Logo, company name

Description automatically generated

COURSE TITLE: **ADDITIVE MANUFACTURING AND PRODUCTION SYSTEMS**

GUIDED BY – Prof. ALBERTO BOSCHETTO

**EXERCISE 3**

**PART\_A FLEXIBLE MANUFACTURING SYSTEMS**

**GROUP NUMBER: 10**

|  |  |
| --- | --- |
| VARUN YASHWANT RASALKAR | **1921452** |
|  |  |
|  |  |

A picture containing LEGO, toy, furniture

Description automatically generated

**PART\_A FLEXIBLE MANUFACTURING SYSTEMS**

Table

Description automatically generated with low confidence

For simplicity we convert the machine names into number in the same sequence as they appear in the table.

Steps involved,

* Dividing the products into manufacturing cells by applying KING’S algorithm.
* Add duplicate machines if necessary.
* Apply HOLLIER method to find the sequence of machines in the manufacturing cell.
* Apply Bottleneck methods to find Production Rate of Manufacturing cell, percentage Utilization of machines and Production rate of each product in the manufacturing cell.
* Apply Extended Bottleneck method to find critical number of products, mean lead time and waiting time in each manufacturing cell based on two different cases where N<N\* and N>=N\*.

**Step 1**. Apply KING’S algorithm. P and M signifies products and machines.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| P/M | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| A | 1 |  |  |  | 1 |  |  |  |  | 1 |  |  |
| B |  |  |  | 1 |  |  | 1 |  | 1 |  |  | 1 |
| C |  | 1 |  |  |  | 1 |  |  |  |  |  |  |
| D |  |  | 1 |  |  | 1 |  |  |  |  | 1 |  |
| E |  |  |  | 1 |  |  |  | 1 | 1 |  |  |  |
| F | 1 |  |  |  | 1 | 1 |  |  |  |  |  |  |
| G |  | 1 |  |  |  |  | 1 |  |  | 1 | 1 |  |

Taking transpose of this table and apply the row and column sorting.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| M/P | A | B | C | D | E | F | G |
| 1 | 1 |  |  |  |  | 1 |  |
| 2 |  |  | 1 |  |  |  | 1 |
| 3 |  |  |  | 1 |  |  |  |
| 4 |  | 1 |  |  | 1 |  |  |
| 5 | 1 |  |  |  |  | 1 |  |
| 6 |  |  | 1 | 1 |  | 1 |  |
| 7 |  | 1 |  |  |  |  | 1 |
| 8 |  |  |  |  | 1 |  |  |
| 9 |  | 1 |  |  | 1 |  |  |
| 10 | 1 |  |  |  |  |  | 1 |
| 11 |  |  |  | 1 |  |  | 1 |
| 12 |  | 1 |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| M/P | A | B | C | D | E | F | G | Row Sorting |
| 1 | 1 |  |  |  |  | 1 |  | 66 |
| 2 |  |  | 1 |  |  |  | 1 | 17 |
| 3 |  |  |  | 1 |  |  |  | 8 |
| 4 |  | 1 |  |  | 1 |  |  | 36 |
| 5 | 1 |  |  |  |  | 1 |  | 66 |
| 6 |  |  | 1 | 1 |  | 1 |  | 26 |
| 7 |  | 1 |  |  |  |  | 1 | 33 |
| 8 |  |  |  |  | 1 |  |  | 4 |
| 9 |  | 1 |  |  | 1 |  |  | 36 |
| 10 | 1 |  |  |  |  |  | 1 | 65 |
| 11 |  |  |  | 1 |  |  | 1 | 9 |
| 12 |  | 1 |  |  |  |  |  | 32 |
|  | 2^6 | 2^5 | 2^4 | 2^3 | 2^2 | 2^1 | 2^0 |  |
|  | 64 | 32 | 16 | 8 | 4 | 2 | 1 |  |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| M/P | A | B | C | D | E | F | G | Row Sorting |
| 1 | 1 |  |  |  |  | 1 |  | 66 |
| 5 | 1 |  |  |  |  | 1 |  | 66 |
| 10 | 1 |  |  |  |  |  | 1 | 65 |
| 4 |  | 1 |  |  | 1 |  |  | 36 |
| 9 |  | 1 |  |  | 1 |  |  | 36 |
| 7 |  | 1 |  |  |  |  | 1 | 33 |
| 12 |  | 1 |  |  |  |  |  | 32 |
| 6 |  |  | 1 | 1 |  | 1 |  | 26 |
| 2 |  |  | 1 |  |  |  | 1 | 17 |
| 11 |  |  |  | 1 |  |  | 1 | 9 |
| 3 |  |  |  | 1 |  |  |  | 8 |
| 8 |  |  |  |  | 1 |  |  | 4 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| M/P |  |  | A | B | C | D | E | F | G |
| 1 | 2^11 | 2048 | 1 |  |  |  |  | 1 |  |
| 5 | 2^10 | 1024 | 1 |  |  |  |  | 1 |  |
| 10 | 2^9 | 512 | 1 |  |  |  |  |  | 1 |
| 4 | 2^8 | 256 |  | 1 |  |  | 1 |  |  |
| 9 | 2^7 | 128 |  | 1 |  |  | 1 |  |  |
| 7 | 2^6 | 64 |  | 1 |  |  |  |  | 1 |
| 12 | 2^5 | 32 |  | 1 |  |  |  |  |  |
| 6 | 2^4 | 16 |  |  | 1 | 1 |  | 1 |  |
| 2 | 2^3 | 8 |  |  | 1 |  |  |  | 1 |
| 11 | 2^2 | 4 |  |  |  | 1 |  |  | 1 |
| 3 | 2^1 | 2 |  |  |  | 1 |  |  |  |
| 8 | 2^0 | 1 |  |  |  |  | 1 |  |  |
| COLOM SORTING | |  | 3584 | 480 | 24 | 22 | 385 | 3088 | 588 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| M/P | A | F | G | B | E | C | D |
| 1 | 1 | 1 |  |  |  |  |  |
| 5 | 1 | 1 |  |  |  |  |  |
| 10 | 1 |  | 1 |  |  |  |  |
| 4 |  |  |  | 1 | 1 |  |  |
| 9 |  |  |  | 1 | 1 |  |  |
| 7 |  |  | 1 | 1 |  |  |  |
| 12 |  |  |  | 1 |  |  |  |
| 6 |  | 1 |  |  |  | 1 | 1 |
| 2 |  |  | 1 |  |  | 1 |  |
| 11 |  |  | 1 |  |  |  | 1 |
| 3 |  |  |  |  |  |  | 1 |
| 8 |  |  |  |  | 1 |  |  |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| M/P | A | F | G | B | E | C | D |
| 1 | 1 | 1 |  |  |  |  |  |
| 5 | 1 | 1 |  |  |  |  |  |
| 10\* | 1 |  |  |  |  |  |  |
| 6\* |  | 1 |  |  |  |  |  |
| 10 |  |  | 1 |  |  |  |  |
| 2\* |  |  | 1 |  |  |  |  |
| 11\* |  |  | 1 |  |  |  |  |
| 4 |  |  |  | 1 | 1 |  |  |
| 9 |  |  |  | 1 | 1 |  |  |
| 7 |  |  | 1 | 1 |  |  |  |
| 12 |  |  |  | 1 |  |  |  |
| 8 |  |  |  |  | 1 |  |  |
| 6 |  |  |  |  |  | 1 | 1 |
| 2 |  |  |  |  |  | 1 |  |
| 11 |  |  |  |  |  |  | 1 |
| 3 |  |  |  |  |  |  | 1 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| product | A | B | C | D | E | F | G |
| demand | 40 | 29 | 49 | 34 | 31 | 23 | 33 |

**Step 2** Apply HOLLIER method in each Manufacturing cell.

MANUFACTURIN CELL\_1

|  |  |  |
| --- | --- | --- |
| **M/P** | A | F |
| 1 | 1 | 1 |
| 5 | 1 | 1 |
| 10\* | 1 |  |
| 6\* |  | 1 |

|  |  |  |
| --- | --- | --- |
| P(A) | 0.634921 | PART MIX |
| P(F) | 0.365079 |

|  |  |  |  |
| --- | --- | --- | --- |
| product | A | F | SUM |
| demand | 40 | 23 | 63 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PART\_A | OPERATIONS | L/U | 1 | 5 | 10 | L/U |
| PART\_F | OPERATIONS | L/U | 1 | 5 | 6 | L/U |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |
| |  | | --- | |  | | **F** | 1 | 5 | 10 | 6 |
|  | 1 |  | 23 |  |  |
|  | 5 |  |  |  | 23 |
|  | 10 |  |  |  |  |
|  | 6 |  |  |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |
| |  | | --- | |  | | **A** | 1 | 5 | 10 | 6 |
|  | 1 |  | 40 |  |  |
|  | 5 |  |  | 40 |  |
|  | 10 |  |  |  |  |
|  | 6 |  |  |  |  |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |  |  |
| |  | | --- | |  | | **SUM** | 1 | 5 | 10 | 6 | FROM | FROM/TO |
|  | 1 |  | 63 |  |  | 63 | infinity |
|  | 5 |  |  | 40 | 23 | 63 | 1 |
|  | 10 |  |  |  |  | 0 | 0 |
|  | 6 |  |  |  |  | 0 | 0 |
|  | TO | 0 | 63 | 40 | 23 | 126 |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| CELL\_1 | Option a | 1 | 5 | 10 | 6 |
| Option b | 1 | 5 | 6 | 10 |

|  |  |
| --- | --- |
| product | demand |
| G | 33 |
| B | 29 |
| E | 31 |
| SUM | 93 |

MANUFACTURING CELL\_2

|  |  |  |  |
| --- | --- | --- | --- |
| **M/P** | G | B | E |
| 10 | 1 |  |  |
| 2\* | 1 |  |  |
| 11\* | 1 |  |  |
| 4 |  | 1 | 1 |
| 9 |  | 1 | 1 |
| 7 | 1 | 1 |  |
| 12 |  | 1 |  |
| 8 |  |  | 1 |

|  |  |  |
| --- | --- | --- |
| P(G) | 0.35484 | PART MIX |
| P(B) | 0.31183 |
| P(E) | 0.33333 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| PART\_G | OPERATIONS | L/U | 2 | 7 | 10 | 11 | L/U |
| PART\_B | OPERATIONS | L/U | 4 | 7 | 9 | 12 | L/U |
| PART\_E | OPERATIONS | L/U | 4 | 8 | 9 | L/U |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |  |  |  |  |
| |  | | --- | |  | | **G** | 10 | 2 | 11 | 4 | 9 | 7 | 12 | 8 |
|  | 10 |  |  | 33 |  |  |  |  |  |
|  | 2 |  |  |  |  |  | 33 |  |  |
|  | 11 |  |  |  |  |  |  |  |  |
|  | 4 |  |  |  |  |  |  |  |  |
|  | 9 |  |  |  |  |  |  |  |  |
|  | 7 | 33 |  |  |  |  |  |  |  |
|  | 12 |  |  |  |  |  |  |  |  |
|  | 8 |  |  |  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |  |  |  |  |
| |  | | --- | |  | | **B** | 10 | 2 | 11 | 4 | 9 | 7 | 12 | 8 |
|  | 10 |  |  |  |  |  |  |  |  |
|  | 2 |  |  |  |  |  |  |  |  |
|  | 11 |  |  |  |  |  |  |  |  |
|  | 4 |  |  |  |  |  | 29 |  |  |
|  | 9 |  |  |  |  |  |  | 29 |  |
|  | 7 |  |  |  |  | 29 |  |  |  |
|  | 12 |  |  |  |  |  |  |  |  |
|  | 8 |  |  |  |  |  |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |  |  |  |  |
| |  | | --- | |  | | **E** | 10 | 2 | 11 | 4 | 9 | 7 | 12 | 8 |
|  | 10 |  |  |  |  |  |  |  |  |
|  | 2 |  |  |  |  |  |  |  |  |
|  | 11 |  |  |  |  |  |  |  |  |
|  | 4 |  |  |  |  |  |  |  | 31 |
|  | 9 |  |  |  |  |  |  |  |  |
|  | 7 |  |  |  |  |  |  |  |  |
|  | 12 |  |  |  |  |  |  |  |  |
|  | 8 |  |  |  |  | 31 |  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |  |  |  |  |  |  |
| |  | | --- | |  | | **SUM** | 10 | 2 | 11 | 4 | 9 | 7 | 12 | 8 | FROM | FROM/TO |
|  | 10 |  |  | 33 |  |  |  |  |  | 33 | 1 |
|  | 2 |  |  |  |  |  | 33 |  |  | 33 | Infinite |
|  | 11 |  |  |  |  |  |  |  |  | 0 | 0 |
|  | 4 |  |  |  |  |  | 29 |  | 31 | 60 | infinite |
|  | 9 |  |  |  |  |  |  | 29 |  | 29 | 0.483 |
|  | 7 | 33 |  |  |  | 29 |  |  |  | 62 | 1 |
|  | 12 |  |  |  |  |  |  |  |  | 0 | 0 |
|  | 8 |  |  |  |  | 31 |  |  |  | 31 | 1 |
|  | TO | 33 | 0 | 33 | 0 | 60 | 62 | 29 | 31 | 248 |  |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| CELL\_2 | Option a | 2 | 4 | 10 | 7 | 8 | 9 | 11 | 12 |
| Option b | 4 | 2 | 7 | 8 | 10 | 9 | 12 | 11 |

MANUFACTURING CELL\_3

|  |  |  |
| --- | --- | --- |
| **M/P** | C | D |
| 6 | 1 | 1 |
| 2 | 1 |  |
| 11 |  | 1 |
| 3 |  | 1 |

|  |  |
| --- | --- |
| product | demand |
| C | 49 |
| D | 34 |
| SUM | 83 |

|  |  |  |
| --- | --- | --- |
| P(C) | 0.590361 | PART MIX |
| P(D) | 0.409639 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PART\_C | OPERATIONS | L/U | 2 | 6 | L/U |  |
| PART\_D | OPERATIONS | L/U | 3 | 6 | 11 | L/U |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |
| |  | | --- | |  | | **C** | 6 | 2 | 11 | 3 |
|  | 6 |  |  |  |  |
|  | 2 | 49 |  |  |  |
|  | 11 |  |  |  |  |
|  | 3 |  |  |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |
| |  | | --- | |  | | **D** | 6 | 2 | 11 | 3 |
|  | 6 |  |  | 34 |  |
|  | 2 |  |  |  |  |
|  | 11 |  |  |  |  |
|  | 3 | 34 |  |  |  |

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FROM | TO | |  | | --- | |  | |  |  |  |  |  |
| |  | | --- | |  | | **SUM** | 6 | 2 | 11 | 3 | FROM | FROM/TO |
|  | 6 |  |  | 34 |  | 34 | 0.409639 |
|  | 2 | 49 |  |  |  | 49 | Infinite |
|  | 11 |  |  |  |  | 0 | 0 |
|  | 3 | 34 |  |  |  | 34 | Infinite |
|  | TO | 83 | 0 | 34 | 0 | 117 |  |

**Step 3** Applying Bottleneck methods and taking some assumptions.

Certain values such as loading time and unloading time are not given so, it is approximated and assumed to be 4 mins and 2 mins respectively. The material handling time (**Tr**) is given to be 2 mins. The number of servers is 1 and so the frequency of operation becomes 1. **fijk = 1.0**

A picture containing text

Description automatically generated

Workload of a station

A picture containing text, clock, watch

Description automatically generatedChart

Description automatically generated with medium confidence

Workload of the handling system

Extended bottleneck method:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| N | < | N\* | → | case 1 |
| N | >= | N\* | → | case 2 |

Text

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Description automatically generated

Diagram, text

Description automatically generated with medium confidence Case 1

A picture containing text

Description automatically generatedText

Description automatically generated Case 2

*Tw = waiting time & MLT= mean lead time*

|  |
| --- |
| **Bottleneck Method** |
|  |

MANUFACTURIN CELL\_1

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PART | MIX P(j) | OPERATION (k) | DESCRIPTION | STATION (i) | SERVER | TIME tijk (min) |
|
| **A** | 0.634921 | 1 | L/U | 1 | 1 | 4 |
| 2 | 1 | 2 | 1 | 1260 |
| 3 | 5 | 3 | 1 | 150 |
| 4 | 10 | 4 | 1 | 15 |
| 5 | L/U | 1 | 1 | 2 |
| **F** | 0.365079 | 1 | L/U | 1 | 1 | 4 |
| 2 | 1 | 2 | 1 | 960 |
| 3 | 5 | 3 | 1 | 90 |
| 4 | 6 | 5 | 1 | 150 |
| 5 | L/U | 1 | 1 | 2 |

`

|  |  |  |
| --- | --- | --- |
| **Workload (min)** | WL\_(L/U) | 6 |
| WL\_1 | 1150.47619 |
| WL\_5 | 128.0952381 |
| WL\_10 | 9.523809524 |
| WL\_6 | 54.76190476 |
| WL\_(n+1) | 8 |

|  |
| --- |
| Bottleneck is maximum of all Workloads |
| **Bottleneck is WL\_1 which means machine SLM 280** |

|  |  |
| --- | --- |
| **Production Rate at Bottleneck Station** | |
| **Rp** | 0.000869205 | | pc/min |
| **Rp** | 0.052152318 | | pc/hr |

|  |  |  |  |
| --- | --- | --- | --- |
| production rate A | **Rp\*P(j)\_A** | **0.033112583** | **pc/hr** |
| production rate F | **Rp\*P(j)\_F** | **0.019039735** | **pc/hr** |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | in % |
| **Utilization** | U\_(L/U) | = | WL\_(L/U)\*Rp | 0.005215232 | 0.521523 |
| U\_1 | = | WL\_1\*Rp | 1 | 100 |
| U\_5 | = | WL\_5\*Rp | 0.11134106 | 11.13411 |
| U\_10 | = | WL\_10\*Rp | 0.008278146 | 0.827815 |
| U\_6 | = | WL\_6\*Rp | 0.047599338 | 4.759934 |
| U\_(n+1) | = | WL\_(n+1)\*Rp | 0.006953642 | 0.695364 |

|  |
| --- |
| **Extended Bottleneck Method** |
|

Text

Description automatically generatedText

Description automatically generated

|  |  |
| --- | --- |
| MLT\_1 | 1356.857143 min |
| N\* | 1.179387417 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **N** | **MLT\_1 (min)** | **Rp (pc/min)** | **MLT\_2 (min)** | **Tw (min)** |
| 1 | 1356.857143 | 0.000736997 |  | 0 |
| 2 |  | 0.000869205 | 2300.952381 | 944.0952 |
| 3 |  | 0.000869205 | 3451.428571 | 2094.571 |

|  |
| --- |
| **Bottleneck Method** |
|  |

MANUFACTURIN CELL\_2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PART | MIX P(j) | OPERATION | DESCRIPTION | STATION | SERVER | TIME tijk (min) |
|
| **G** | 0.354839 | 1 | L/U | 1 | 1 | 4 |
| 2 | 2 | 2 | 1 | 1260 |
| 3 | 7 | 3 | 1 | 240 |
| 4 | 10 | 4 | 1 | 30 |
| 5 | 11 | 5 | 1 | 60 |
| 6 | L/U | 1 | 1 | 2 |
| **B** | 0.311828 | 1 | L/U | 1 | 1 | 4 |
| 2 | 4 | 2 | 1 | 1620 |
| 3 | 7 | 3 | 1 | 90 |
| 4 | 9 | 4 | 1 | 90 |
| 5 | 12 | 5 | 1 | 60 |
| 6 | L/U | 1 | 1 | 2 |
| **E** | 0.333333 | 1 | L/U | 1 | 1 | 4 |
| 2 | 4 | 2 | 1 | 1380 |
| 3 | 8 | 3 | 1 | 60 |
| 4 | 9 | 4 | 1 | 60 |
| 5 | L/U | 1 | 1 | 2 |

|  |  |  |
| --- | --- | --- |
| **Workload (min)** | WL\_(L/U) | 6 |
| WL\_2 | 447.0967742 |
| WL\_4 | 965.1612903 |
| WL\_7 | 113.2258065 |
| WL\_10 | 10.64516129 |
| WL\_11 | 21.29032258 |
| WL\_9 | 48.06451613 |
| WL\_12 | 18.70967742 |
| WL\_8 | 20 |
| WL\_(n+1) | 9.333333333 |

|  |
| --- |
| Bottleneck is maximum of all Workloads |
| **Bottleneck is WL\_4 which means machine DWS XPRO S** |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Production Rate at Bottleneck Station** | | | |  |  |
|  |  |  | **Rp** | 0.001036096 | pc/min |
|  |  |  | **Rp** | 0.062165775 | pc/hr |

|  |  |  |  |
| --- | --- | --- | --- |
| production rate G | **Rp\*Pj\_G** | **0.022058824** | **pc/hr** |
| production rate B | **Rp\*Pj\_B** | **0.019385027** | **pc/hr** |
| production rate E | **Rp\*Pj\_E** | **0.020721925** | **pc/hr** |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | in % |
| **Utilization** | U\_(L/U) | = | WL\_(L/U)\*Rp | 0.006217 | 0.621657754 |
| U\_2 | = | WL\_2\*Rp | 0.463235 | 46.32352941 |
| U\_4 | = | WL\_4\*Rp | 1 | 100 |
| U\_7 | = | WL\_7\*Rp | 0.117313 | 11.73128342 |
| U\_10 | = | WL\_10\*Rp | 0.011029 | 1.102941176 |
| U\_11 | = | WL\_11\*Rp | 0.022059 | 2.205882353 |
| U\_9 | = | WL\_9\*Rp | 0.049799 | 4.979946524 |
| U\_12 | = | WL\_12\*Rp | 0.019385 | 1.938502674 |
| U\_8 | = | WL\_8\*Rp | 0.020722 | 2.072192513 |
| U\_(n+1) | = | WL\_(n+1)\*Rp | 0.00967 | 0.967023173 |

|  |
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| **Extended Bottleneck Method** |
|  |

|  |  |
| --- | --- |
| MLT\_1 | 1659.52688 |
| N\* | 1.71942959 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **N** | **MLT\_1 (min)** | **Rp (pc/min)** | **MLT\_2 (min)** | **Tw (min)** |
| 1 | 1659.52688 | 0.000602581 |  | 0 |
| 2 |  | 0.001036096 | 1930.322581 | 270.7957 |
| 3 |  | 0.001036096 | 2895.483871 | 1235.957 |

|  |
| --- |
| **Bottleneck Method** |
|  |

MANUFACTURIN CELL\_3

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| PART | MIX P(j) | OPERATION | DESCRIPTION | STATION | SERVER | TIME tijk (min) |
|
| **C** | 0.590361 | 1 | L/U | 1 | 1 | 4 |
| 2 | 2 | 2 | 1 | 1380 |
| 3 | 6 | 3 | 1 | 120 |
| 4 | L/U | 1 | 1 | 2 |
| **D** | 0.409639 | 1 | L/U | 1 | 1 | 4 |
| 2 | 3 | 4 | 1 | 900 |
| 3 | 6 | 3 | 1 | 60 |
| 4 | 11 | 5 | 1 | 30 |
| 5 | L/U | 1 | 1 | 2 |

|  |  |  |
| --- | --- | --- |
| **Workload (min)** | WL\_(L/U) | 6 |
| WL\_2 | 814.6987952 |
| WL\_6 | 95.42168675 |
| WL\_11 | 12.28915663 |
| WL\_3 | 368.6746988 |
| WL\_(n+1) | 6.819277108 |

|  |
| --- |
| Bottleneck is maximum of all Workloads |
| **Bottleneck is WL\_2 which means machine Manual Removal job shop** |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Production rate at bottleneck station** | | | |  |  |
|  |  |  | **Rp** | 0.001227448 | pc/min |
|  |  |  | **Rp** | 0.07364685 | pc/hr |

|  |  |  |  |
| --- | --- | --- | --- |
| production rate C | **Rp\*P(j)\_C** | 0.043478261 | pc/hr |
| production rate D | **Rp\*P(j)\_D** | 0.030168589 | pc/hr |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | in % |
| **Utilization** | U\_(L/U) | = | WL\_(L/U)\*Rp | 0.007365 | 0.7364685 |
| U\_2 | = | WL\_2\*Rp | 1 | 100 |
| U\_6 | = | WL\_6\*Rp | 0.117125 | 11.71251109 |
| U\_11 | = | WL\_1\*Rp | 0.015084 | 1.508429459 |
| U\_3 | = | WL\_3\*Rp | 0.452529 | 45.25288376 |
| U\_(n+1) | = | WL\_(n+1)\*Rp | 0.00837 | 0.837030464 |

|  |
| --- |
| **Extended Bottleneck Method** |
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|  |  |
| --- | --- |
| MLT\_1 | 1303.903614 |
| N\* | 1.600473233 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **N** | **MLT\_1 (min)** | **Rp (pc/min)** | **MLT\_2 (min)** | **Tw (min)** |
| 1 | 1303.903614 | 0.000766928 |  | 0 |
| 2 |  | 0.001227448 | 1629.39759 | 325.494 |
| 3 |  | 0.001227448 | 2444.096386 | 1140.193 |