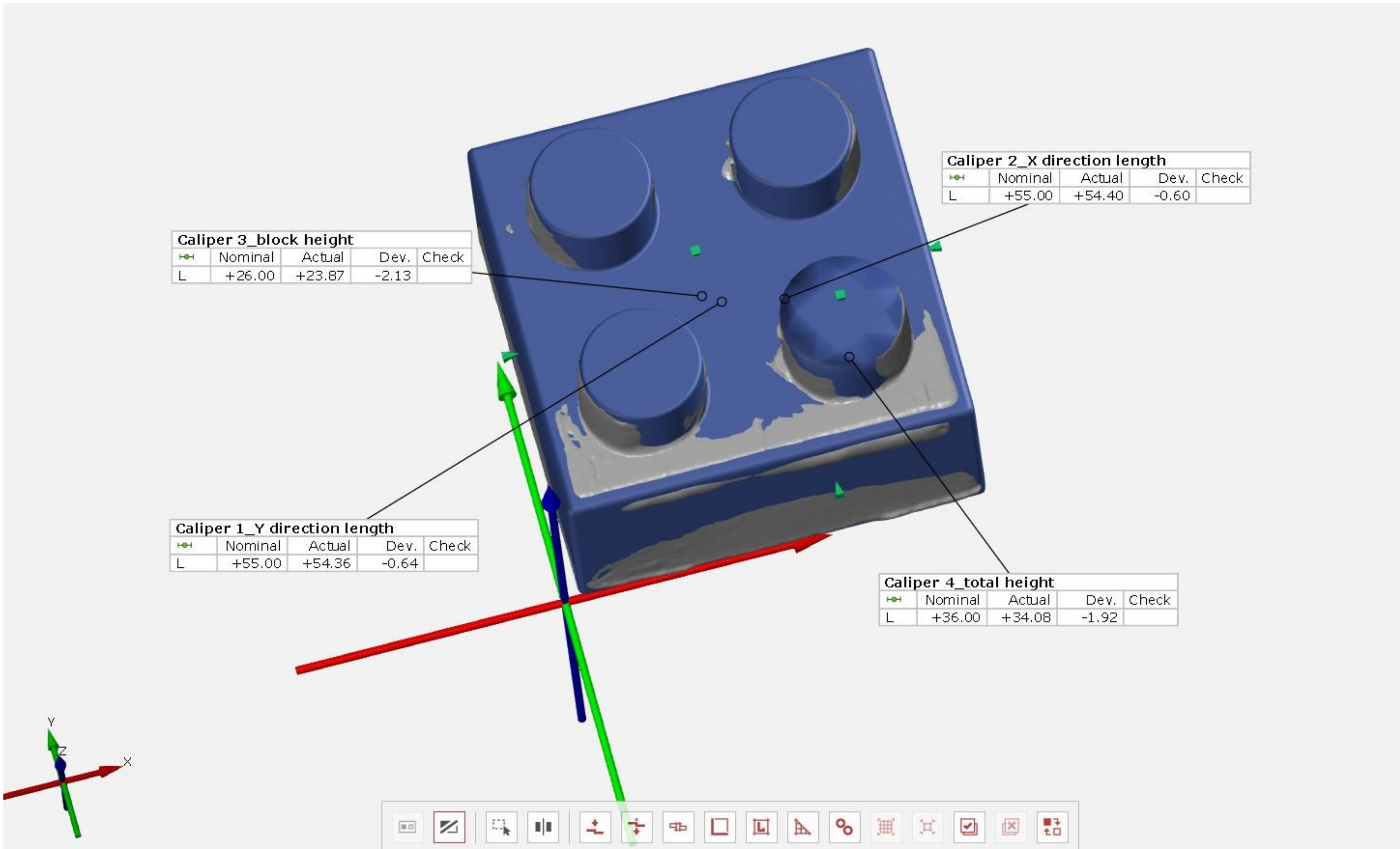
# OBSERVATIONS: DEVIATION IN DISTANCE BETWEEN CYLINDERS (FROM THE CENTRE)



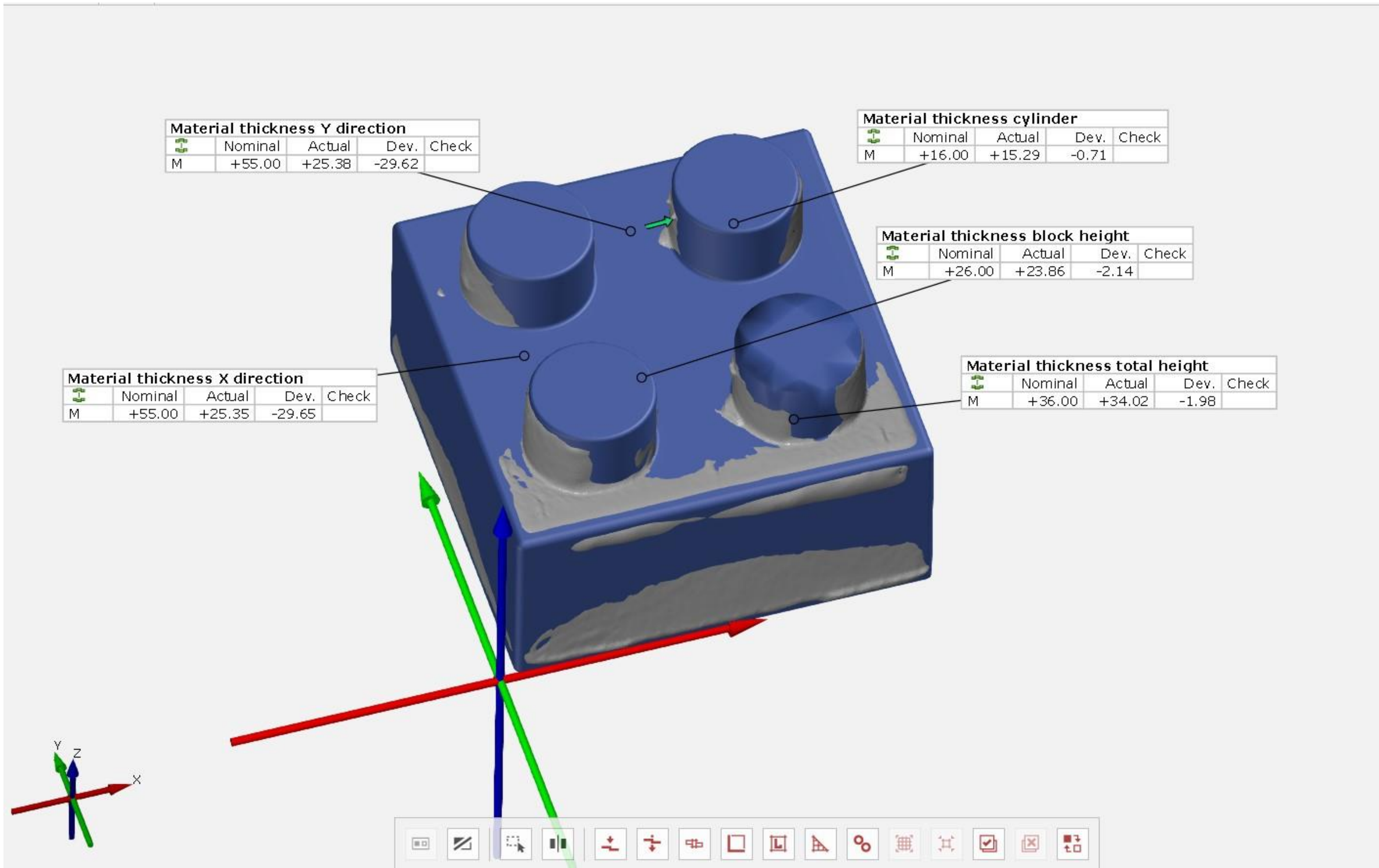
# OBSERVATIONS: DEVIATION IN DIAMETER OF CURVES



# OBSERVATIONS: DEVIATION IN LINEAR DIMENSIONS



# OBSERVATIONS: DEVIATION IN MATERIAL THICKNESS



# CONCLUSION AND REVIEW

- Study of this lego block is related with comparison of CAD model and STL model to know efficiency of reverse engineering process with respect to CAD model.
- To represent this we have used deviation by imposing the CAD model and reverse engineered STL model.
- Some of the deviation are under and maybe acceptable range.

# COORDINATE MEASUREMENT MACHINE (EXERCISE B)

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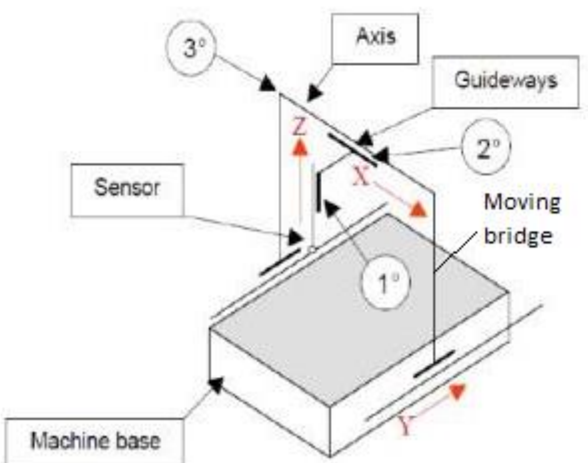
COORDINATE MEASUREMENT MACHINE

CMM FOR MEASUREMENT OF ASSIGN PART :

1) Considering the dimension of given component 100mmx60mm x20mm we have selected mobile bridge type CMM which have high accuracy with low flexibility for medium component . It is the most commonly used machine.
2) Mobile bridge measure head determines values on the Z-axis by moving up and down on a bridge that spans the machine's base. The head determines values for the X-axis by moving back and forth across the bridge. Values on the Y-axis are determined by moving the entire bridge over the granite base.




**Crysta-Plus M443**

# SPECIFICATIONS

| Type: Bridge | | Model No. | Crysta-Plus M443 |
|---|---|---|---|
| Range | | X axis | 15.74" (400mm) |
| | | Y axis | 15.74" (400mm) |
| | | Z axis | 11.81" (300mm) |
| Resolution | | | |
| Work table | Material | | |
| | Size | | 24.56" x 31.69" (624mm x 805mm) |
| | Tapped insert | | |
| Workpiece | Max. height | | 18.89" (480mm) |
| | Max. load | | 396 lbs. |
| Mass (incl. stand) | | | 793 lbs. (360kg) |
| Dimensions W x D x H | | | 38.62 x 41.22 x77.44" (981 x 1047 x 1967mm) |

This specification meets our requirement for the assign component .

Probe selection :

Probe selection is based on the :

1) complexity of the component .
2) Height of the component . This is required for the length of the probe if length of the probe is less that height of the component this may lead to the obstacle.

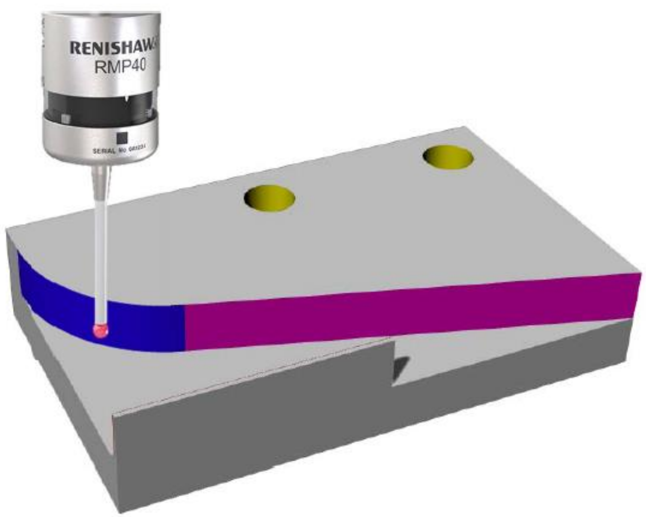
For assigned component we can select probe of length greater than 20mm .

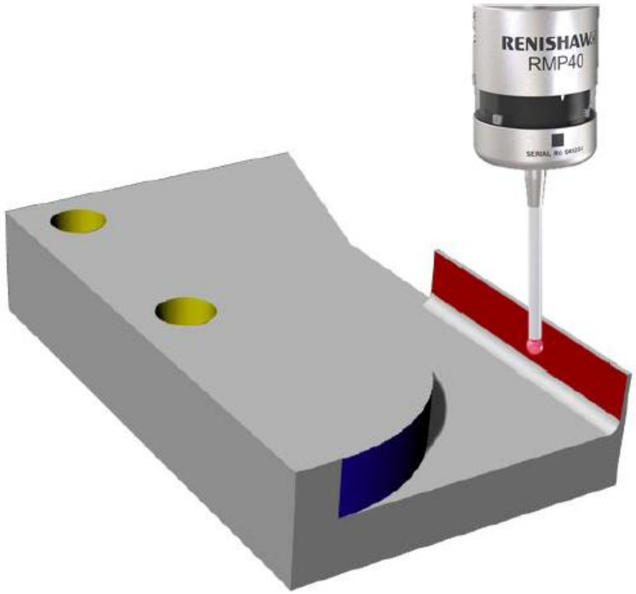
**Probe Mount:** Autojoint
**Stylus Mount:** M4

**TP7 -** High-accuracy touch trigger probe **CMM:CNC**

The TP7M is a high-accuracy touch trigger probe with a maximum repeatability of $2\sigma \leq 0.25\mu m$. The TP7M can mount a long stylus up to 150mm long. In combination with the longest autojoint probe extension of 200mm for direct mounting to the PH10M or PH10MQ, gives the TP7M a maximum access distance of 350mm.

# PROGRAM METHODOLOGY




| COLOR | SURFACE | # OF COORDINATES TAKEN | REMARKS |
|---|---|---|---|
| BLUE | CURVED | 2 | 2 collinear points for a straight line |
| RED | PLANE WALL | 3 | 3 non collinear points for a curve |

# PART PROGRAMMING FOR THE DIMENSION OF THE COMPONENT

| PROGRAM LINES | | TEXT INDICATIONS |
|---|---|---|
| N1 | G90 | (absolute coordinates) |
| N2 | G21 | (unit set to mm) |
| N3 | G30 | (to the reference point) |
| N4 | G49 | (compensation disable) |
| N5 | G00 X95 Y54 | |
| N6 | Z50 | (to the clearence height) |
| N7 | Z2 | |
| N8 | G01 Z-5 F150 | |
| N9 | G38.2 Y61 F150 | Red wall 1st point (slow down until the contact) |
| N10 | G01 Y54 F150 | |
| N11 | X55 | |
| N12 | G38.2 Y61 F150 | Red wall 1st point (+ 2 mm in Y axis) |
| N13 | G30 | |
| N14 | G90 | (absolute coordinates) |
| N15 | G21 | (unit set to mm) |
| N16 | G30 | (to the reference point) |
| N17 | G49 | (compensation disable) |
| N18 | G00 X98.5 Y22 | |
| N19 | Z50 | |
| N20 | G01 Z-5 F150 | |
| N21 | G38.2 Y15 F150 | Blue Wall 1st Point (- 2 mm in Y axis) |
| N22 | G01 Y22 F150 | |
| N23 | G03 X94.6 Y29.8 I-30 J0 F150 | |
| N24 | G38.2 Y22.8 F150 | Blue Wall 2nd Point (- 2 mm in Y axis) |
| N25 | G01 Y29.8 F150 | |
| N26 | G03 X88.6 Y36.2 I-30 J0 F150 | |
| N27 | G38.2 Y29.2 F150 | Blue Wall 3rd Point (- 2 mm in Y axis) |
| N28 | G30 | |
| N29 | M30 | |

**Part Positioning :**

Fixing the component on the table so that it doesn't move while measurement . Defining the plane of the object , in our case we are using 3 planes and defining each plane using three point and save using programming. Precaution to be taken while defining the plane that we don't hit the component with upper part of the probe, this will led to inaccurate measurement of the component. Defining the part zeros and storing using programming.

We placed the part on the machine bench . Part bottom surface is parallel to the bench surface . Setting the part zeros using the CMM programming and proceeding with the measurement of the component with reference with the zero part.

Touch trigger probe used for the measurement of the component . For measurement of component using touch trigger probe we require touching of component at every specific interval of distance. Using the line formula to calculate the distance between two point.

We can use clamp and cylinders of appropriate size Placing the component on the cylinder block and resisting the top surface using the clamp having an Extendable thin rod ( to restrict the vibration of the Component and falling off condition due to external Unknown forces acting on the component) .

**Observation :**

We are placing the component bottom surface parallel to the bench and then carrying out the measurement . Placing the component parallel to the bench make the measurement simple.

If the component is not align i.e bottom part of the component and bench surface carrying out the measurement become quite complicated .

In this we have to calculate the inclination of the bottom part with the beach surface and storing in the system.

While carrying out the inclination error can be found which is due to unproper contact of probe i.e perpendicular contact of probe with the surface, this will eliminate the error.

# CNC PROGRAMMING (EXERCISE 1)

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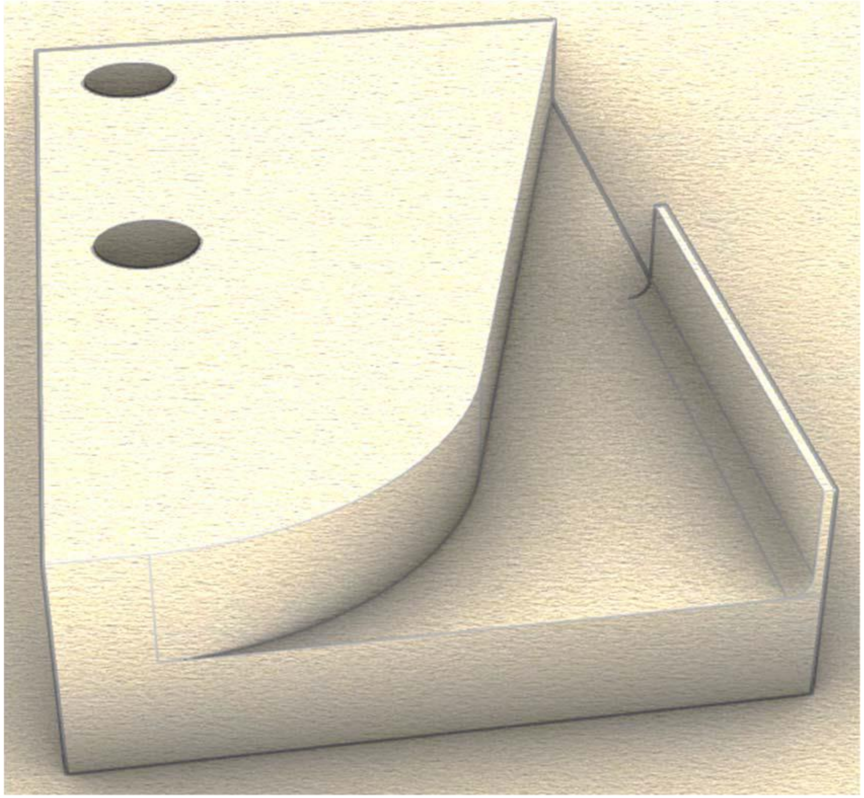
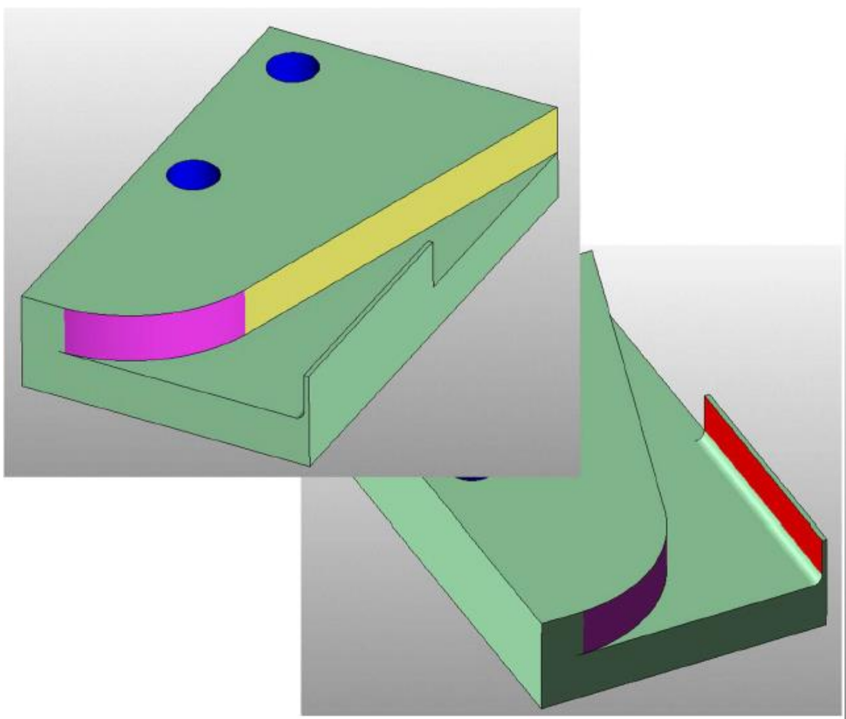
# OBJECTIVE

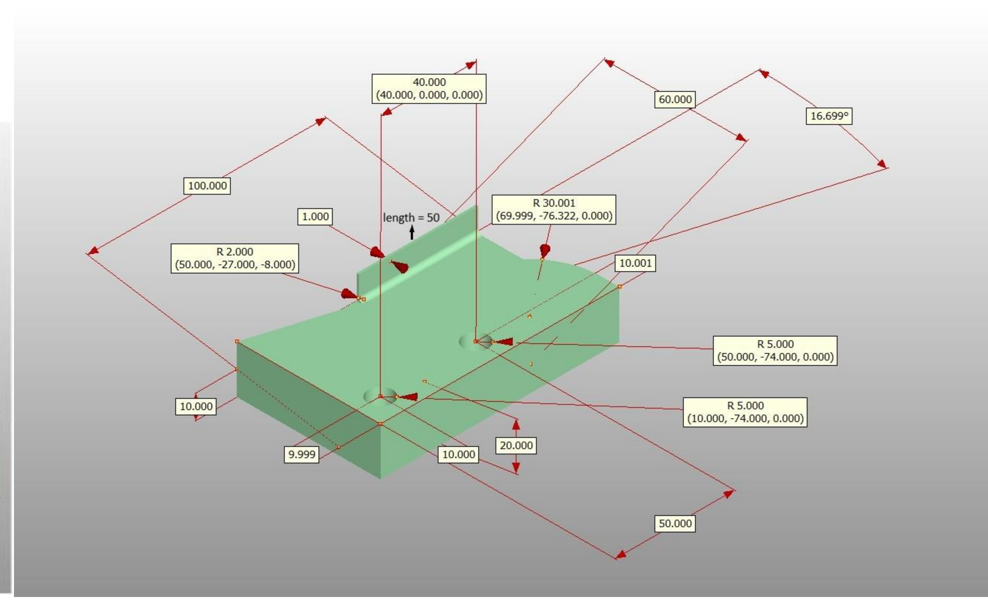
To manually develop a part program to machine the C40 steel component given in an STL file.



# PREREQUISITE REQUIREMENTS

| | Ra requirement over zone | | | | |
|---|---|---|---|---|---|
| Group | *Blue* | Fuxia | Yellow | Red | *thin wall thickness tolerance* |
| 5 | *1,2* | | | | *0,015* |





# THE MACHINING CENTER SELECTION

- Vertical Machining Center: JYOTI k2x8i (India)

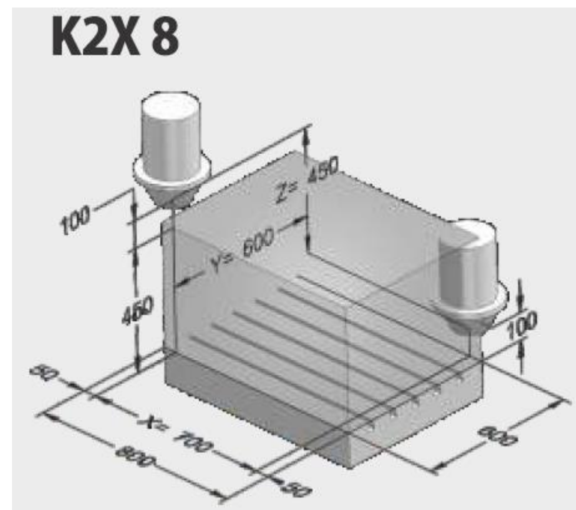

## Electro Spindle

| | K2X 8 |
|---|---|
| Taper | HSK 63-A |
| Rotating Speed | 100 - 24000 rpm |
| Power (S6-40% / S1) | 25 kW / 20 kW |
| Torque (S6-40% / S1) | 40 Nm / 32 Nm |
| Characteristic Speed | 6000 rpm |

## Tool Changer

| | K2X 8 |
|---|---|
| Pockets Qty. | 20 |
| Type | Disk |
| Tool Taper | HSK 63-A |
| **Tool Dimensions :** | |
| Max. Ø Contiguous / Non Contiguous | 90 mm |
| Max. Length | 300 mm |
| Max. Weight | 8 kg |
| Max. Weight Admissible in Magazine | 80 kg |
| **Tool Changing Time :** | |
| Tool to Tool | 5 sec |
| Chip to Chip | 11.5 sec |

Bed Info




| | |
|---|---|
| Table Area (L X W) | 800 x 600 mm |
| Admissible Load | 500 kg |

# THE RAW MATERIAL AND CUTTING TOOL’S GRADE SELECTION

- C40 steel (equivalent to SAE 1040 steel in the United States).
- It’s a medium carbon steel with the carbon % of 0.370-0.440.

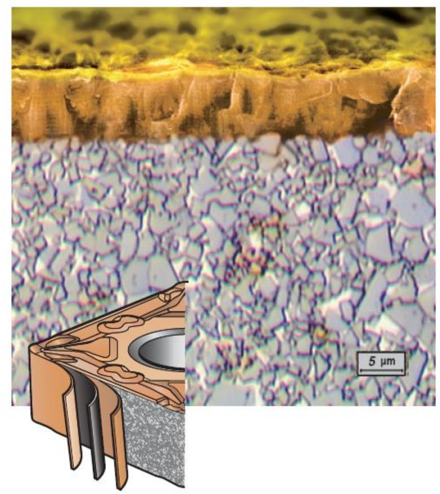
Material Selection = C40 Steel (medium carbon %)

Grade Selection = Coated Carbide (PVD)

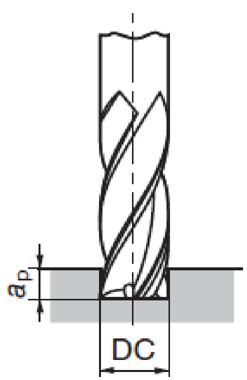
Recommended Cutting Parameters Acc. To The Catalog

## PVD coating of inserts

Physical Vapor Deposition

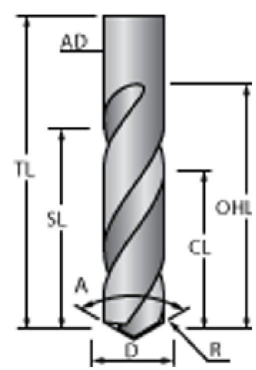



- PVD coatings are generally tougher than CVD coatings.
- PVD coatings are often used in combination with fine-grained substrates to coat “sharp” cutting edges.
- Total thickness of the PVD layers is often between .0001 – .0002 inch (3 – 6 µm).
- The coating is applied at approx. 932° F (500° C).




### For Endmills

| Work Material / Cond. | Structural Steel SS | | Carbon Steel SC (150 to 250HB) | |
|---|---|---|---|---|
| DC (mm) | Spindle Speed (min⁻¹) | Feed Rate (mm/min) | Spindle Speed (min⁻¹) | Feed Rate (mm/min) |
| 1.0 | 19,600 | 200 | 19,600 | 250 |
| 2.0 | 11,200 | 270 | 11,200 | 340 |
| 4.0 | 6,400 | 370 | 6,400 | 460 |
| 6.0 | 4,600 | 450 | 4,600 | 560 |
| 8.0 | 3,400 | 450 | 3,400 | 560 |
| 10.0 | 2,800 | 450 | 2,800 | 560 |
| 12.0 | 2,300 | 450 | 2,300 | 560 |
| 16.0 | 1,700 | 360 | 1,700 | 450 |
| 20.0 | 1,350 | 300 | 1,350 | 380 |
| 25.0 | 1,080 | 240 | 1,080 | 304 |
| Standard Depth-of-cut $a_p$ | 0.2DC | | | |




### For Drills

| Drill Diameter DC (mm) | Cutting Conditions | Soft Steel/General Steel (Up to 300HB) |
|---|---|---|
| ø3.0 | $v_c$ | 30 - **60** - 70 |
| | $f$ | 0.1 - **0.15** - 0.2 |
| ø4.0 | $v_c$ | 30 - **60** - 80 |
| | $f$ | 0.12 - **0.17** - 0.22 |
| ø5.0 | $v_c$ | 40 - **60** - 100 |
| | $f$ | 0.15 - **0.2** - 0.25 |
| ø8.0 | $v_c$ | 40 - **80** - 120 |
| | $f$ | 0.18 - **0.23** - 0.3 |
| ø10.0 | $v_c$ | 50 - **80** - 130 |
| | $f$ | 0.2 - **0.25** - 0.35 |

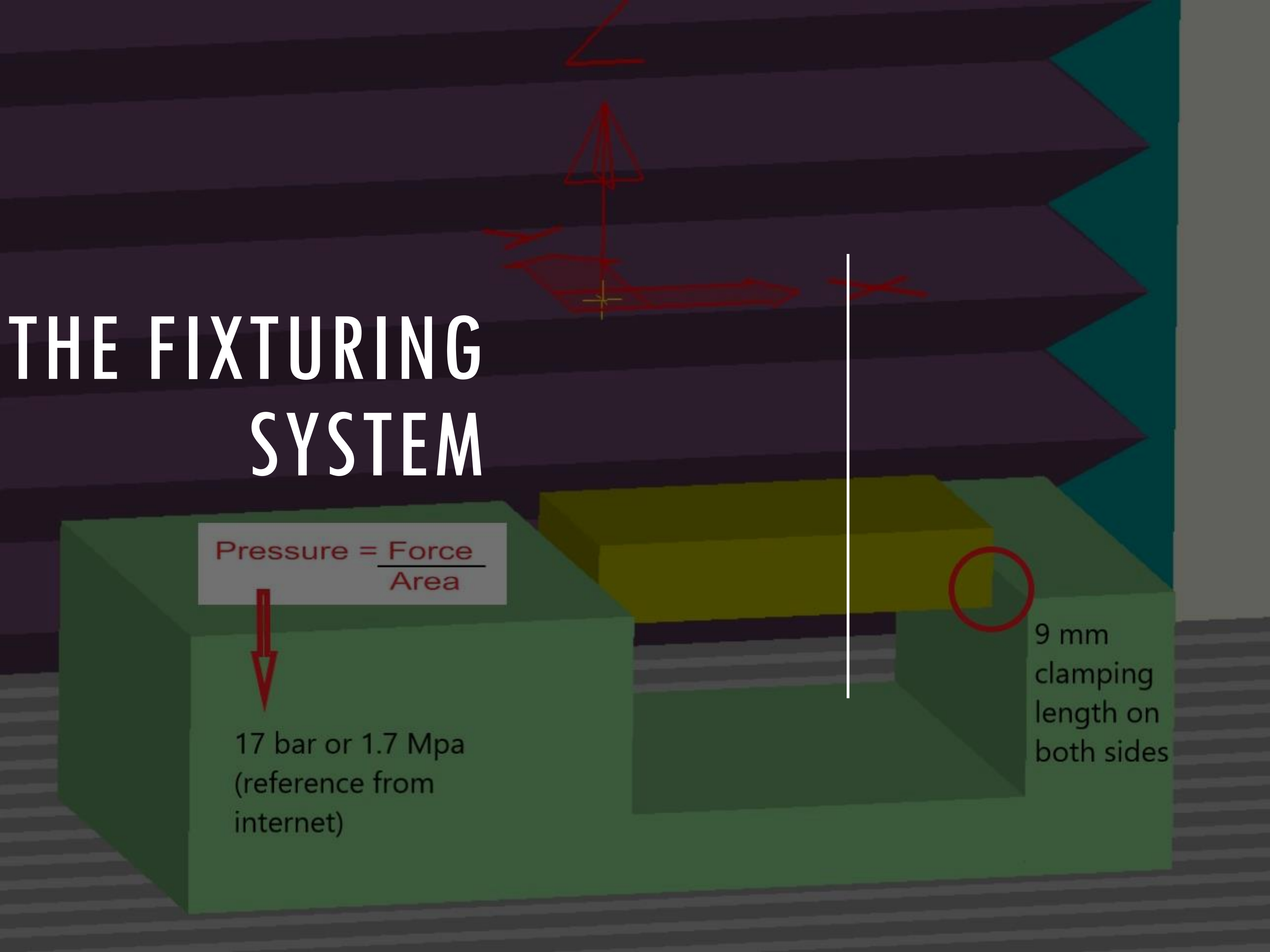
CLASSIFICATION OF CARBIDE TIPS ACCORDING TO THEIR RANGES OF APPLICATION

| Symbol | Identification colour for Carbide | Range of Application | | | | | |
|---|---|---|---|---|---|---|---|
| | | Desig-nation | Composition % | | | Material to be Machined | Machining Conditions |
| | | | W | TiC +TaC | Co | | |
| | | P01 | 51 | 43 | 6 | Steel, Steel casting | Precision turning and boring requiring high finish and close tolerance, high cutting speed, small chip sections, not subject to vibrations. |
| | | P10 | 65 | 26 | 9 | Steel, Steel casting | Turning, Threading and Milling, high cutting speed, small or medium chip section. |
| | | P20 | 76 | 14 | 10 | Steel, Steel casting, Malleable cast iron forming long chips | Turning, Milling, medium cutting speed and medium chip section, Planing with small chip section. |
| | | P30 | 82 | 8 | 10 | Steel, Steel casting, Malleable cast iron forming long chips | Turning, Milling, Planing, medium or low cutting speed, medium or large chip section and machining under unfavourable conditions such as hetero-geneous materials, changing hardness or chip sections, intermittent turning or subject to vibrations. |
| P | French Blue | P40 | 74 | 12 | 14 | Steel, Steel casting with sand inclusions or shrinkage cavities | Turning, Planing, Shaping, low cutting speed, large chip section with possibility of using large rake angle; for machining under unfavourable con-ditions, such as heterogeneous materials, changing hardness or chip sections, intermittent turning or subject to vibrations; and work on automatic machines. |

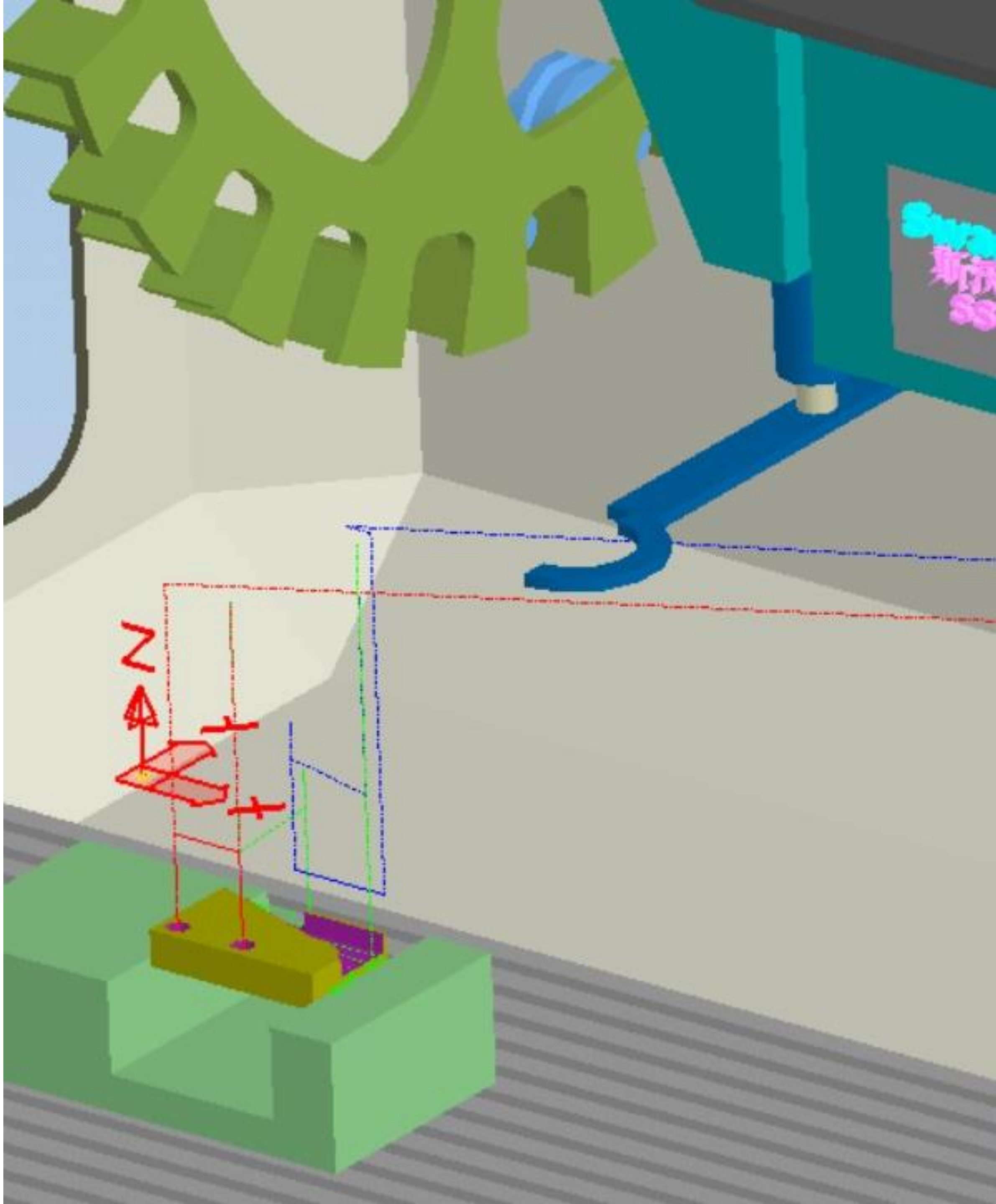
Our ISO grade selection

# CUTTING TOOL'S ISO CARBIDE GRADE SELECTION

# THE FIXTURING SYSTEM



# CNC SETUP (SWANSOFT CNC SIMULATOR APPLICATION)

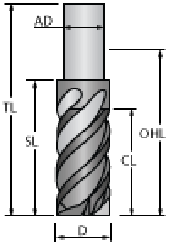


# THE TOOL SYSTEMS

**1-Drilling**



**DRILL MILL**




D: 10 mm
AD: 10

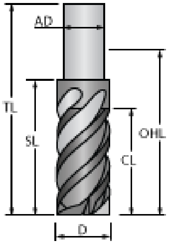
TL: 80 mm
OHL: 50 mm
CL: 25 mm
SL: 30 mm
H: 100 mm

H 1 D 1
Flutes: 2

**2-Groove & Side Milling**



**END MILL**




D: 10 mm
AD: 10

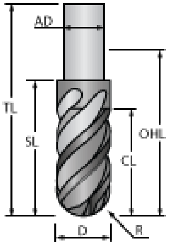
TL: 70 mm
OHL: 50 mm
CL: 15 mm
SL: 17 mm
H: 100 mm

H 2 D 2
Flutes: 2

**3-Profile Milling**



**BALL NOSE MILL**




D: 4 mm
R: 2 mm
AD: 6

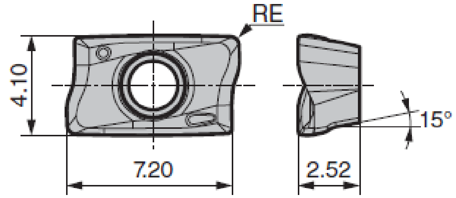
TL: 57 mm
OHL: 25 mm
CL: 6 mm
SL: 20 mm
H: 100 mm

H 3 D 3
Flutes: 2

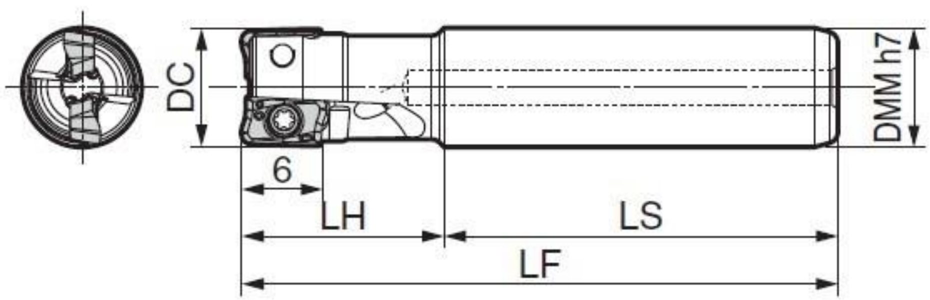
# DRILLING OP#1 TOOL SELECTION (SUMITOMO CATALOG)

## Inserts

P Steel M Stainless Steel K Cast Iron N Non-Ferrous Metal S Exotic Alloy H Hardened Steel




| Grade | | Coated Carbide | | | | | | | Carbide | DLC | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Application | High Speed/Light | P | | | K | | M S | | K N | N | |
| | General Purpose | | P M | P M | K | | M S | M S | | N | |
| | Roughing | | P M | P M | | K | | M S | | | Dimensions (mm) |
| Cat. No. | | ACP100 | ACP200 | ACP300 | ACK200 | ACK300 | ACM200 | ACM300 | H1 | DL1000 | Corner Radius RE |
| AXMT 060204PDER-L | | ● | ● | ● | ● | ● | ● | ● | — | — | 0.4 |
| 060208PDER-L | | ● | ● | ● | ● | ● | ● | ● | — | — | 0.8 |
| 060212PDER-L | | ● | ● | ● | ● | ● | ● | ● | — | — | 1.2 |

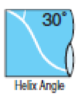


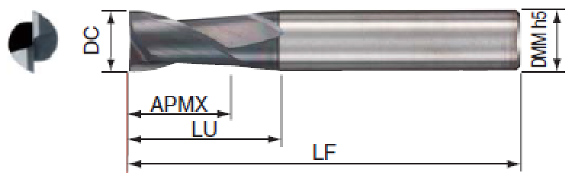

## Body (Standard Type)

Dimensions (mm)

| Cat. No. | Stock | Diameter DC | Shank DMM | Head LH | Shank LS | Total Length LF | No. of Teeth | Weight (kg) |
|---|---|---|---|---|---|---|---|---|
| WEX 1010E | ● | 10 | 10 | 25 | 55 | 80 | 2 | 0.03 |

# GROOVE & SIDE MILLING OP#2 TOOL SELECTION (SUMITOMO CATALOG)



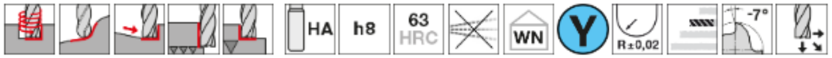

| DC | Tolerance |
|---|---|
| D ≤ 3.0 | 0 −0.015 |
| 3.0 < D ≤ 12 | 0 −0.020 |
| 12.0 < D | 0 −0.030 |

■ Body

| Cat. No. | Stock | Dimensions (mm) | | | | |
|---|---|---|---|---|---|---|
| | | Cutting diameter DC | Depth of cut APMX | Cutting Edge Length LU | Total Length LF | Shank diameter DMM |
| GSX 20050C-1.5D | ● | 0.5 | 1.0 | 1.4 | 40 | 4 |
| 20100C-1.5D | ● | 1.0 | 1.5 | 2.5 | 40 | 4 |
| 20150C-1.5D | ● | 1.5 | 2.3 | 3.3 | 40 | 4 |
| 20200C-1.5D | ● | 2.0 | 3.0 | 4.0 | 40 | 4 |
| 20250C-1.5D | ● | 2.5 | 3.8 | 4.8 | 40 | 4 |
| GSX 20300C-1.5D | ● | 3.0 | 4.5 | 6.0 | 45 | 6 |
| 20350C-1.5D | ● | 3.5 | 5.3 | 6.8 | 45 | 6 |
| 20400C-1.5D | ● | 4.0 | 6.0 | 7.5 | 45 | 6 |
| 20450C-1.5D | ● | 4.5 | 6.8 | 8.3 | 50 | 6 |
| 20500C-1.5D | ● | 5.0 | 7.5 | 9.5 | 50 | 6 |
| GSX 20550C-1.5D | ● | 5.5 | 8.3 | 10.3 | 50 | 6 |
| 20600C-1.5D | ● | 6.0 | 9.0 | — | 50 | 6 |
| 20650C-1.5D | ● | 6.5 | 10.0 | 12.0 | 60 | 8 |
| 20700C-1.5D | ● | 7.0 | 11.0 | 13.0 | 60 | 8 |
| 20750C-1.5D | ● | 7.5 | 12.0 | 14.0 | 60 | 8 |
| GSX 20800C-1.5D | ● | 8.0 | 12.0 | — | 60 | 8 |
| 20850C-1.5D | ● | 8.5 | 13.0 | 15.0 | 70 | 10 |
| 20900C-1.5D | ● | 9.0 | 14.0 | 16.0 | 70 | 10 |
| 20950C-1.5D | ● | 9.5 | 15.0 | 17.0 | 70 | 10 |
| 21000C-1.5D | ● | 10.0 | 15.0 | — | 70 | 10 |

# CONTOUR MILLING #OP3 TOOL SELECTION (GUHRING CATALOG)

| | |
|---|---|
| P | ○ |
| M | |
| K | ● |
| N | |
| S | |
| H | ● |




## 4MM GF300 B Carbide ball nose end mill nano-Si

**EDP/Part Number:** 9033590040000

**Series Number:** 3359

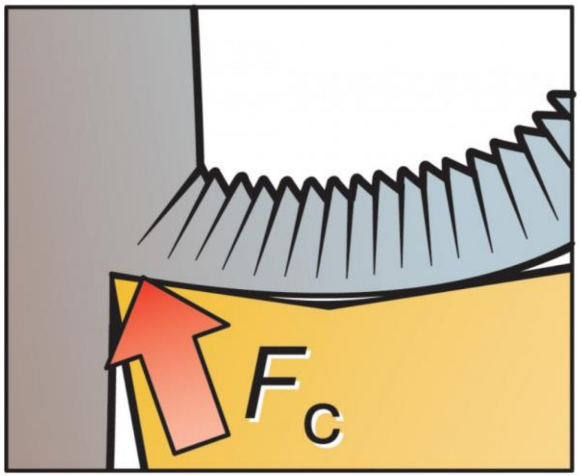
**Order Code:** 4.000

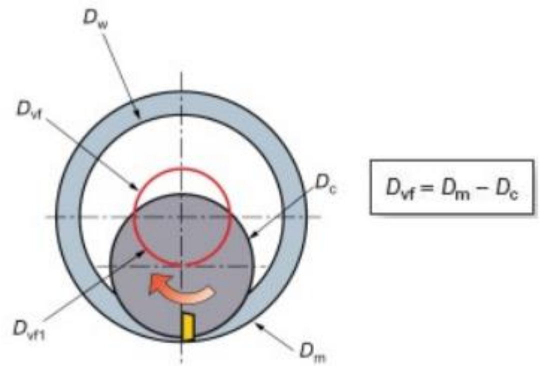
- neck clearance
- centre cutting

| | Dia | Shank dia | Neck dia. | OAL | LOC | Reach | Corner | Corner | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Order Code | d1 | d2 | d3 | l1 | l2 | l3 | Radius | Chamfer | Flutes | Shank Type |
| | (mm) | (mm) | mm | (mm) | (mm) | (mm) | (mm) | (mm) | | |
| 4.000 | 4.0 | 6.0 | | 57.00 | 6.00 | | BALL | | 2 | HA cylindrical |

# KEY CONCEPTS FOR CALCULATING MICRO-CYCLES

Specific cutting force

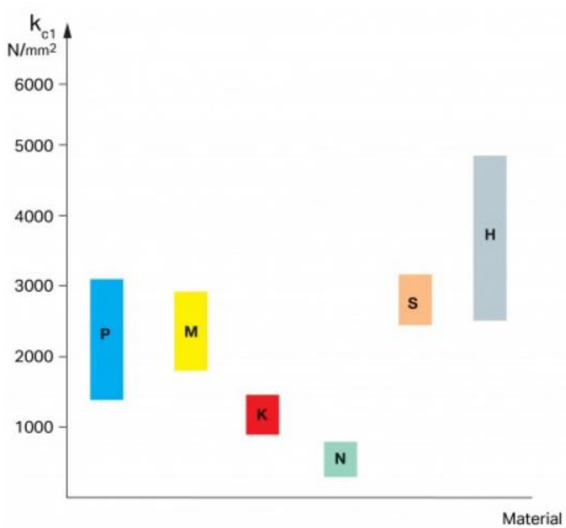



**Circular milling – 2 axes**

Circular milling is an alternate method to the traditional use of boring tools. Circular milling can be performed by moving most 90 degree cutters in a circular tool path.

Another way to finish the holes in the component but it takes more cut time than using the drill mill.

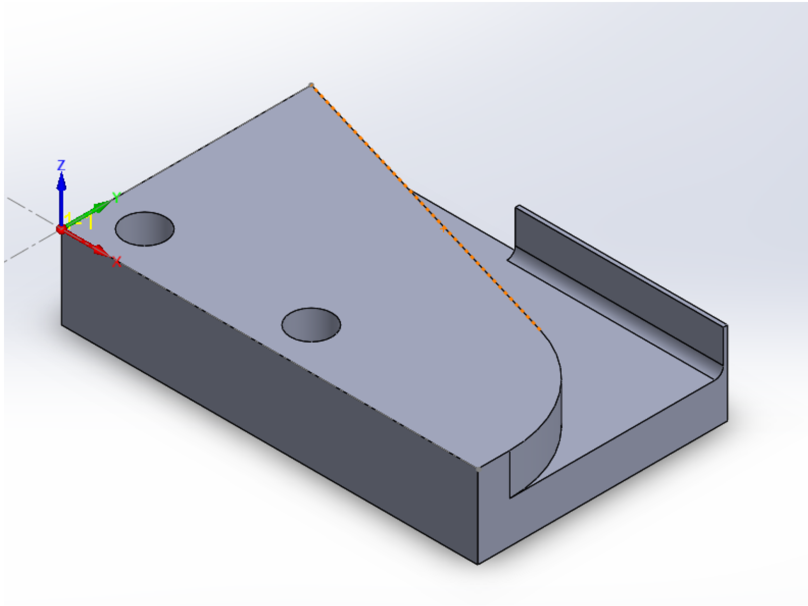



We selected 1500 N/sq. mm for C40 steel

| MICRO CYCLES | | | | | | | | Cutting Parameters | | | | | | Calculations For Operation #03 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Operations Number | Operations | Tool | Tool Ø (mm) | Tool Radius (mm) | No. of Teeth or Flutes | Cut Length/ Pass (mm) | No of passes | RPM | ω (rad/s) | Vt (m/s) | Vf (mm/ min) | fz (mm/rev) & (mm/t) | Cut Time (seconds) | Parameters for achieving the required maximum tolerance of 0.015 mm | |
| 1 | Drilling | Indexable Insert Drill | 10 | 5 | 2 | 20 | 2 | 3822 | 400 | 2.00 | 611 | 0.08 | 4 | Power (W) | 7 |
| 2 | Groove & Side Milling | Solid Carbide Flat Endmill | 10 | 5 | 2 | 300 | 10 | 2866 | 300 | 1.50 | 573 | 0.10 | 314 | Force (N) | 3 |
| 3 | Contour Milling | Solid Carbide Ballnose Endmill | 4 | 2 | 2 | 50 | 10 | 9554 | 1000 | 2.00 | 134 | 0.01 | 224 | Deflection (mm) | 0.014 |
| | | | | | | | | | | | | | | Bending Stress (MPa) | 21 |
| Total Cut Time | | | | | | | | | | | | | 542 | Calculations For Operation #01 | |
| Total Production Time = Total Cut Time + Part loading/unloading time + Tool Idle Time | | | | | | | | | | | | | 740 approx. | Blue Holes Surface Roughness (Ra) | 0.50 |

# THE PROCESS PARAMETERS

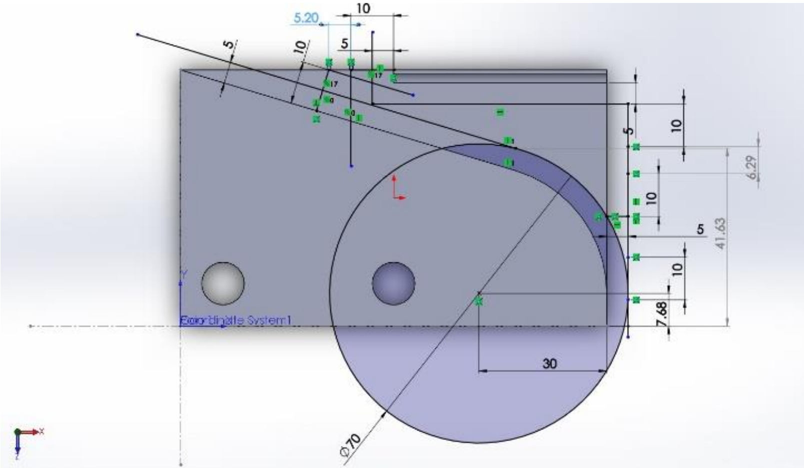
# THE CNC PART PROGRAM



First, we developed a 3D CAD model in SolidWorks from the dimensions provided in STL file for a better understanding to cut the component to the desired geometric dimensions and tolerances.

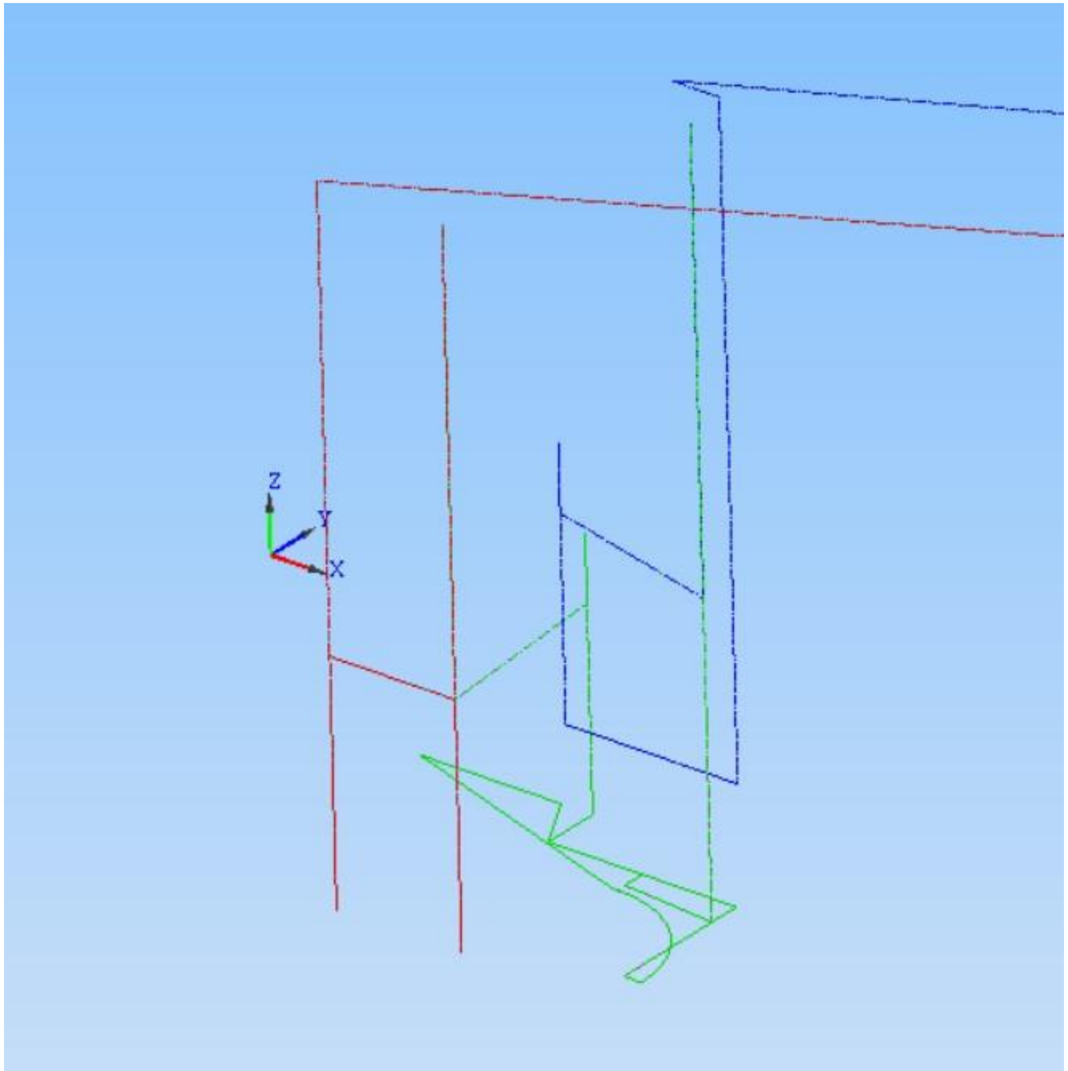
Secondly, we manually developed toolpaths and the corresponding part program for all required machining operations.

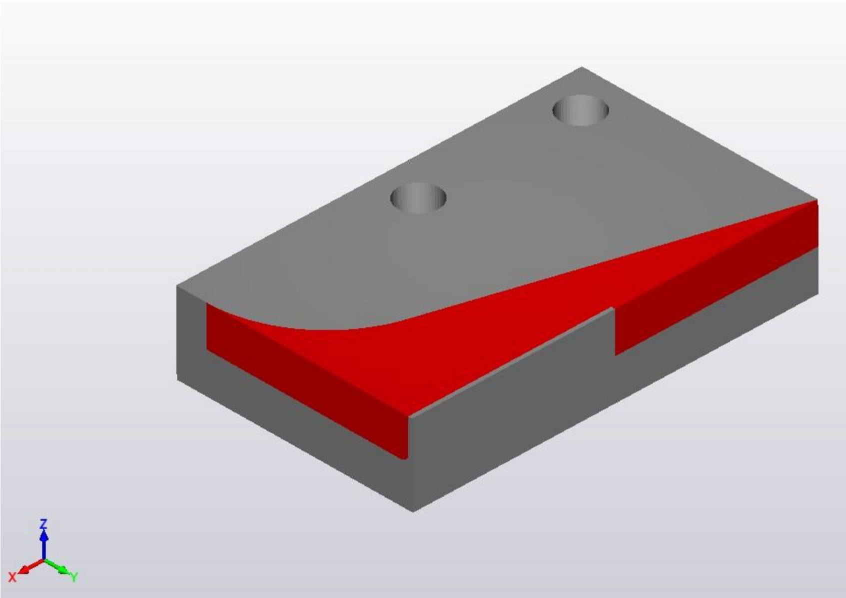
- We took Zero Part reference coordinate system as shown above
- Stock dimensions of 100X60Y20Z in mm (LENGTH x WIDTH x HEIGHT)



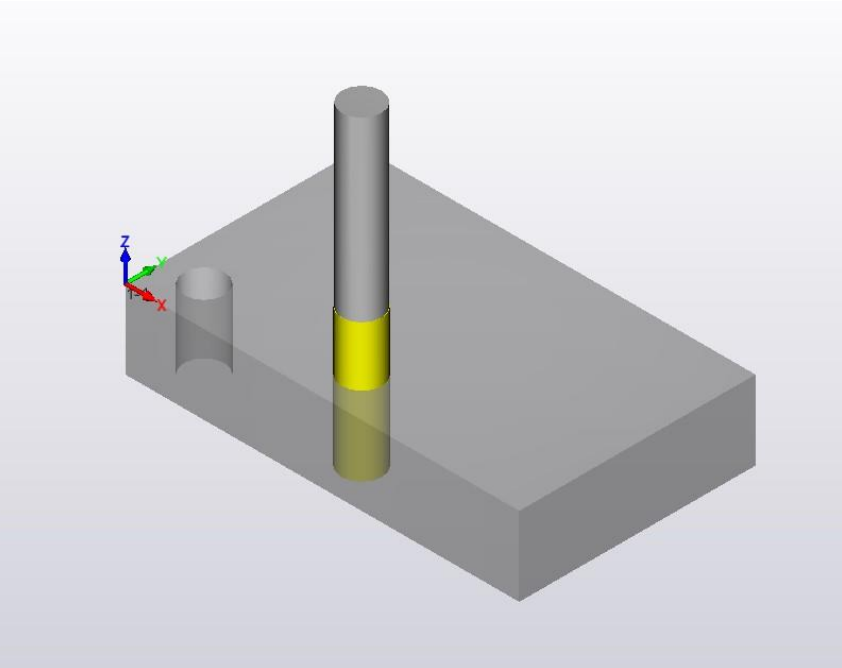
# THE TOOLPATH

- Red line represents drilling operation.
- Green line represents one pass of side and groove milling operation.
- Blue line represents one pass of the contour milling operation.





Red color represents the remaining material after the operation.

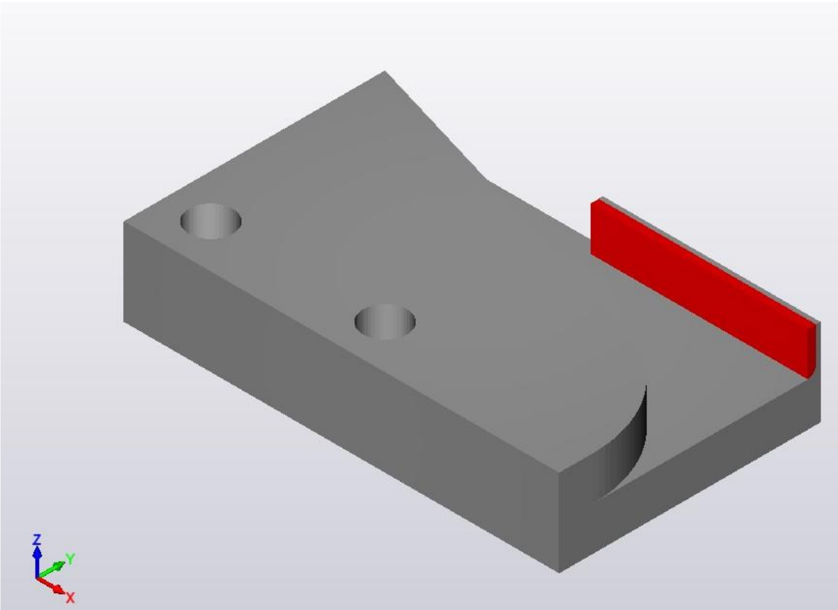


SolidCam Simulation

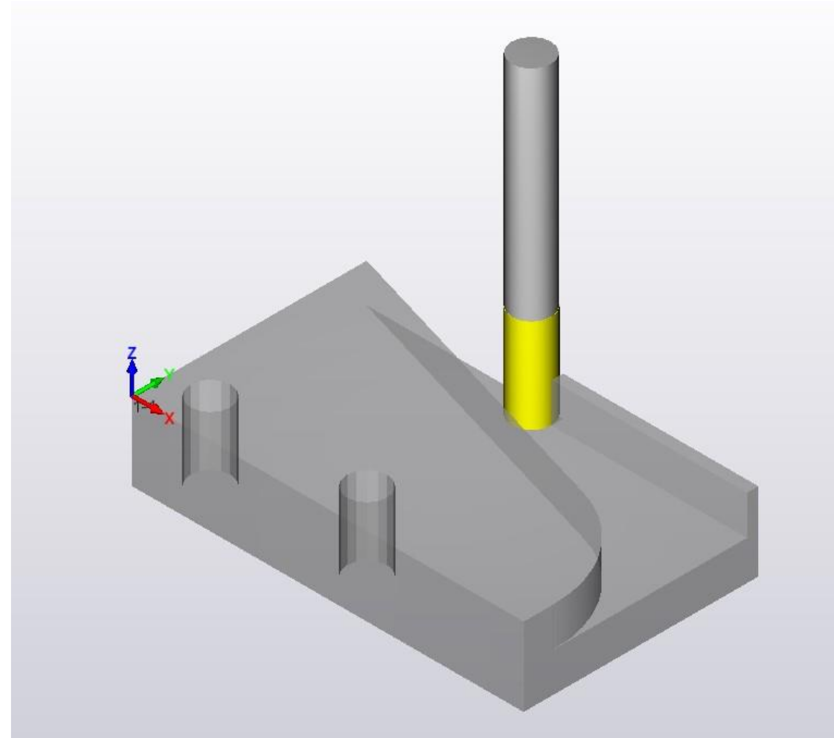
# THE PROGRAM – DRILLING OP#1

# THE PROGRAM – DRILLING OP#1

| PROGRAM LINES | | **TEXT INDICATIONS** |
|---|---|---|
| O0001 | | **PROGRAM NUMBER AND ID** |
| N1 | G90G17G40G80G00 | **INITIAL SETTINGS, UNIT SETTING, AND CANCELLATIONS** |
| N2 | **M06T1** | **T01 INTO SPINDLE FOR DRILLING OPERATION** |
| N3 | (Ø 10 indexable insert dill) | |
| N4 | G00G54G90X10.Y10.S3822M03 | **RAPID MOVEMENT OF THE TOOL TO THE STARTING POINT - RPM SET - SPINDLE ON** |
| N5 | G43H1Z70.M08 | **TOOL LENGTH OFFSET - CLEAR ABOVE WORK - COOLANT ON** |
| N6 | Z50. | **CLEARANCE LEVEL BEFORE OPERATION** |
| N7 | G98G81X10.Y10.Z-22.R2.F611. | **TOOL RETRACT POINT AFTER DRILL OPERATION - DRILL CYCLE ON - FEED SET** |
| N8 | G80 | **DRILL CYCLE CANCELLED** |
| N9 | X50. | |
| N10 | G98G81X50.Y10.Z-22.R2.F611. | **SECOND HOLE POSITION** |
| N11 | G80 | |
| N12 | M09 | **COOLANT OFF** |
| N13 | M05 | **SPINDLE STOP** |
| N14 | M01 | **OPTIONAL STOP** |




Red color represents the remaining material after the operation.

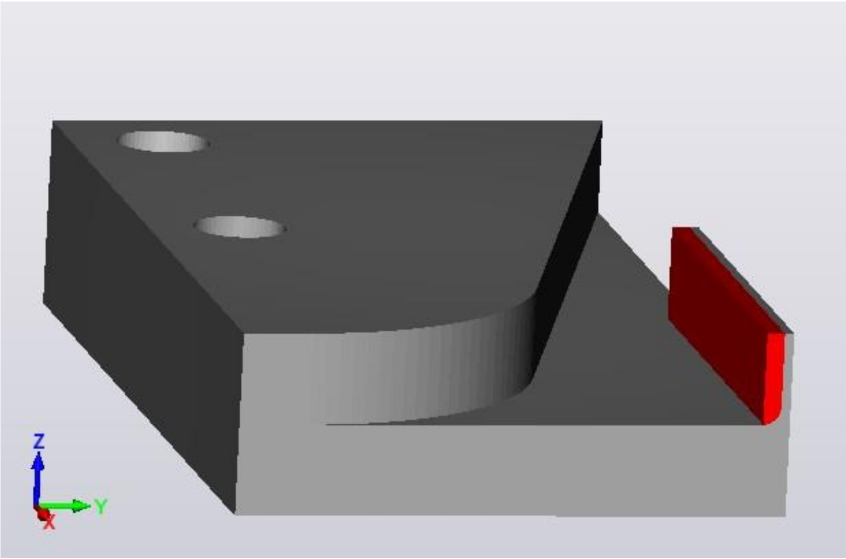



SolidCam Simulation

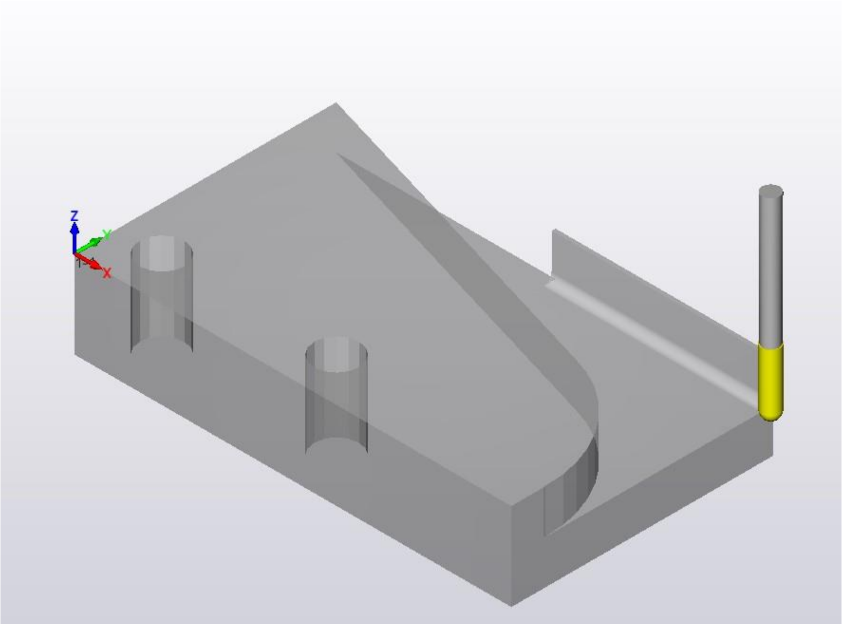
# THE PROGRAM – GROOVE & SIDE MILLING OP#2

# THE PROGRAM – GROOVE & SIDE MILLING OP#2

| PROGRAM LINES | | TEXT INDICATIONS |
| --- | --- | --- |
| N15 | G40G80G00 | |
| N16 | **M06T2** | **T02 REPLACES T01 IN SPINDLE FOR GROOVE AND SIDE MILLING** |
| N17 | (Ø 10 flat endmill) | |
| N18 | G00G54G90X45.Y70.S2866M03 | **PROGRAM WITHOUT CUTTER COMPENSATION** |
| N19 | G43H2Z70.M08 | **TOOL LENGTH ADJUSTMENT FOR TOOL 2** |
| N20 | Z50. | **CLEARANCE LEVEL BEFORE OPERATION** |
| N21 | Z2. | **SECOND CLEARANCE LEVEL JUST FOR SAFETY** |
| N22 | G01Z-1.F573 | **FIRST PASS TILL THE DEPTH Z = -1 mm** |
| N23 | X45.Y52. | |
| N24 | X105.Y52. | |
| N25 | X105.Y6.18 | |
| N26 | G03X73.62Y41.63I-30J0F573 | **CCW CIRULAR INTERPOLATION** |
| N27 | G01X-10.Y70.F573 | |
| N28 | X35. | |
| N29 | X45.Y52. | |
| N30 | X75. | |
| N31 | Y44.93 | |
| N32 | X105.Y42. | |
| N33 | G00Z50. | |
| | | **THIS TOOL PATH IS REPEATED 9 TIMES MORE TILL Z = -10 mm** |
| N99 | M09 | |
| N100 | M05 | |
| N101 | M1 | |




Red color represents the remaining material after the operation.



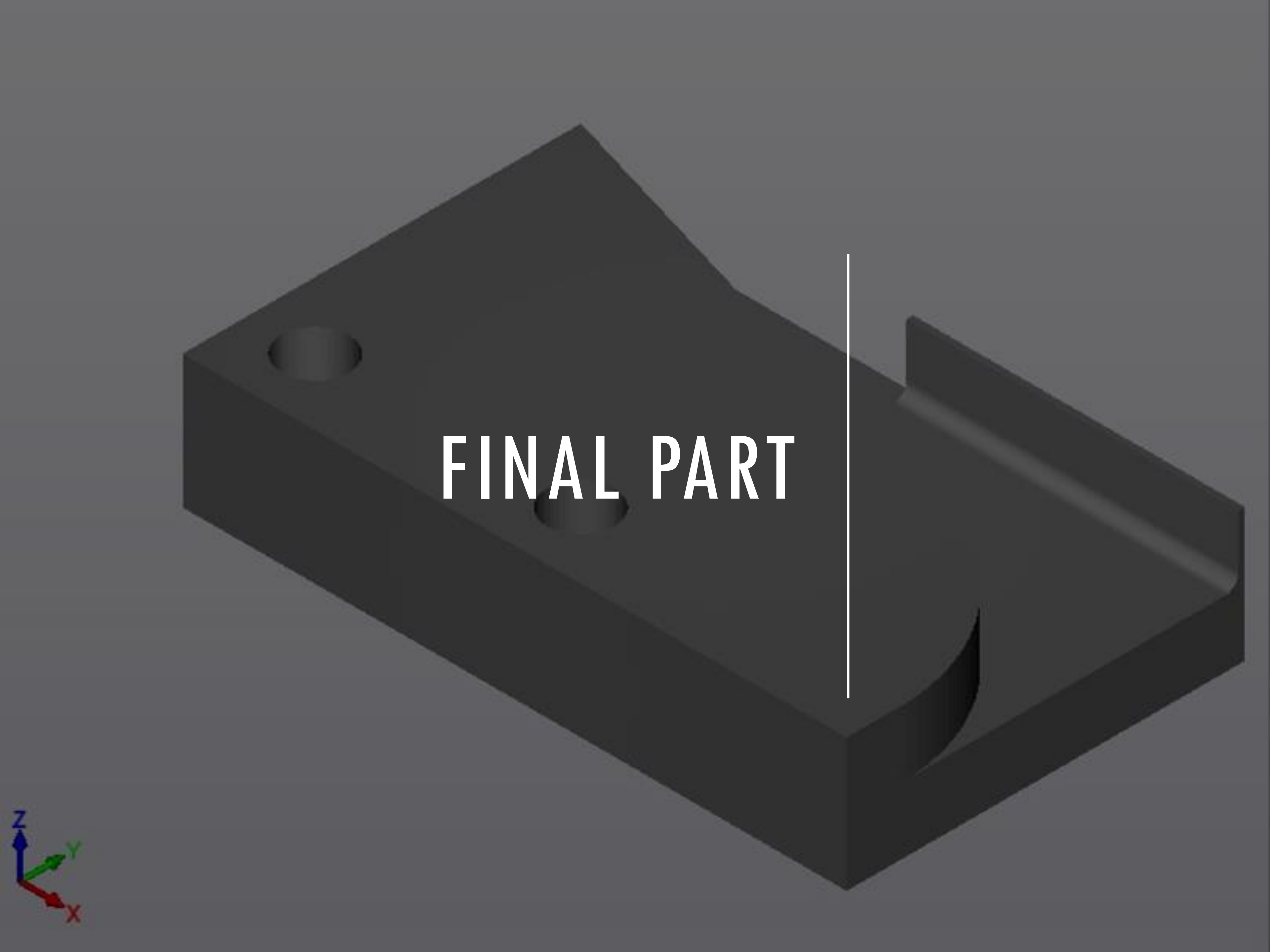

SolidCam Simulation

# THE PROGRAM – CONTOUR MILLING #OP3

# THE PROGRAM – CONTOUR MILLING #OP3

| PROGRAM LINES | TEXT INDICATIONS |
|---|---|
| N101 M1 | |
| N102 G90G17G40G80G00 | |
| N103 **M06T3** | **T03 REPLACES T02 IN SPINDLE FOR CONTOUR MILLING** |
| N104 (Ø 4 ball nose endmill) | |
| N105 G00G54G90X47.6Y57.S6688M03 | |
| N106 G43H3Z70.M08 | **TOOL LENGTH ADJUSTMENT FOR TOOL 3** |
| N107 S4000 | |
| N108 Z50. | **CLEARANCE LEVEL BEFORE OPERATION** |
| N109 Z2. | **SECOND CLEARANCE LEVEL JUST FOR SAFETY** |
| N110 G01Z-1.F67. | **FIRST PASS TILL THE DEPTH Z = -1 mm** |
| N111 X50.F516. | |
| N112 X100. | |
| N113 X102.4 | |
| N114 G00Z50. | |
| | **THIS TOOL PATH IS REPEATED 9 TIMES MORE TILL Z = -10 mm** |
| N115 M09 | |
| N116 M05 | |
| N117 G00G28G91Z0 | **PROGRAM RESTART** |
| N118 G00G28G91X-15.0Y0. | |
| N119 G90 | |
| N120 M06T1 | |
| N121 M30 | **END OF PROGRAM** |
| N122 % | **STOP CODE - END OF FILE TRANSFER** |

# FINAL PART



# ADDITIVE MANUFACTURING (EXERCISE 2)

PROF. ALBERTO BOSCHETTO

TEAM LE FRECCE (GROUP #5)
Aditya Chaudhary (1846481)
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Sandeep Gupta (1844011)
Sandeep Goud (1873893)

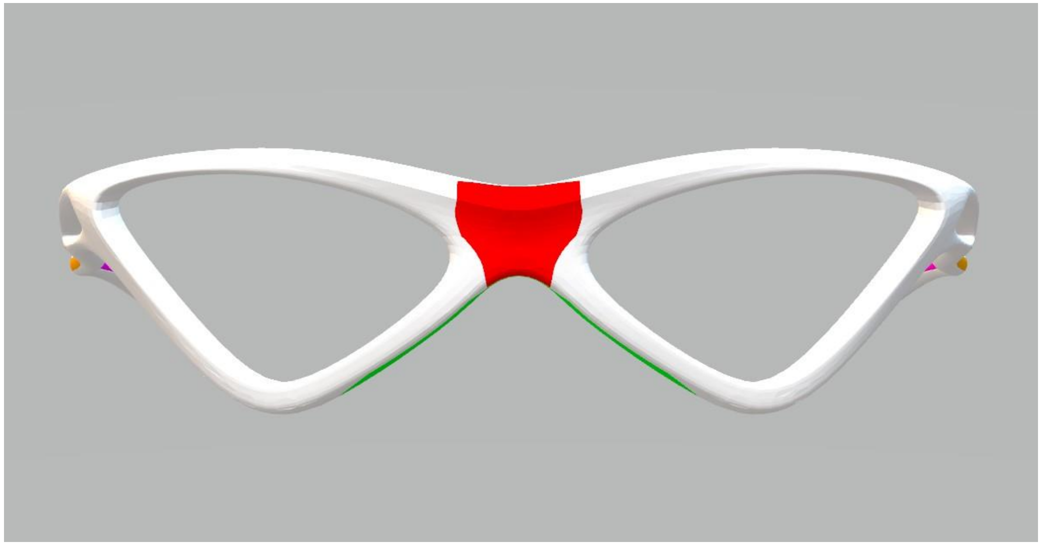
SAPIENZA
UNIVERSITÀ DI ROMA

# OBJECTIVE

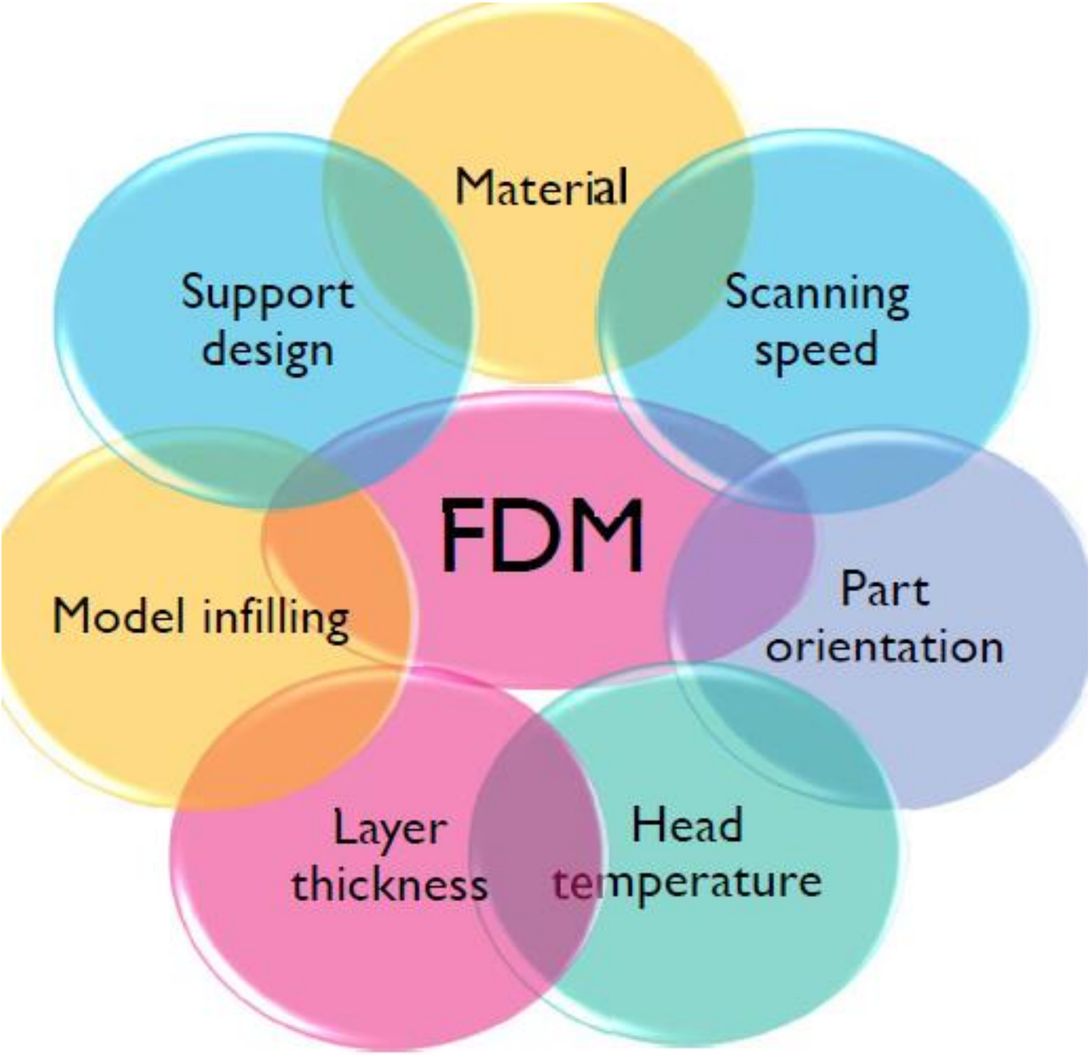
To fabricate two small batches of sun-glasses via FDM having a specific surface roughness requirement value in the following table:

| Group | Machine | Batch 1 | Scale batch 1 | Batch 2 | Scale batch 2 | Ra max |
|---|---|---|---|---|---|---|
| 5 | 1200 | 15 | 1,1 | 10 | 0,75 | red surface 30 µm |

| Sequence | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| **The steps of AM processes** | 3D solid model creation | Conversion to the STL format | Computer Aided Manufacturing | STL slicing and check | Support generation | Toolpath generation and physical fabrication | Post processing |
| **Data** | Given | Given | To Do | To Do | To Do | To Do | To Do |



# COMPUTER AIDED MANUFACTURING: SELECTION OF PROCESS PARAMETERS



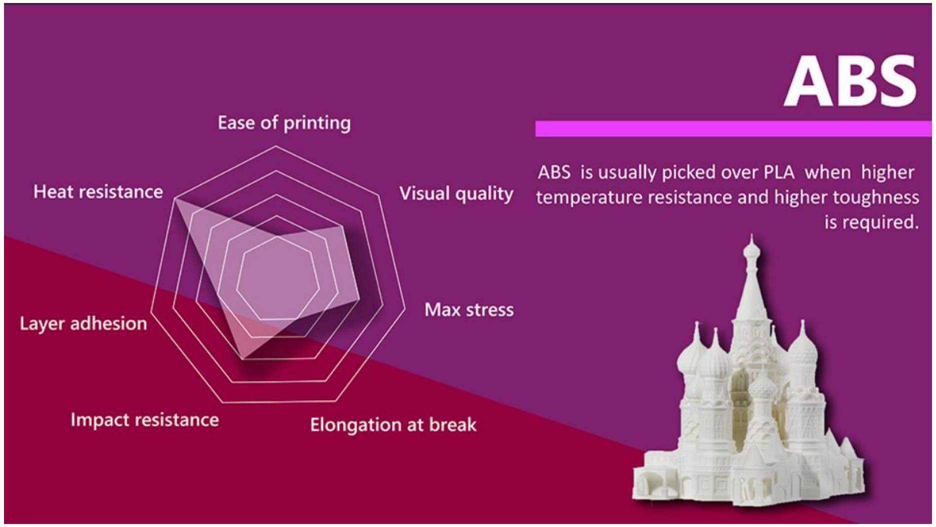
# FDM PROCESS OVERVIEW

Fused Deposition Modeling is an AM technology, where we use material extrusion process. Here we use ABS material, that is deposited in layers with required thickness. Fused material is spread continuously on the platform using nozzle. Interior solid area and support structure is filled using some fill-strategy. Part is oriented in best way to satisfy the production rate, time and cost.

| | |
|---|---|
| **Size** | 33 x 29 x 45" |
| **Extruders** | 1 |
| **Supported Materials** | Proprietary ABS*plus* filament |
| **Connectivity** | Ethernet |
| **Layer Thickness** | 0.254mm (quality)/ 0.33mm (fast) |
| **Build Volume** | 10 x 10 x 12" |


# MACHINE SELECTION

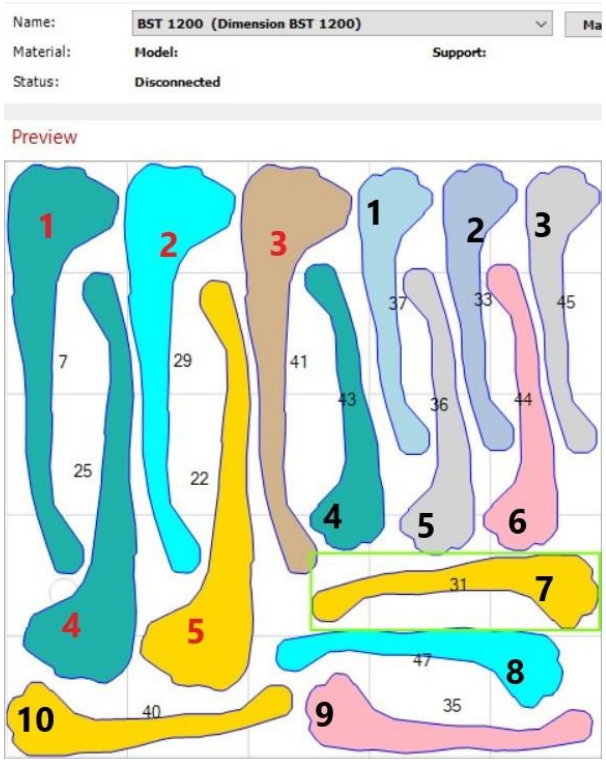
# MATERIAL SELECTION



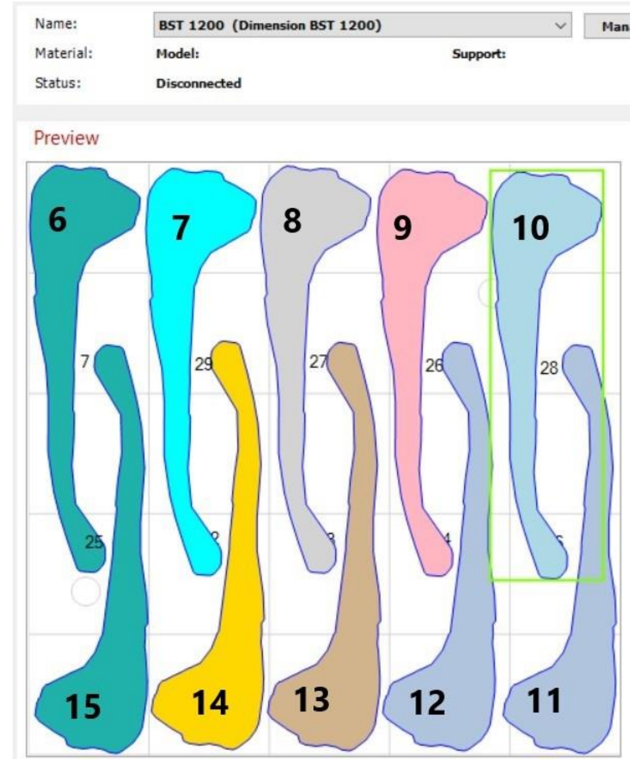

- Based on the requirement to fabricate 2 batches of 2 different scales, we decided to distribute them to fully utilize the space.
- Chamber 1 and 2 distribution is in the next page and please ignore extra numbers representation.

| CHAMBER | BATCH 1 | BATCH 2 |
|---|---|---|
| **1** | 10 | 0 |
| **2** | 5 | 10 |
| **TOTAL FABRICATED** | 15 | 10 |
| **MODEL MATERIAL (cubic cm)** | 196.3 | 240.08 |
| **SUPPORT MATERIAL (cubic cm)** | 873.99 | 973.51 |
| **TIME (min)** | 102:12:00 | 102:18:00 |

# PART ORIENTATION SELECTION




CHAMBER 1




CHAMBER 2

# CHAMBER DISTRIBUTION

# PART ORIENTATION SELECTION

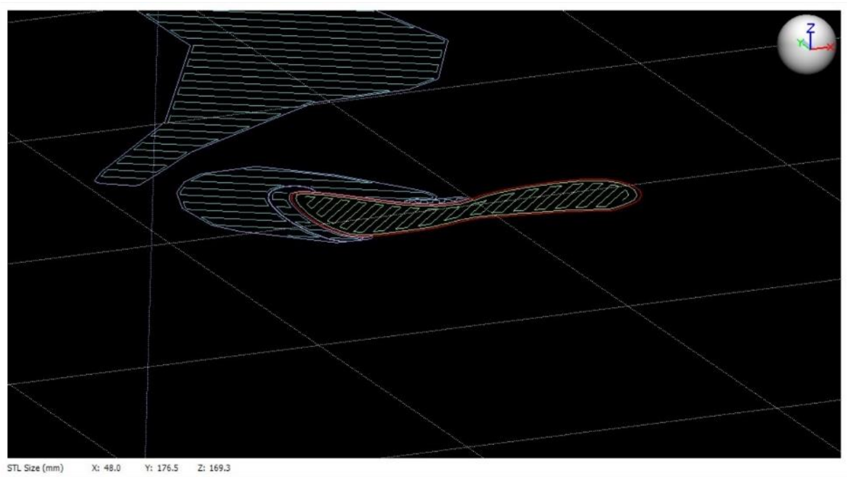
We checked various orientation angles and found the following orientation coupled with 0.3302 mm layer thickness as the most economic solution.

- First, we compared all possible orientations and found the orientation of 90° about y-axis as the optimized parameter (highlighted in pink color).
- Secondly, we compared this optimized values with the layer thickness of 0.3302 mm highlighted in green color).

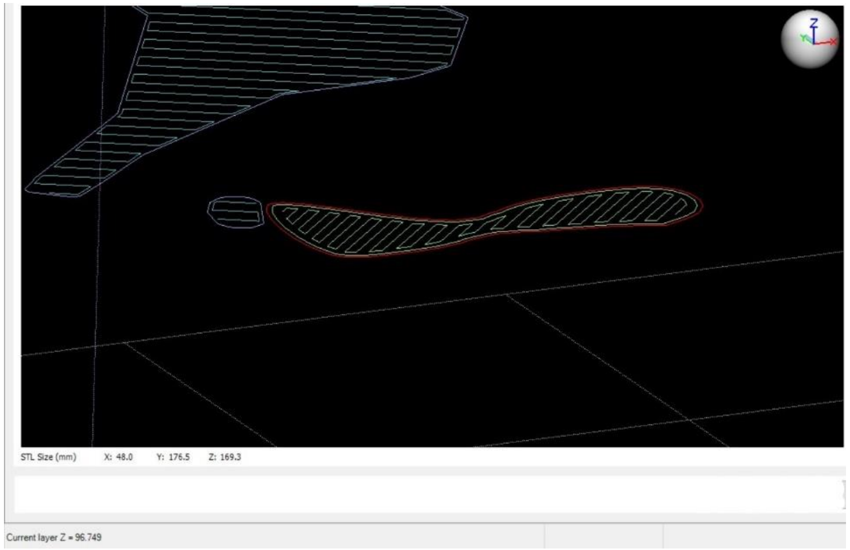
| Orientation Angle | Build Time Estimate (min) | Model Material (cubic cm) | Support Material (cubic cm) | Layer Resolution (mm) |
|---|---|---|---|---|
| Default | 5:03 | 18.321 | 43.031 | 0.254 |
| 180° in x dir | 4:27 | 18.339 | 33.135 | 0.254 |
| 90° in x dir | 4:54 | 18.065 | 26.45 | 0.254 |
| 270° in x dir | 10:59 | 18.016 | 138.331 | 0.254 |
| 90° in y dir | 10:13 | 24.007 | 97.295 | 0.254 |
| 90° in y dir | 7:36 | 23.905 | 98.571 | 0.3302 |

# HEAD TEMPERATURE SELECTION

| | |
|---|---|
| Extrusion Head | • 270° for ABS |
| Build Platform | • 110° for ABS |
| Build Room | • 75° for ABS |

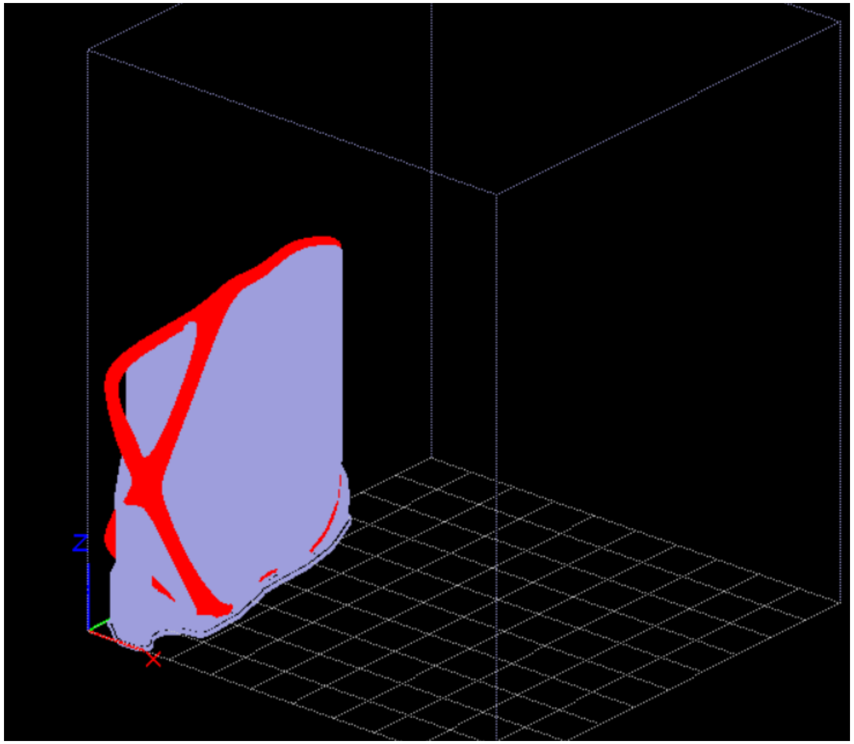


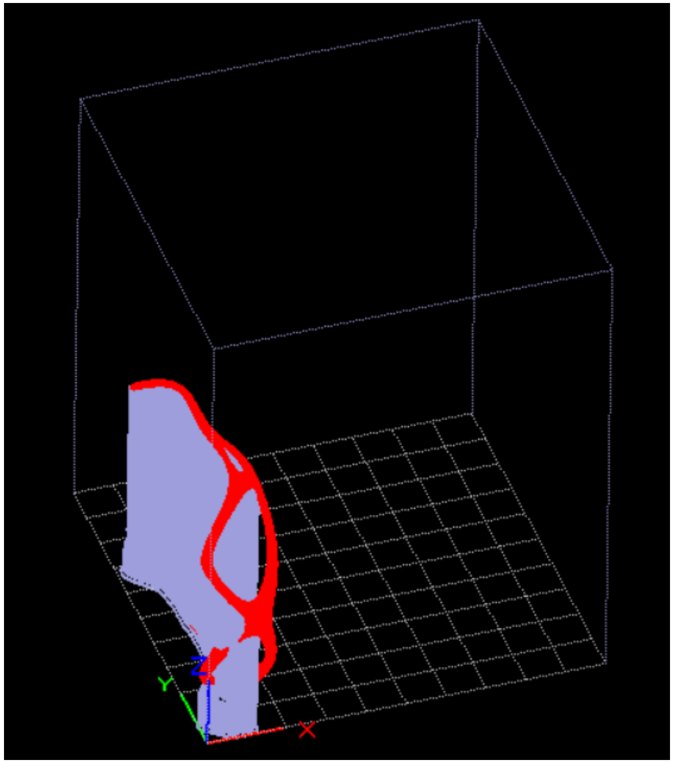

First raster layer of glass




Final raster layer of glass

# MODEL INFILLING SELECTION

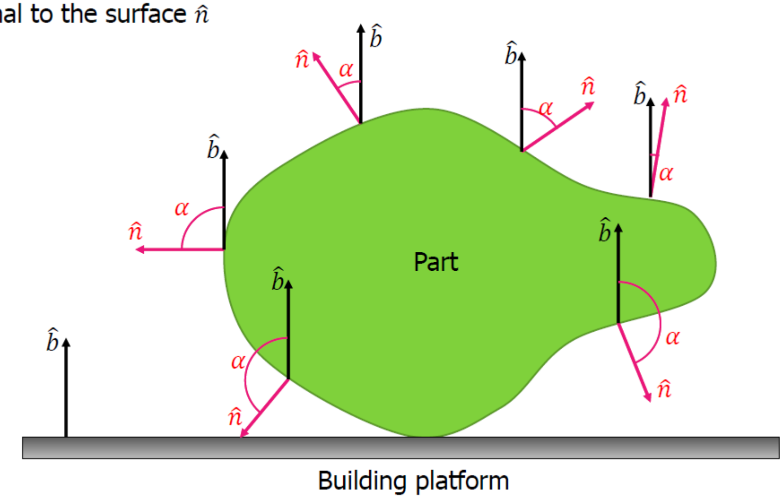


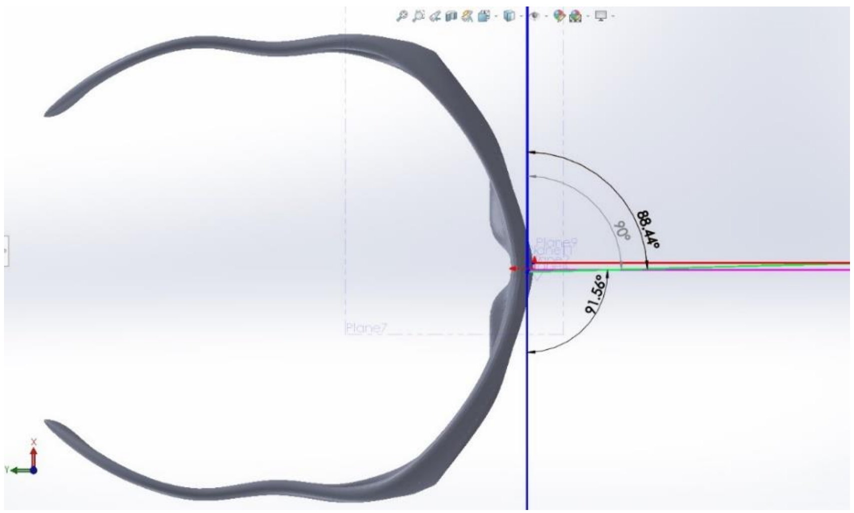

# AUTOMATIC SUPPORT DESIGN

# DEPOSITION ANGLE

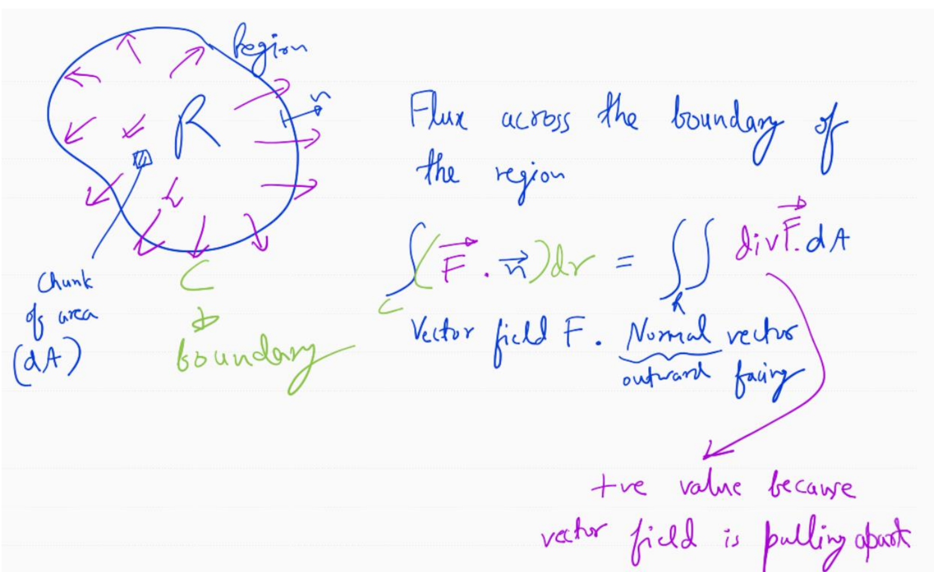
**Deposition angle** $\alpha$: angle between the stratification direction $\hat{b}$ and the normal to the surface $\hat{n}$




We can find the deposition angle from the Gauss's Theorem but there are infinite normal vectors so in this case we approximate the angle.

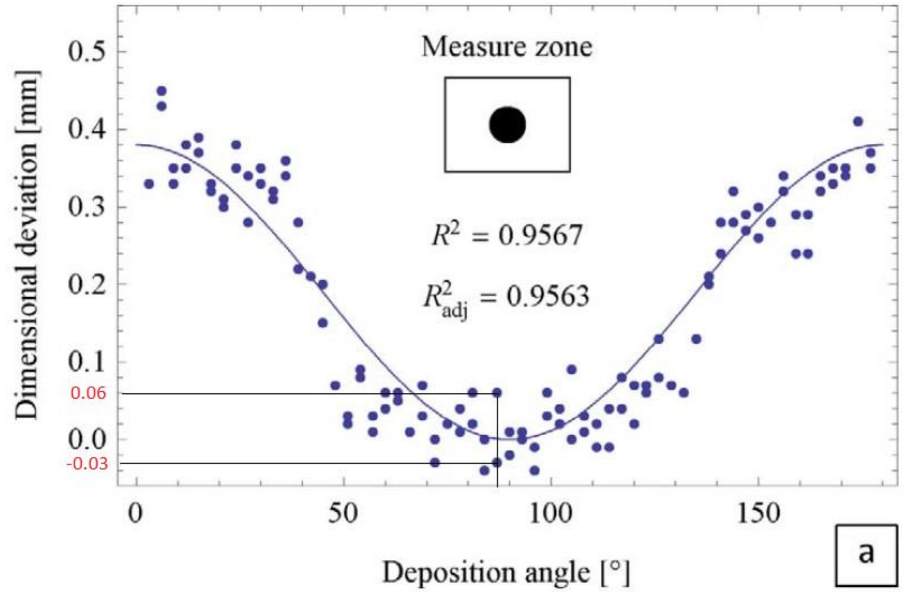



We constructed 3 random normal vectors with the help of parallel planes of 3 distinct surface triangulations on red surface and approximated the average to be 89°.

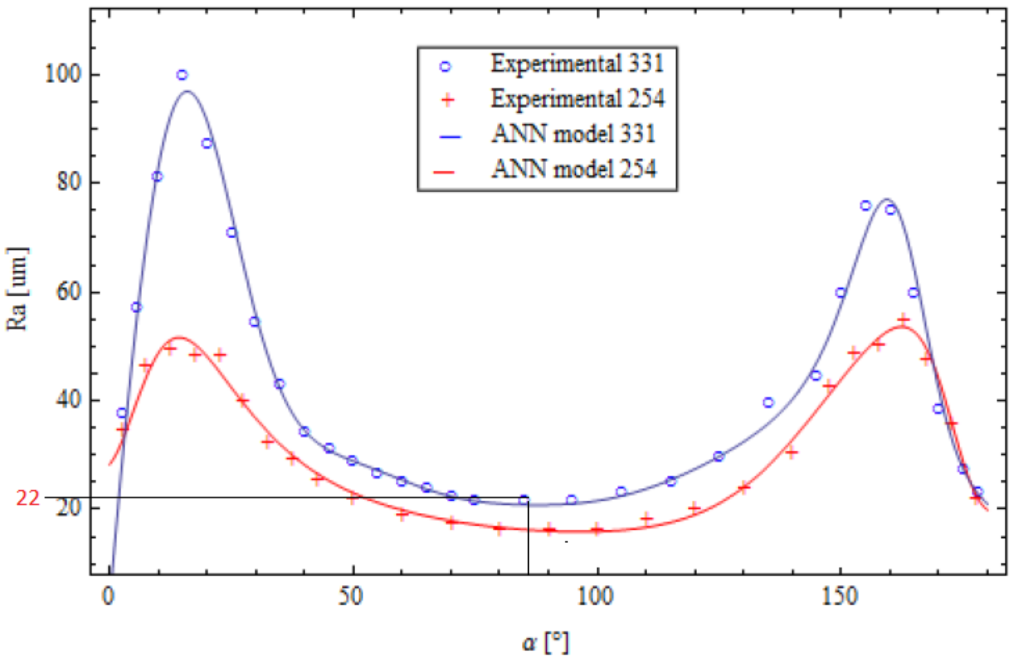


# SURFACE ROUGHNESS

Optimum deposition angle that we used is 89°. The roughness obtained for red area is of 22 μm and dimensional deviation range found to be (-0.03 to 0.06) mm.




(Boschetto A., Bottini L. (2014). Accuracy prediction in Fused Deposition Modeling. International journal of Advanced Manufacturing Technology.)




(Boschetto, Giordano, Veniali (2013). Surface roughness prediction in Fused Deposition Modeling by neural networks. International Journal of Advanced Manufacturing Technology)

# FLEXIBLE ASSEMBLY SYSTEM (EXERCISE 3)_PART A

PROF. ALBERTO BOSCHETTO

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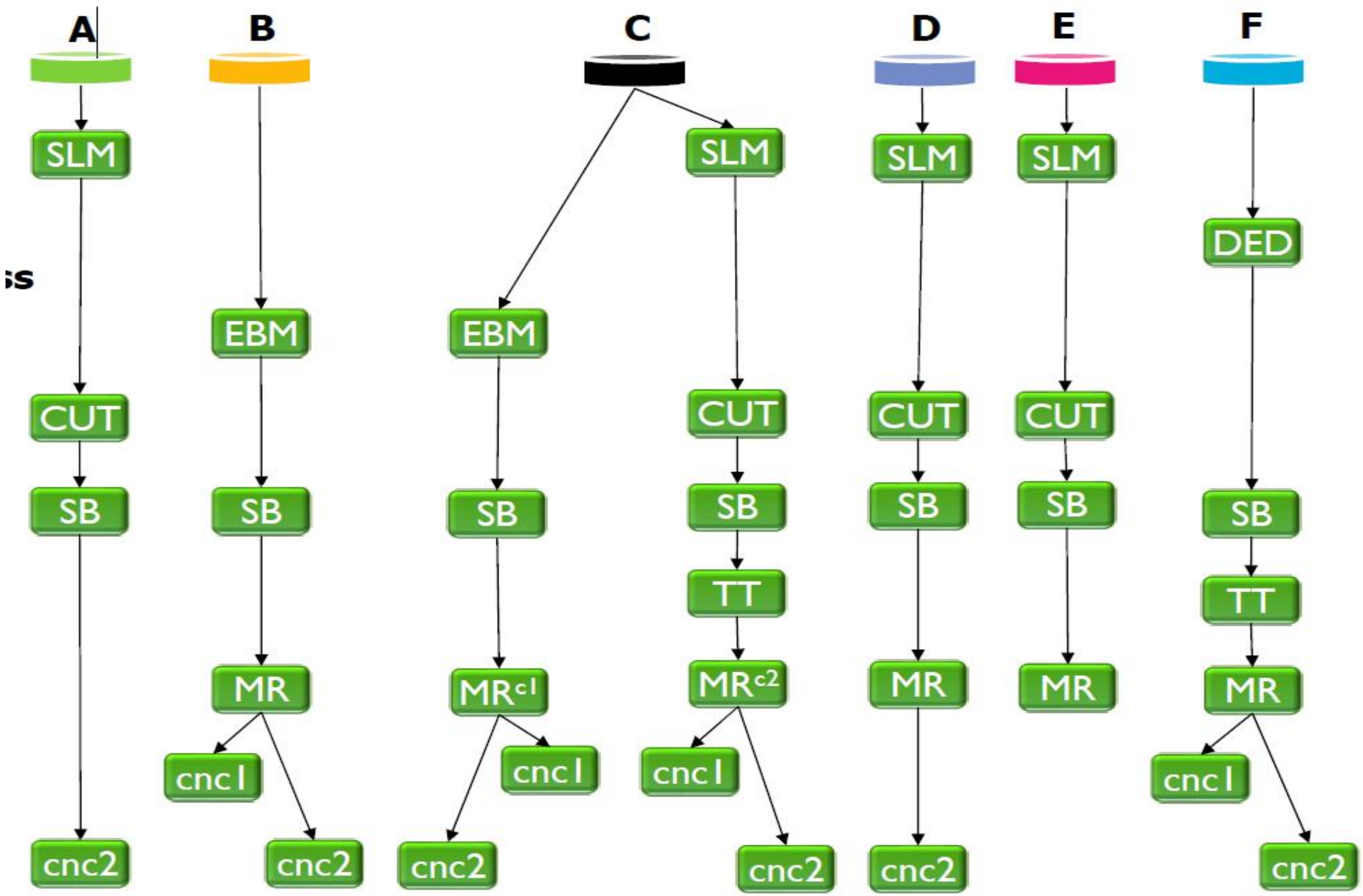
# FLEXIBLE MANUFACTURING SYSYTEM

Six types of components must be produced through a Flexible Manufacturing System. We have to divide the production system into cells and find the layout of each cell. And for each cell we have to determine the production rate, mean lead time and utilization indices. The  machine codes and monthly demands are given in the table:

| Product code | Demand/Month |
|---|---|
| A | 25 |
| B | 36 |
| C | 19 |
| D | 23 |
| E | 11 |
| F | 7 |

# MACHINING OPERATION FOR PRODUCTS

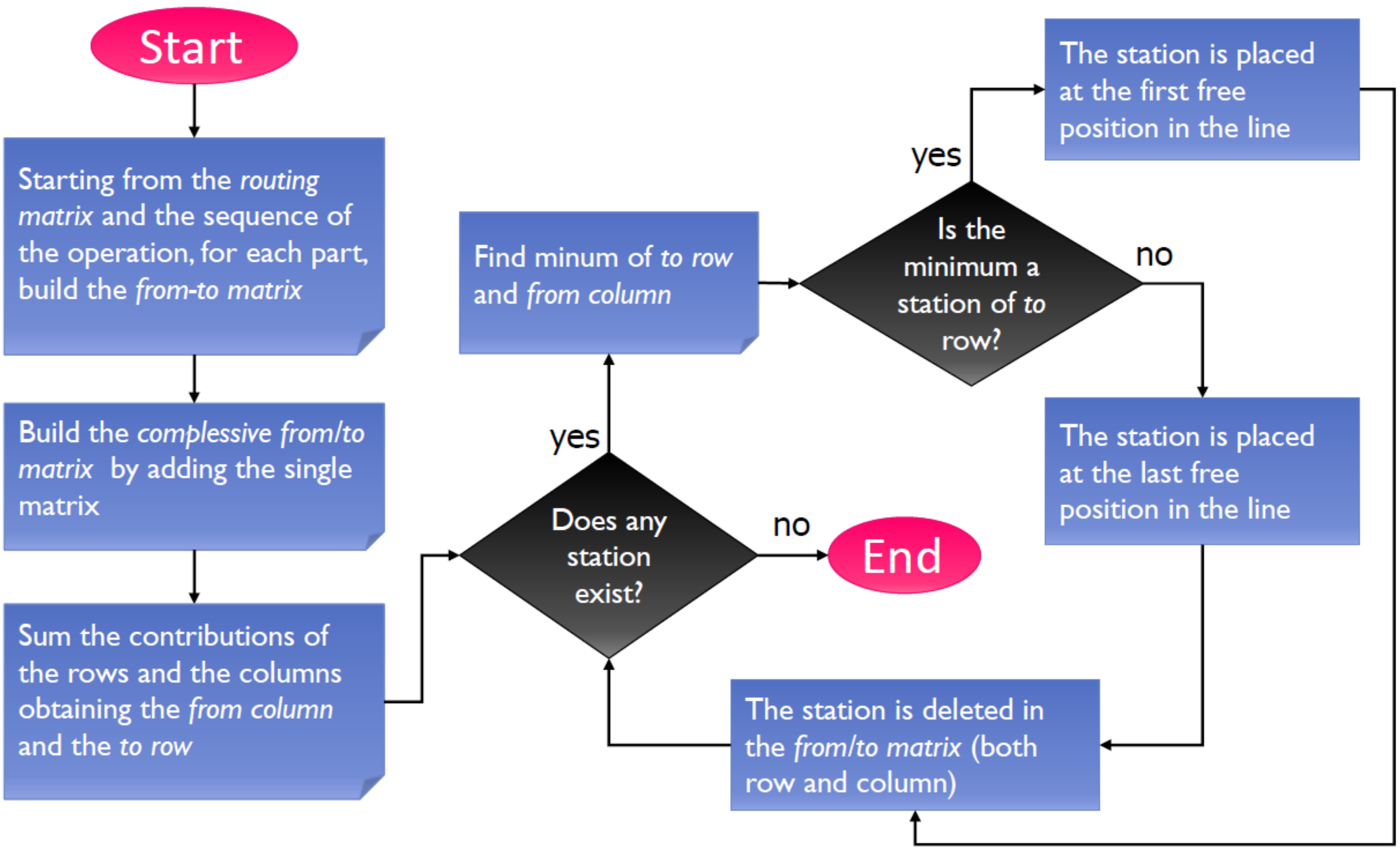


Routing Matrix:

## Part Machine Data

| Machine | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| SLM | 1 | | 1 | 1 | 1 | |
| DED | | | | | | 1 |
| EBM | | 1 | 1 | | | |
| CUT | 1 | | 1 | 1 | 1 | |
| SB | 1 | 1 | 1 | 1 | 1 | 1 |
| TT | | | 1 | | | 1 |
| MR | | 1 | | 1 | 1 | 1 |
| MRc1 | | | 1 | | | |
| MRc2 | | | 1 | | | |
| CNC1 | | 1 | 1 | | | 1 |
| CNC2 | 1 | 1 | 1 | 1 | | 1 |

Hollier Method Algorithm



# Matrix after Sorting

| | D | A | C | E | B | F |
|---|---|---|---|---|---|---|
| m5a | 1 | 1 | 1 | 1 | | |
| m1 | 1 | 1 | 1 | 1 | | |
| m4 | 1 | 1 | 1 | 1 | | |
| m9 | 1 | 1 | | | | |
| m7a | 1 | | 1 | 1 | | |
| m8b | | | 1 | | | |
| m6b | | | 1 | | | |
| m7b | | | | | 1 | 1 |
| m5b | | | | | 1 | 1 |
| m8a | | | | | 1 | 1 |
| m3 | | | | | 1 | |
| m6a | | | | | | 1 |
| m2 | | | | | | 1 |

**Compulsive form for Cell 1**

| | SBa | SLM | CUT | CNC2 | MRa | CNC1b | TTb | sum |
|---|---|---|---|---|---|---|---|---|
| SBa | 0 | 0 | 0 | 25 | 34 | 0 | 19 | 78 |
| SLM | 0 | 0 | 78 | 0 | 0 | 0 | 0 | 78 |
| CUT | 78 | 0 | 0 | 0 | 0 | 0 | 0 | 78 |
| CNC2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MRa | 0 | 0 | 0 | 23 | 0 | 19 | 0 | 42 |
| CNC1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TTb | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 19 |
| | 78 | 0 | 78 | 48 | 53 | 19 | 19 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sequencing | SLM | CNC1b | TTb | Mra | Sba | CUT | CNC2 |

## Compulsive form for Cell 2

| | MRb | SBb | CNC1a | EBM | TTa | DED | sum |
|---|---|---|---|---|---|---|---|
| MRb | 0 | 0 | 43 | 0 | 0 | 0 | 43 |
| SBb | 36 | 0 | 0 | 0 | 7 | 0 | 43 |
| CNC1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| EBM | 0 | 36 | 0 | 0 | 0 | 0 | 36 |
| TTa | 7 | 0 | 0 | 0 | 0 | 0 | 7 |
| DED | 0 | 7 | 0 | 0 | 0 | 0 | 7 |
| sum | 43 | 43 | 43 | 0 | 7 | 0 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sequencing | EBM | Tta | MRb | SBb | DED | CNC1 |

***Workload of a station***: total time a part *j* needing the operations *k* loads a station

$$WL_i = \sum_j \sum_k t_{ijk} \cdot f_{ijk} \cdot p_j$$

***Workload of the handling system***: product between the mean handling time and the mean transferring number needed to complete a part ($n_t$)

$$WL_{n+1} = t_{n+1} \cdot n_t$$

$$n_t = \left( \sum_i \sum_j \sum_k f_{ijk} \cdot p_j \right) - 1 \qquad n_t = \left( \sum_i \sum_j \left[ \left( \sum_k f_{ijk} \right) - 1 \right] \cdot p_j \right)$$

***Bottleneck:***

$$\frac{WL^*}{s^*} = Max_i \frac{WL_i}{s_i}$$

***Production rate***:

$$R_P^* = Min_i \frac{s_i}{WL_i} = \frac{s^*}{WL^*}$$

**s*** # of servers within the bottleneck station

**WL*** workload of the bottleneck station

***Production rate for the single mix product***

$$R_{pj}^* = p_j \frac{s^*}{WL^*}$$

## Work Load Cell

### Part A No of Operation-6

| Mix Pj | Des. | Op.K | Station | Servers | Time,tijk(min) |
|---|---|---|---|---|---|
| 0.32 | L/U | 1 | 1 | 1 | 4 |
| | SLM | 2 | 2 | 1 | 450 |
| | CUT | 3 | 3 | 1 | 90 |
| | SB | 4 | 4 | 1 | 30 |
| | CNC2 | 5 | 5 | 1 | 90 |
| | L/U | 6 | 1 | 1 | 2 |

### Part C No of Operation-8

| Mix Pj | Des. | Op.K | Station | Servers | Time,tijk(min) |
|---|---|---|---|---|---|
| 0.24 | L/U | 1 | 1 | 1 | 4 |
| | SLM | 2 | 2 | 1 | 420 |
| | CUT | 3 | 3 | 1 | 90 |
| | SB | 4 | 4 | 1 | 30 |
| | TT | 5 | 5 | 1 | 300 |
| | MR | 6 | 6 | 1 | 150 |
| | CNC1 | 7 | 7 | 1 | 90 |
| | L/U | 8 | 1 | 1 | 2 |

## Part D No of Operation-7

| Mix Pj | Des. | Op.K | Station | Servers | Time,tijk(min) |
|---|---|---|---|---|---|
| 0.29 | L/U | 1 | 1 | 1 | 4 |
| | SLM | 2 | 2 | 1 | 630 |
| | CUT | 3 | 3 | 1 | 60 |
| | SB | 4 | 4 | 1 | 30 |
| | MR | 5 | 5 | 1 | 150 |
| | CNC2 | 6 | 6 | 1 | 90 |
| | L/U | 7 | 1 | 1 | 2 |

## Part E No of Operation-6

| Mix Pj | Des. | Op.K | Station | Servers | Time,tijk(min) |
|---|---|---|---|---|---|
| 0.14 | L/U | 1 | 1 | 1 | 4 |
| | SLM | 2 | 2 | 1 | 390 |
| | CUT | 3 | 3 | 1 | 60 |
| | SB | 4 | 4 | 1 | 30 |
| | MR | 5 | 5 | 1 | 240 |
| | L/U | 6 | 1 | 1 | 2 |

WL(L/U):((4+2)*.32)+((4+2)*.24)+((4+2)*.29)+((4+2)*.14))=5.94

WL(SLM):(450*.32)+(420*.24)+(630*.29)+(390*.14)=482.1

WL(CUT):(90*.32)+(90*.24)+(60*.29)+(60*.14)=76.2

WL(SB):(30*.32)+(30*.24)+(30*.29)+(30*.14)=29.7

WL(CNC2):(90*.32)+(90*.29)=54.9

WL(MR):(150*.29)+(240*.14)+(150*.24)=113.1

WL(TT):(300*0.24)=72

WL(CNC1):(90*.24)=21.6

WORKLOAD HANDLING TIME nt :((6*0.32)+(8*0.24)+(7*0.29)+(6*0.14))-1=5.71

WL(n+1) : n(t) x t(n+1)  =5.71*2=11.42

WL(L/U)=11.4/8=1.425

| Handling time is 2 min. | | |
|---|---|---|
| Workload | Station | Time(min) |
| WL1 | L/U | 5.94 |
| WL2 | SLM | 482.1 |
| WL3 | CUT | 76.2 |
| WL4 | SB | 29.7 |
| WL5 | TT | 72 |
| WL6 | MR | 113.1 |
| WL7 | CNC1 | 21.6 |
| WL8 | CNC2 | 54.9 |
| WL9 | L/U | 1.425 |
| WL(n+1) | | 11.42 |

## **Bottleneck Station is SLM**

- Production of Bottleneck Station
  $Rp^* = S^*/WL^* = 1/482.1 = .002$ pz/min$=0.126$ pz/hr

- **Production rate for Product – A :**
  $Rpa^* = P(A) \times Rp^* = 0.32 * .126 = 0.04$ pz/hrs$=0.00067$ pz/min

- **Production rate for Product – C :**
  $Rpc^* = P(C) \times Rp^* = 0.24 * .126 = 0.0302$ pz/hrs$=0.0005$ pz/min

- **Production rate for Product – D :**
  $Rpd^* = P(D) \times Rp^* = 0.29 * .126 = 0.036$ pz/hrs$=0.0006$ pz/min

- **Production rate for Product – E :**
  $Rpd^* = P(D) \times Rp^* = 0.29 * .126 = 0.036$ pz/hrs$=0.0006$ pz/min

| Production rate | Pieces/min |
|---|---|
| Rp* | 0.002 |
| Rpa* | 0.04 |
| Rpc* | 0.0302 |
| Rpd* | 0.036 |
| Rpe* | 0.017 |

## Utilization For Cell 1

U(L/U)=WL(L/U) x Rp*=5.94*0.002 =0.01188

U(SLM)=WL(SLM) x Rp*=482.1*0.002 = 0.9642

U(CUT)=WL(CUT) x Rp*=76.2*0.002 =0.1542

U(SB)=WL(SB) x Rp*=29.7*0.002 =0.0594

U(CNC1)=WL(CNC1) x Rp*=21.6*0.002 =0.0432

U(CNC2)=WL(CNC2) x Rp*=54.9*0.002 =0.1098

U(TT)=WL(TT) x Rp*=72*0.002 =0.144

U(MR)=WL(MR) x Rp*=113.1*0.002 =0.2262

| Machine | Utilizations(%) |
|---|---|
| L/U | 1 |
| SLM | 96 |
| CUT | 15 |
| SB | 5 |
| TT | 14 |
| MR | 22 |
| CNC1 | 4 |
| CNC2 | 10 |
| L/U | 1 |

Workload of cell 2:

Part B No of Operation-6

| Mix Pj | Des. | Op.K | Station | Servers | Time,tijk(min) |
|---|---|---|---|---|---|
| | L/U | 1 | 1 | 1 | 4 |
| | EBM | 2 | 2 | 1 | 720 |
| 0.84 | SB | 3 | 3 | 1 | 60 |
| | MR | 4 | 4 | 1 | 120 |
| | CNC1 | 5 | 5 | 1 | 90 |
| | L/U | 6 | 1 | 1 | 2 |
| | | | | | |

Part B No of Operation-6

| Mix Pj | Des. | Op.K | Station | Servers | Time,tijk(min) |
|---|---|---|---|---|---|
| | L/U | 1 | 1 | 1 | 4 |
| | DED | 2 | 2 | 1 | 690 |
| 0.163 | SB | 3 | 3 | 1 | 60 |
| | TT | 4 | 4 | 1 | 360 |
| | MR | 5 | 5 | 1 | 240 |
| | CNC1 | 6 | 6 | 1 | 120 |
| | L/U | 7 | 1 | 1 | 2 |

**Workload for Cell-2:**

WL(L/U):((4+2)*.84)+(4+2)*.163)=6.018

WL(EBM):(720*.84)=604.8

WL(DED):(690*.163)=112.47

WL(SB):((60)*.84)+(60)*.163))=60.18

WL(TT):(360*.163)=58.68

WL(MR):((120)*.84)+(240)*.163))=139.92

WL(CNC):((90)*.84)+(120)*.163))=95.16

WORKLOAD HANDLING TIME nt:((6*0.84)+(7*.163))-1=5.1816

WL(n+1) : n(t) x t(n+1) = 5.181x2 =10.362

WL(L/U) = 10.36/7=1.48

Handling time is 2 min.

| Workload | Station | Time(min) |
|---|---|---|
| WL1 | L/U | 6.018 |
| WL2 | EBM | 604.8 |
| WL3 | DED | 112.47 |
| WL4 | SB | 60.18 |
| WL5 | TT | 58.68 |
| WL6 | MR | 139.92 |
| WL7 | CNC | 95.16 |
| WL8 | L/U | 1.48 |
| WL(n+1) | | 10.36 |

## Bottleneck Station is EBM

- Production of Bottleneck Station

  $Rp^* = S^*/WL^* = 1/604.2 = 0.001 pz/min = 0.099 pz/hr$

- Production rate for Product – B :

  $Rpb^* = P(B) \times Rp^* = 0.84 * .099 = 0.083 pz/hr = 0.0013\ pz/min$

- Production rate for Product – F:

  $Rpf^* = P(F) \times Rp^* = 0.16 * .099 = 0.015 pz/hr = 0.0002 pz/min$

| Production rate : | |
|---|---|
| Production rate | Pieces/min |
| Rp* | 0.001 |
| Rpb* | 0.0013 |
| Rpf* | 0.0002 |

**Utilization For Cell 2**

U(L/U)=WL(L/U) x Rp*=6.018*0.001=0.006

U(EBM)=WL(EBM) x Rp*=604.8*0.001=0.604

U(DED)=WL(DED) x Rp*=112.47*0.001=0.112

U(SB)=WL(SB) x Rp*=60.18*0.001=0.060

U(TT)=WL(TT) x Rp*=58.68*0.001=0.058

U(MR)=WL(MR) x Rp*=139.92*0.001=0.139

U(CNC)=WL(CNC) x Rp*=95.16*0.001=0.095

| Machine | Utilizations(%) |
|---|---|
| L/U | 0.6 |
| EBM | 60.5 |
| DED | 11.24 |
| SB | 6.01 |
| TT | 5.8 |
| MR | 13.9 |
| CNC | 9.5 |

# FLEXIBLE ASSEMBLY SYSTEM (EXERCISE 3)_PART B

PROF. ALBERTO BOSCHETTO

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# OBJECTIVE

1. The cycle time
2. The balancing efficiency of the two algorithms.
3. The layout of the best solution

# CALCULATION OF CYCLE TIME

To calculate the cycle time we require production rate and line efficiency (line uptime to real availability ratio) .

From the date we have:

Da : Annual Demand (unit/year)

W : Working weeks pr year

S : Shift per week

H : Hours/shift

Rp : Producton Rate

η : .95

To calculate the production rate we have formula

**Rp = Da/(W.S.H)**

For our assign assembly **Rp : 43.56 unit/hr**

After calculating Rp and using line efficiency we calculate Cycle time :

Tc = η / Rp

For assign assembly : **1.31 min .**

## Total Time to calculate the assembly

Twc calculate the total time to complete the assembly we have assign time to calculate the particular process

Twc : $\sum_{n=1}^{20}(Tek)$

Assign assembly : **Twc = 5.03 min**

As we have assume the service time as Tr = 0.08 min per process of assembly

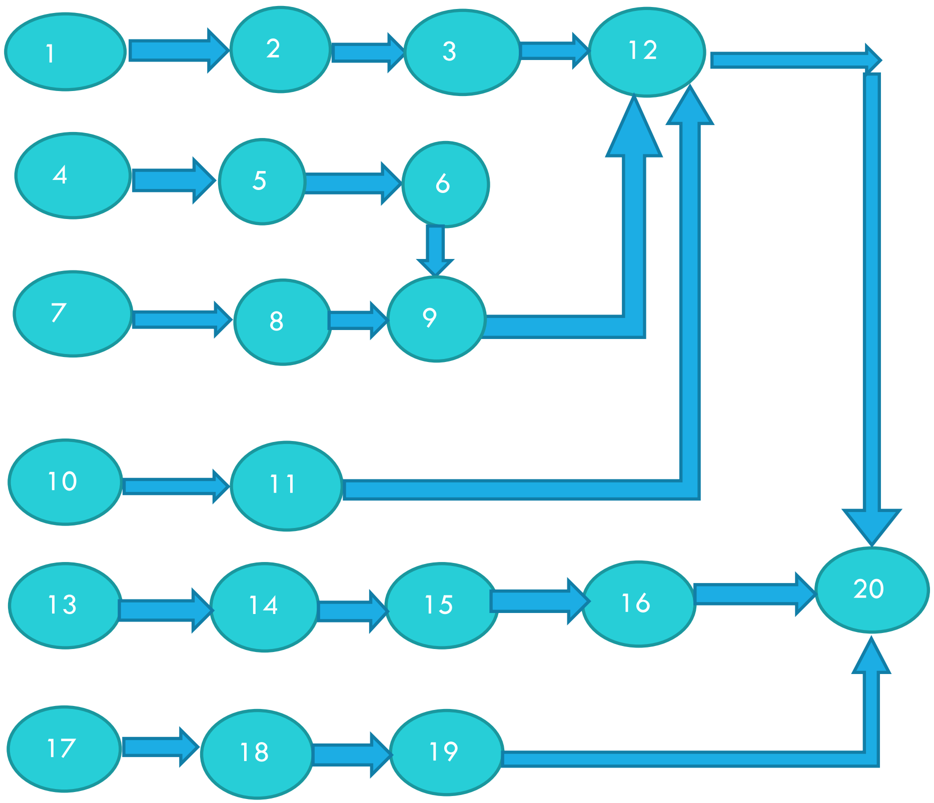
**Total Service time : 1.6 min**

Ts = max [Tsi] ≤ Tc – Tr

For assign assembly **: Ts = 1.23 min**

# PRIORITY GRAPH

To proceed with the priority graph we have assign 20 process to complete the assembly .



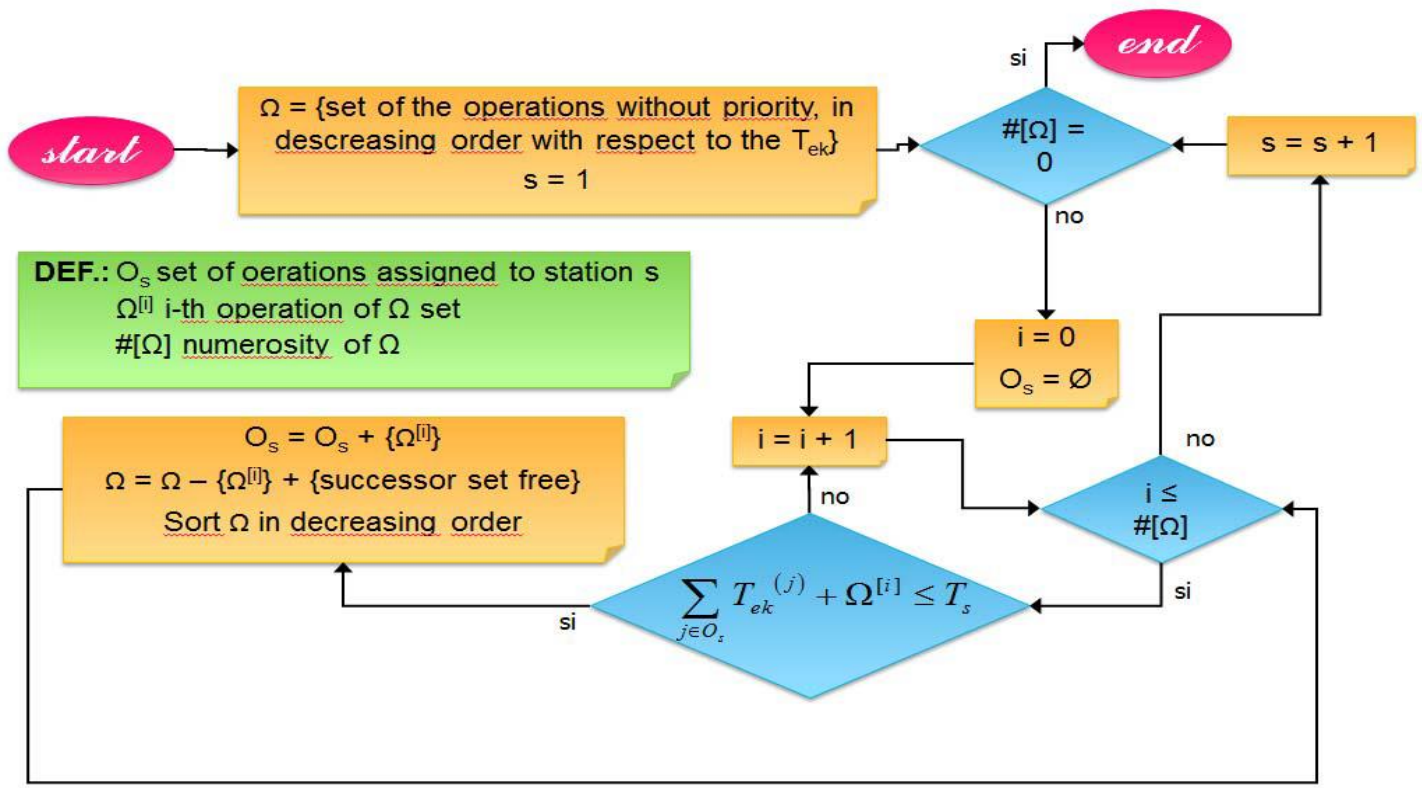
# Time for each process assign : Time required to do manual operation .

| Op. | DESCRIPTION | Tek(sec) | Tek(Min) |
|---|---|---|---|
| 1 | POSITION OF 3 ON 4 | 19 | 0.32 |
| 2 | INSERTION OF 2 IN 3 | 28 | 0.47 |
| 3 | INSERTION OF 1 IN 4 | 15 | 0.25 |
| 4 | POSITION OF 5A ON 4 | 9 | 0.15 |
| 5 | INSERTION OF 5 ON 4 | 13 | 0.22 |
| 6 | INSERTION OF 6 IN 5a | 26 | 0.43 |
| 7 | POSITION OF 7ON 8 | 10 | 0.17 |
| 8 | INSERTION OF 6 IN 7 | 10 | 0.17 |
| 9 | ASSEMBLY OF 6 | 9 | 0.15 |
| 10 | INSERTION OF 17 IN 18 | 12 | 0.20 |
| 11 | INSERTION OF 18 IN 4 | 12 | 0.20 |
| 12 | INSERTION OF 4 IN 8 | 32 | 0.53 |
| 13 | INSERTION OF 10 IN 8 | 14 | 0.23 |
| 14 | INSERTION OF 11 IN 10 | 9 | 0.15 |
| 15 | INSERTION OF 9 IN 10 | 18 | 0.30 |
| 16 | INSERTION OF 12 IN 11 | 15 | 0.25 |
| 17 | INSERTION OF 14 IN 8 | 20 | 0.33 |
| 18 | INSERTION OF 13 IN 14 | 6 | 0.10 |
| 19 | INSERTION OF 15 IN 16 | 5 | 0.08 |
| 20 | INSERTION OF 8 IN 16 | 20 | 0.33 |
| | | | 5.03 |

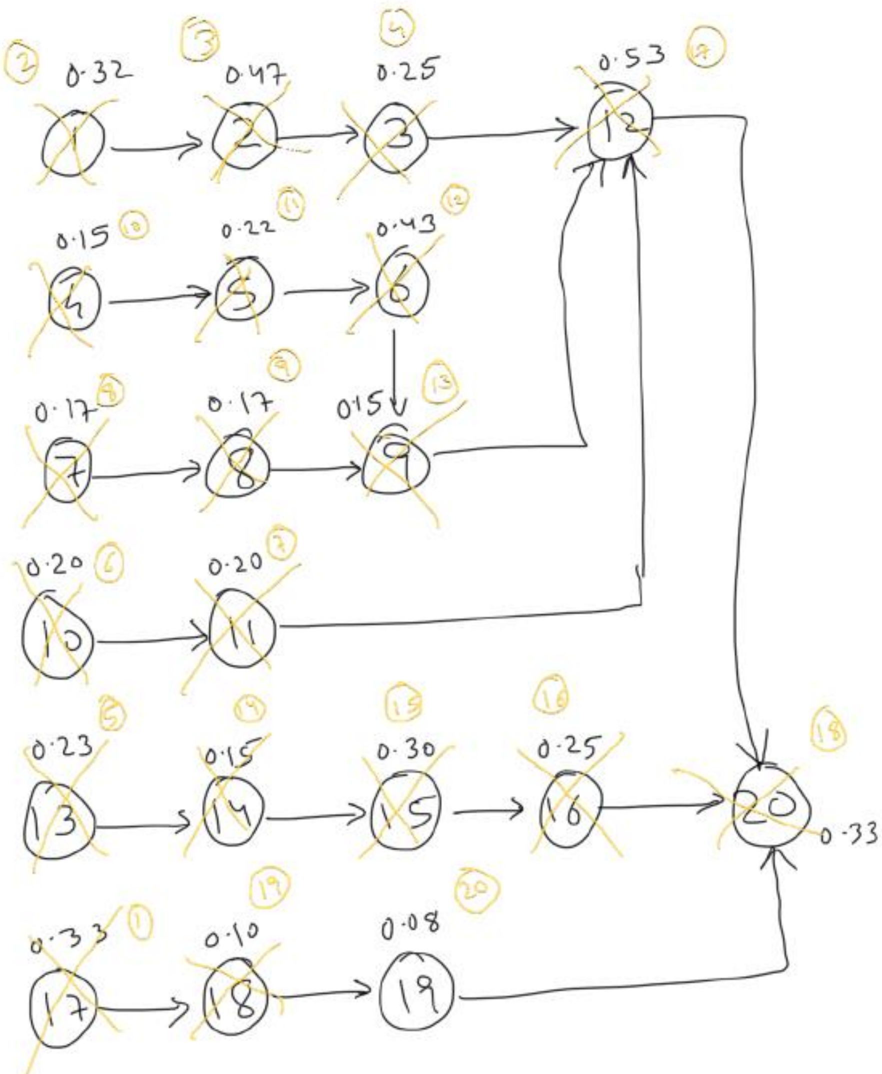
| | | |
|---|---|---|
| Da | 245000 | units/year |
| W | 50 | week/year |
| S | 15 | shift/week |
| H | 7.5 | hours/shift |
| Efficiency | 0.95 | |
| Tr | 0.08 | min |
| Ts | 1.23 | min |
| Tc | 1.31 | min |
| Rp | 43.56 | unit/hr |
| Rp | 0.7259259 | unit/min |
| wstar | 4 | |

# LARGEST CANDIDATE METHOD

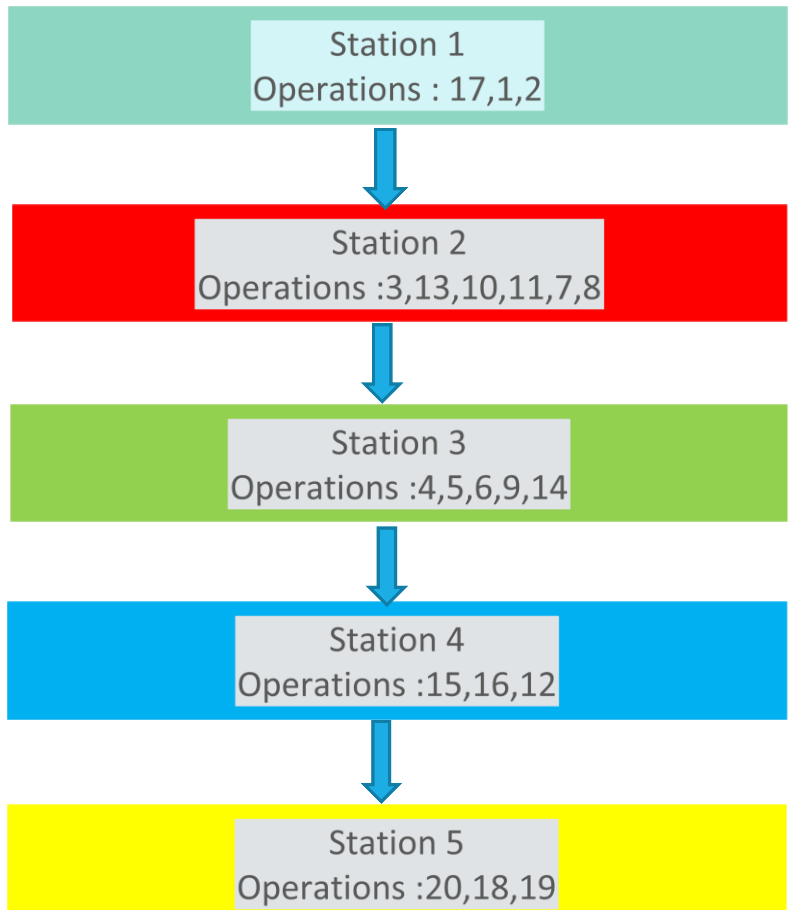
To start the process we need time for each process :



# Largest Candidate Algorithm process



| | | | | |
|---|---|---|---|---|
| | Largest Candidate Method Alorithm | | | |
| S | i | Os | Sum Tek | Set |
| 1 | 0 | [] | 0 | [17,1,13,10,7,4] |
| | 1 | 17 | 0.33 | [1,13,10,7,4,18] |
| | 1 | [17,1] | 0.65 | [2,13,10,7,4,18] |
| | 1 | 17,1,2 | **1.12** | [3,13,10,7,4,18] |
| 2 | 0 | [] | 0.00 | [3,13,10,7,4,18] |
| | 1 | 3 | 0.25 | [13,10,7,4,18] |
| | 1 | 3,13 | 0.48 | [10,7,4,14,18] |
| | 1 | 3,13,10 | 0.68 | [11,7,4,14,18] |
| | 1 | 3,13,10,11 | 0.88 | [7,4,14,18] |
| | 1 | 3,13,10,11,7 | 1.05 | [8,4,14,18] |
| | 1 | 3,13,10,11,7,8 | **1.22** | [4,14,18] |
| 3 | 0 | [] | 0 | [4,14,18] |
| | | 4 | 0.15 | [5,14,10] |
| | | 4,5 | 0.37 | [6,9,14,18] |
| | | 4,5,6 | 0.80 | [9,14,18] |
| | | 4,5,6,9 | 0.95 | [14,18] |
| | | 4,5,6,9,14 | **1.10** | [15,18] |
| 4 | 0 | [] | 0 | [15,18] |
| | | 15 | 0.30 | [16,18] |
| | | 15,16 | 0.55 | [12,20,18] |
| | | 15,16,12 | **1.08** | [20,18] |
| 5 | 0 | [] | 0 | [20,18] |
| | | 20 | 0.33 | [18] |
| | | 20,18 | 0.43 | [19] |
| | | 20,18,19 | **0.52** | [] |

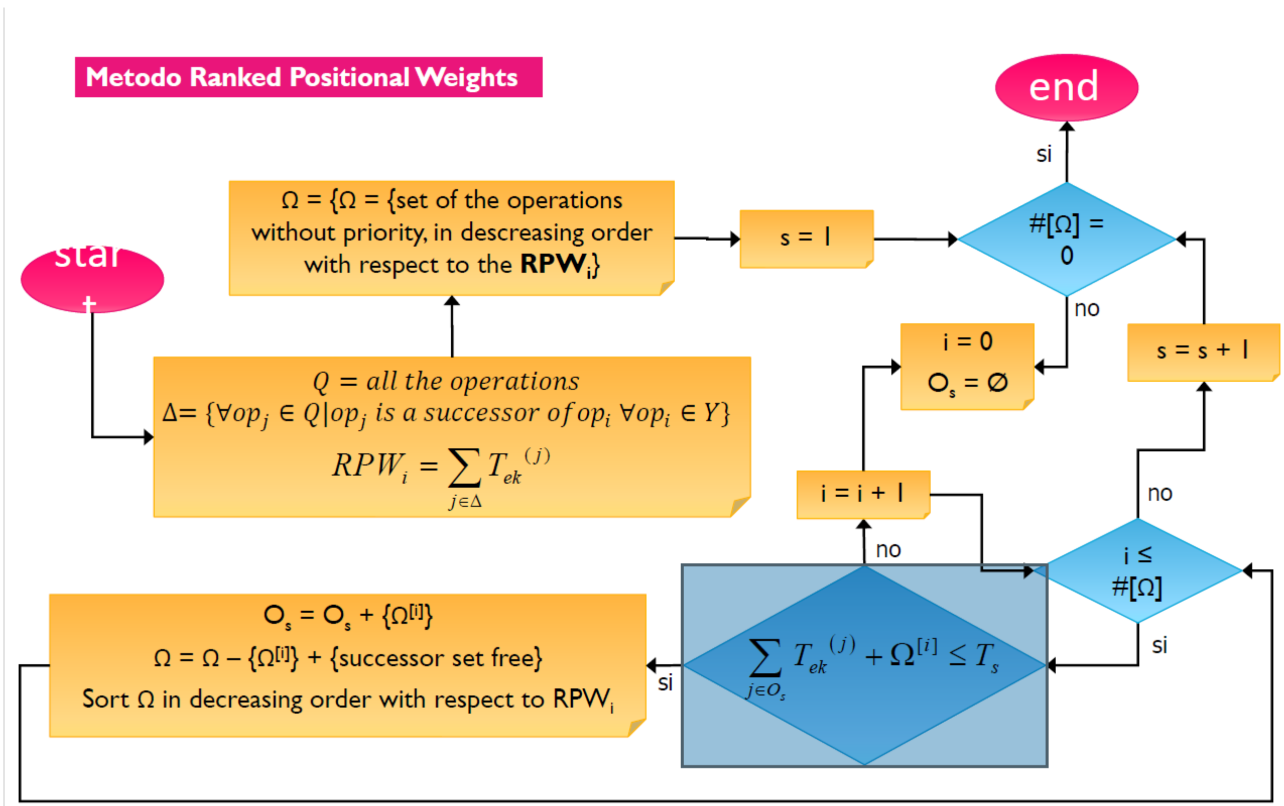

Station 1
Operations : 17,1,2
Station 2
Operations :3,13,10,11,7,8
Station 3
Operations :4,5,6,9,14
Station 4
Operations :15,16,12
Station 5
Operations :20,18,19

# RANKED POSITIONAL METHOD

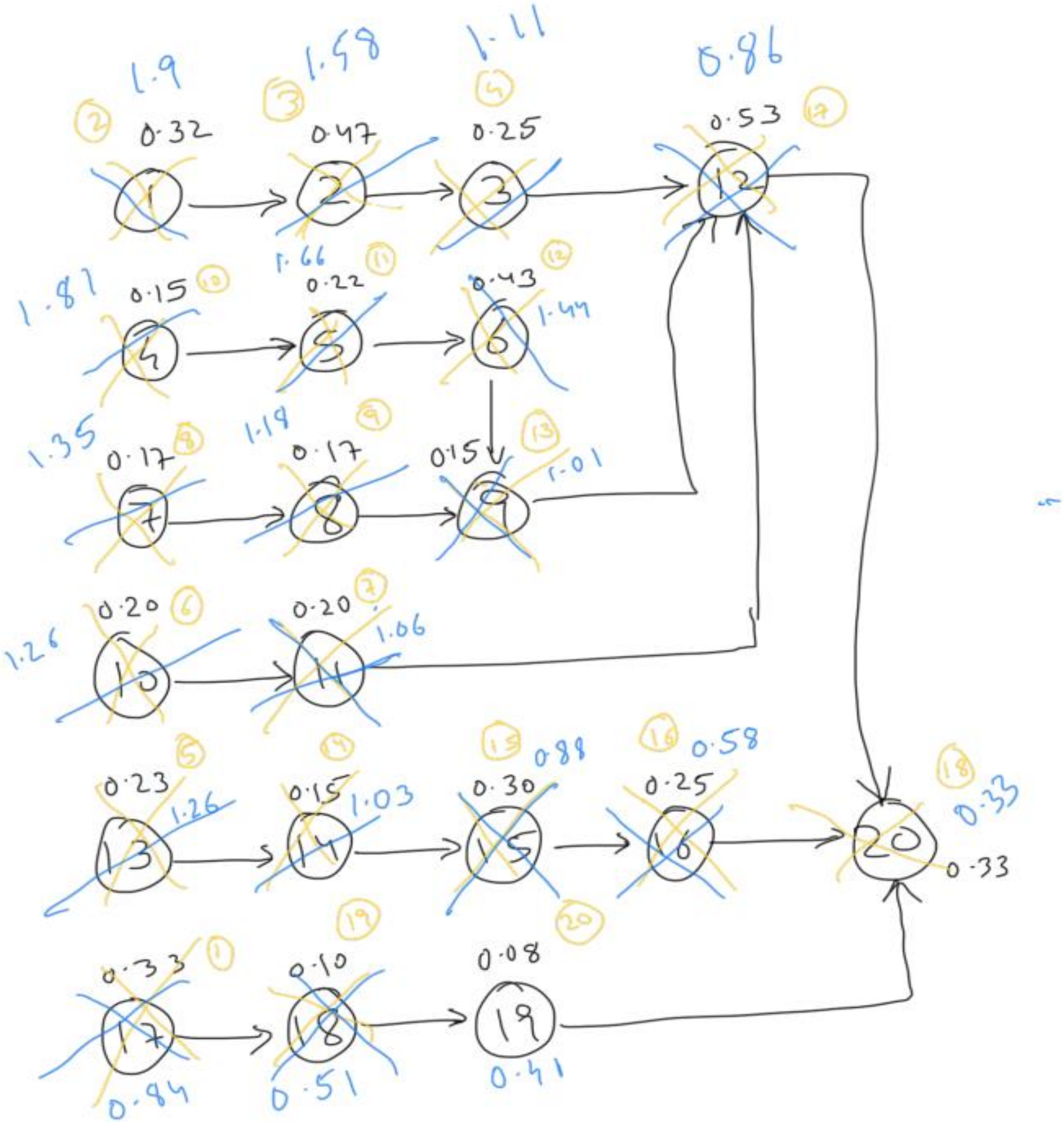
To procced with Ranked Positional Method we need summation of time of the proceeding process to complete the assembly which is defined by RPW .

| Op. | DESCRIPTION | Tek(sec) | Tek(Min) | RPW(MIN) |
|---|---|---|---|---|
| 1 | POSITION OF 3 ON 4 | 19 | 0.32 | 1.90 |
| 2 | INSERTION OF 2 IN 3 | 28 | 0.47 | 1.58 |
| 3 | INSERTION OF 1 IN 4 | 15 | 0.25 | 1.12 |
| 4 | POSITION OF 5A ON 4 | 9 | 0.15 | 1.82 |
| 5 | INSERTION OF 5 ON 4 | 13 | 0.22 | 1.67 |
| 6 | INSERTION OF 6 ON 5 | 26 | 0.43 | 1.45 |
| 7 | POSITION OF 7ON 8 | 10 | 0.17 | 1.35 |
| 8 | INSERTION OF 6 IN 7 | 10 | 0.17 | 1.18 |
| 9 | ASSEMBLY OF 6 | 9 | 0.15 | 1.02 |
| 10 | INSERTION OF 17 IN 18 | 12 | 0.20 | 1.27 |
| 11 | INSERTION OF 18 IN 4 | 12 | 0.20 | 1.07 |
| 12 | INSERTION OF 4 IN 8 | 32 | 0.53 | 0.87 |
| 13 | INSERTION OF 10 IN 8 | 14 | 0.23 | 1.27 |
| 14 | INSERTION OF 11 IN 10 | 9 | 0.15 | 1.03 |
| 15 | INSERTION OF 9 IN 10 | 18 | 0.30 | 0.88 |
| 16 | INSERTION OF 12 IN 11 | 15 | 0.25 | 0.58 |
| 17 | INSERTION OF 14 IN 16 | 20 | 0.33 | 0.85 |
| 18 | INSERTION OF 13 IN 14 | 6 | 0.10 | 0.52 |
| 19 | INSERTION OF 15 IN 16 | 5 | 0.08 | 0.42 |
| 20 | INSERTION OF 8 IN 16 | 20 | 0.33 | 0.33 |
| | | | 5.03 | |

RRW is summation of process time as per the priority graph .



Ranked Positional Method

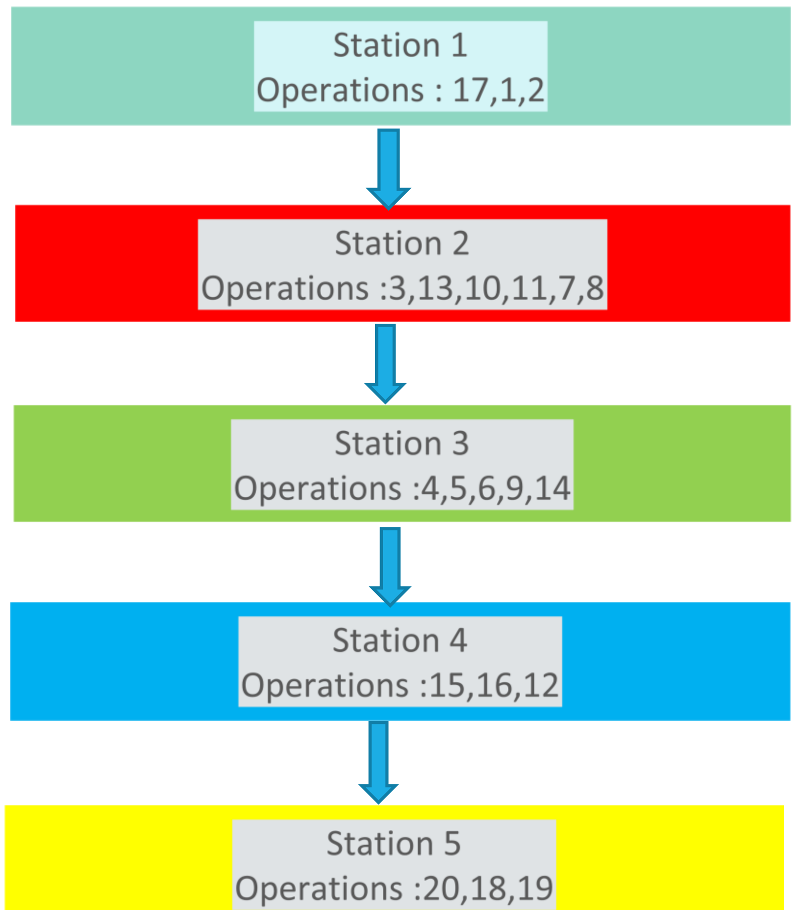


Following the algorithm we have assign the particular operation to each station .

No of Station : 5

| S | i | Os | Sum Tek | Set |
|---|---|---|---|---|
| 1 | | [] | [] | [1,4,7,10,13,17] |
| | | 1 | 0.32 | [4,2,7,10,13,17] |
| | | 1,4 | 0.47 | [5,2,7,10,13,17] |
| | | 1,4,5 | 0.68 | [2,6,7,10,13,17] |
| | | 1,4,5,2 | 1.15 | [6,7,10,13,3,17] |
| 2 | | [] | [] | [6,7,10,13,3,17] |
| | | 6 | 0.43 | [7,10,13,3,17] |
| | | 6,7 | 0.60 | [10,13,8,3,17] |
| | | 6,7,10 | 0.80 | [13,8,3,11,17] |
| | | 6,7,10,13 | 1.03 | [8,3,11,14,17] |
| | | 6,7,10,13, 8 | 1.20 | [3,11,14,9,17] |
| 3 | | [] | [] | [3,11,14,9,17] |
| | | 3 | 0.25 | [11,14,9,17] |
| | | 3,11 | 0.45 | [14,9,17] |
| | | 3,11,14 | 0.60 | [9,15,17] |
| | | 3,11,14,9 | 0.75 | [15,12,17] |
| | | 3,11,14,9, 15 | 1.05 | [12,17,16] |
| 4 | | [] | [] | [12,17,16] |
| | | 12 | 0.53 | [17,16] |
| | | 12,17 | 0.87 | [16,18] |
| | | 12,17,16 | 1.12 | [18,20] |
| | | 12,17,16, 18 | 1.22 | [19,20] |
| 5 | | [] | [] | [19,20] |
| | | 19 | 0.08 | [20] |
| | | 19,20 | 0.42 | [] |

# Station and its process as per the Ranked Positional Method



**Balancing Efficiency of both the process (Eb) :**

Largest Candidate Method :
Eb= Twc/(w*Ts)=0.827397

Ranked Positional Method :
Eb= Twc/(w*Ts)= 0.838889

While analysis Line balancing we select Ranked Positional Method and its station and process .

# THE END