Impact of Improved Facility Layout on Energy Consumption in Industry

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March, 2019

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I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this work at every step and for every new thought which You setup in my mind to improve it. Indeed I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

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Abstract

Energy is important factor for developing nation like Pakistan. As developing country, more factories and buildings are being constructed but construction get reduced by land utilized in agriculture. Therefore role of facility layout becomes important. Changes in facility layout can cause changes in energy utilized by facility. Authors' tries to develop relations on improving facility layout can effect energy consumption. A study was performed at local automotive industry production line of cylinder head to study their changes in energy consumption by improving production line. Multi criteria decision methods (MCDM) like analytical hierarchical process (AHP) and The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were used on model developed by Simul8 software with help of value added and non-value added time of production line. MCDM with the help of model making software can help improve facility layout and reduce energy consumption and space utilization for production industries and offices. Also for further verification of optimized model VMS can be used to draw max production capacity line (amount of products produce to satisfy customer needs

Keywords: Energy consumption; MCDM; Facility layout; Value and non-value added time

Table of Contents

List of Figures

List of Tables

CHAPTER 1: INTRODUCTION

Thesis is divided in to multiple parts based upon studies (case study) conducted software used and verification using multiple methods (VSM and Linear optimization). First data is conducted in automotive industry of Pakistan which produce motor cycle parts and assemble them to make motorcycles. Case study was based on cylinder head for cd – 70 production line. Model was replicated on software like simul8 and Promodel. Simul8 tells about maximum capacity and bottle necks in production line and Promodel tells about customer/ consumer needs and production capacities.

Background

Term facility layout is quite common for every industry and offices. Every new and old industry wants to make better use of their space availability. Industry wants to increase their production capacity and area available for moving and storing parts. On the other hand, offices want to use facility in such a way that all worker can communicate and their manager can see and assess them easily.

1.1.1 Facility Layout

For any workspace, facility layout have given special importance. It is a key factor for efficient and effective production. Facility layout is combination of multiple characteristics of production and customers' demands.

Different survey have been performed from last fifty years to study and understand facility layout problems and flexible manufacturing. Problem of facility layout was divided into linear equation to optimize results of survey [1]. Flexible manufacturing system is shown below in figure.

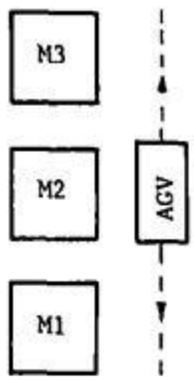


Figure 1: FMS Linear model [1]

1.1.1.1 Flexible manufacturing System FMS

Flexible manufacturing system is defined as a system in facility layout where machine is used as soon as it is available for operation. As can be shown from the image below.

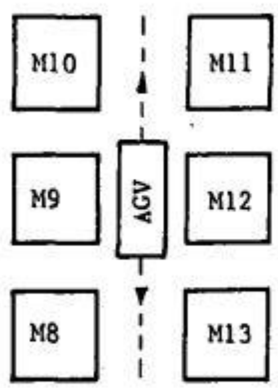


Figure 2: Flexible manufacturing system

1.1.2 Optimization

Based on need at new concept came in to being which utilize current available resources to maximum. In a factory it is important to utilize all work force and machinery available as it because stake holder cost and loss of profit. Multi department optimization problem is shown below.\

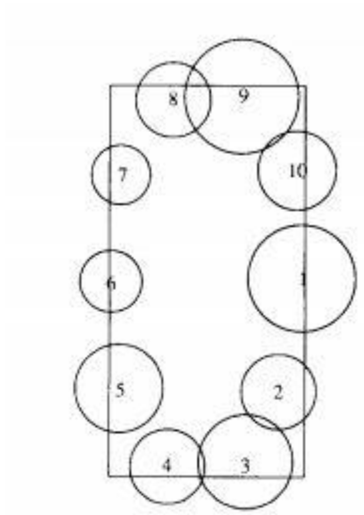


Figure 3: optimization model

The image above shows 10 different departments. Few of department are independent and few are overlapping each other. Few are bigger so it means they have more room for improvement and few interlinked so it means we can utilize each other facilities in case of break down or maintenance.[2]

CHAPTER 2: LITERATURE REVIEW

2.1. Energy consumption

First, before understanding concept of energy consumption we need to know what is energy and what it matter to different people. In early stages of Iron Age it even doesn't matter how much energy casting or forging use. As we move on to steel age process become more refine, concept of energy consumption came in to being. People want to make high quality products efficiently.

Energy have different meaning to different people as in casting and hardening process energy is directly saved by controlling factors.

Based on study research paper related to industry research are categories into four categories.

2.1.1 Ceramics (Formation of ceramics)

Ceramics are products usually developed by non-organic and non-metallic material. Usually they have high melting and boiling temperature so when working with such systems/ material it is important to keep in mind exact temperature and pressure to save energy. One of the few process is to flexible manufacturing system in which every kiln is utilized as soon as it is available.

Image below show the distribution of ceramics of European nations.[3, 4]

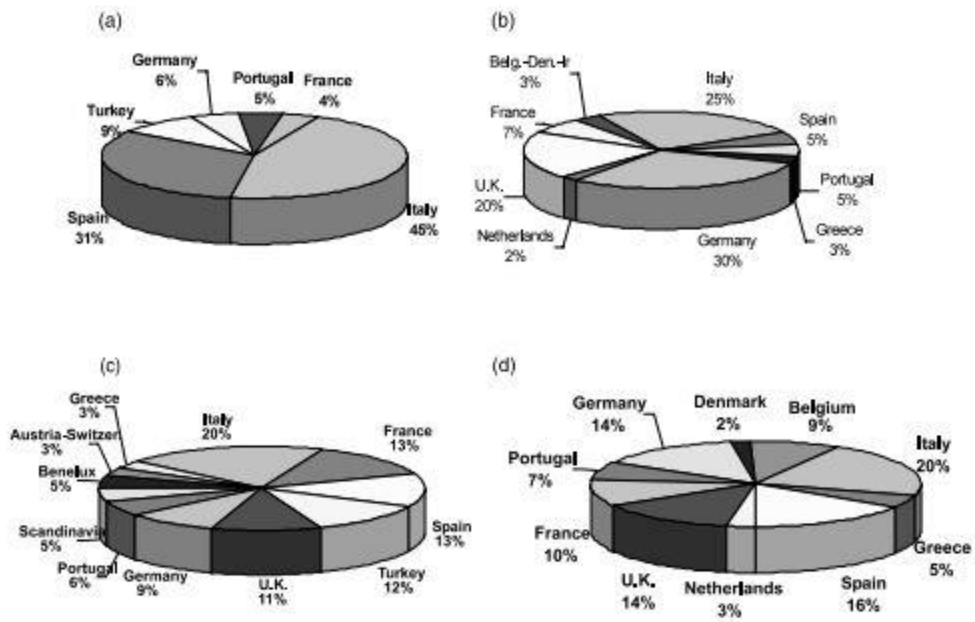


Figure 4: distribution of European ceramics industry[3]

Image above show distribution of ceramics industry by categorizing into 4 parts.

2.1.2 Casting (casting operations annealing, hardness, reheating, melting)

Casting is process of converting raw metal in to desired shape by directly melting in a furnace (blow furnace, electric furnace etc.). Green part is produced by this method is further goes through process of quenching Hardening and annealing before using in operations. The image below show growth of steel industry aka casting industry in 1990 and 2000 decade.[5]

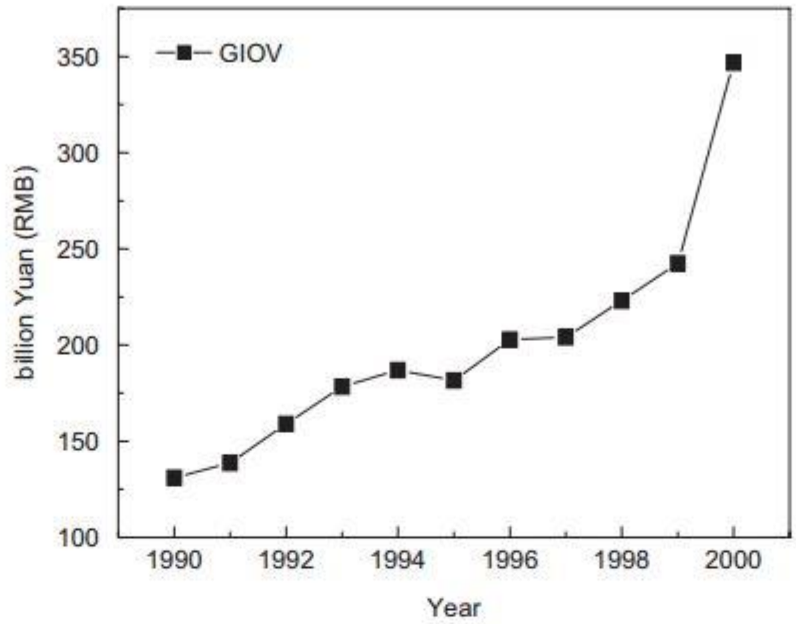


Figure 5: growth in Yuan[6, 7]

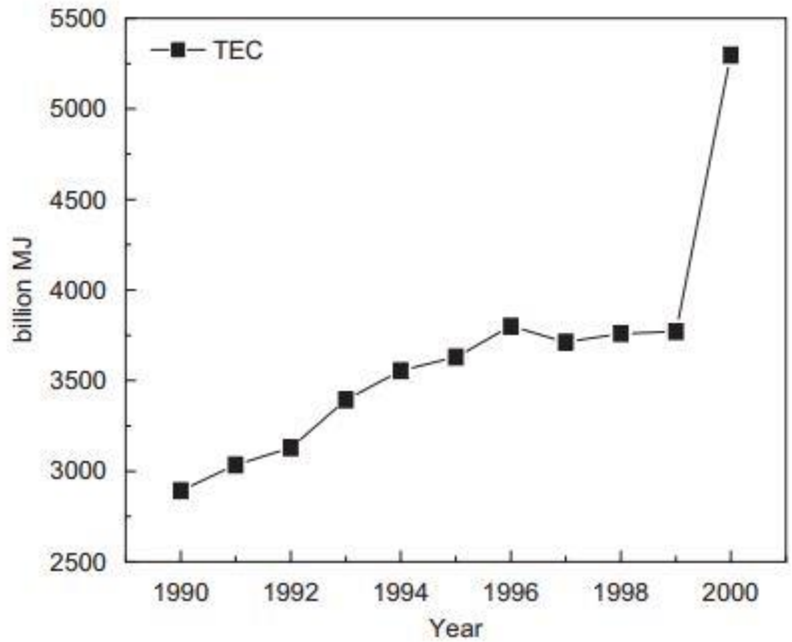


Figure 6: growth in MJ[6]

2.1.3 Facility Layout (Comparing energy for different facility layout production)

Facility layout is known as the arrangement of machines or desk in such a way that it can utilize maximum capability and control amount of energy required to move from one operation to another. For any workspace, facility layout have given special importance. It is a key factor for efficient and effective production. Facility layout is combination of multiple characteristics of production and customers' demands.[8]

Different survey have been performed from last fifty years to study and understand facility layout problems and flexible manufacturing. Problem of facility layout was divided into linear equation to optimize results of survey. The image below is tells us about facility layout and proposed flow chart of industry decision making.[9, 10]

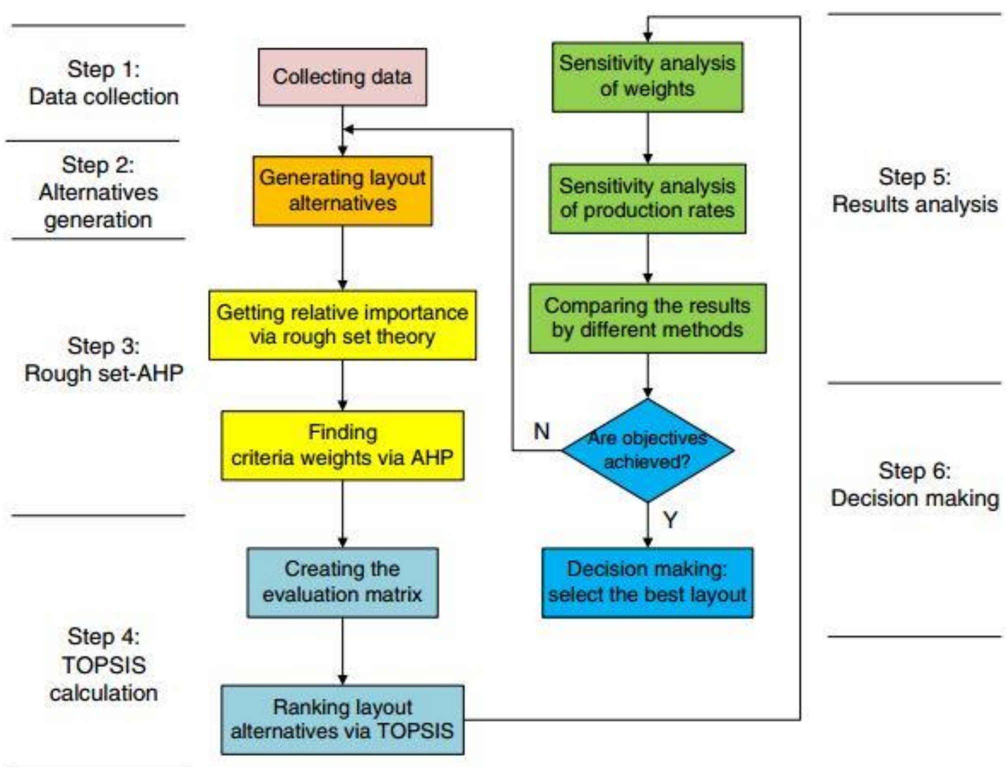


Figure 7: proposed flow chart [9]

2.1.4 Value Added Time (Reduction of handling and non -value added time)[11]

Value added time is amount of time required to perform operations. It can be calculated by stop watch when a part enter machine and operations are performed and leaves machine. [12]

Non-value added time is time taken to place a part in to machine and time to take out of machine and moving it to next machine.

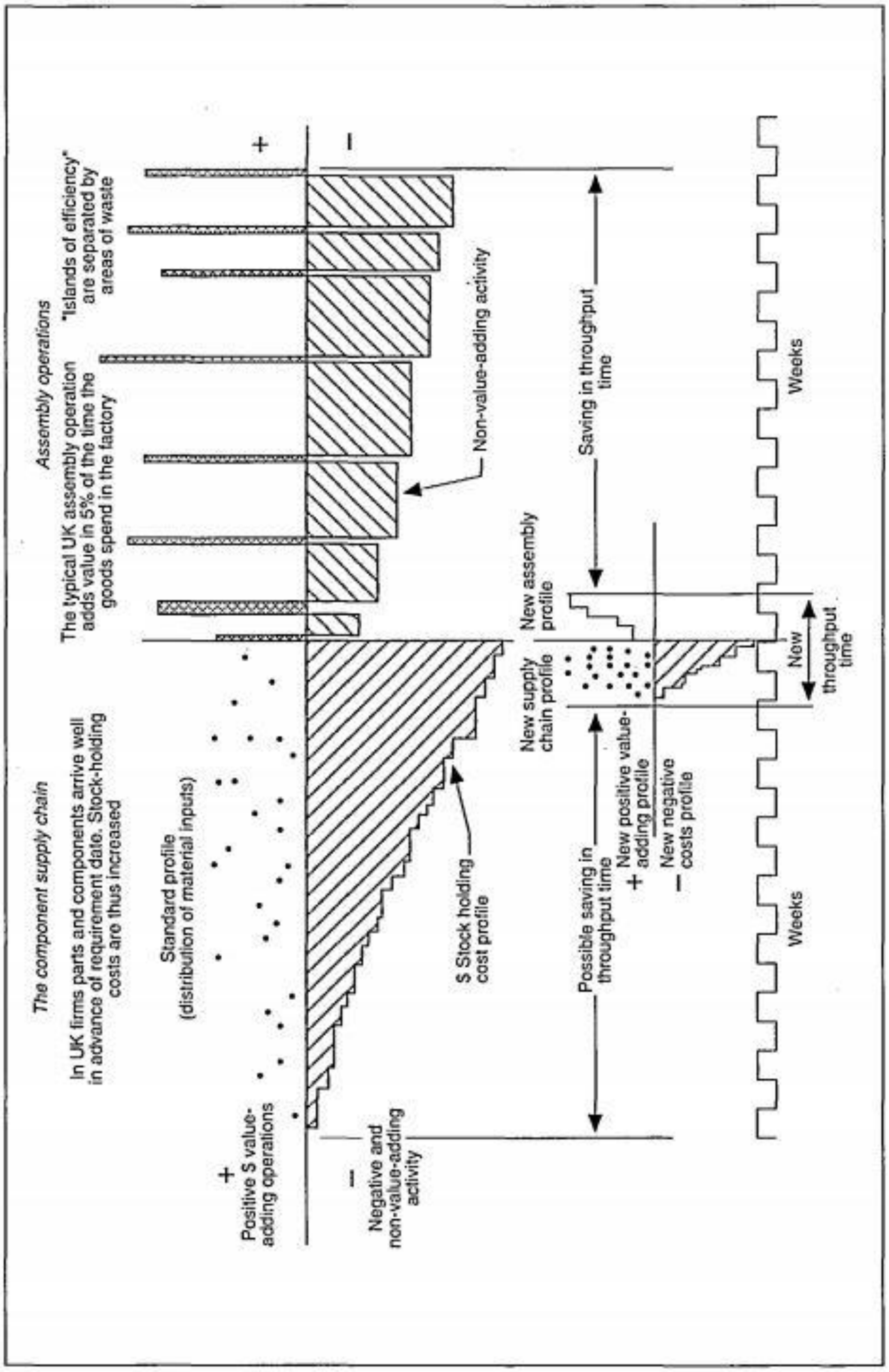


Figure 8: value added time performance measurement[13]

The image above shows distribution of work based on supply chain management and value added time and non-value added time. From image above it was clear that amount of time specifically value added time is less than 10 percentage of total time spend on part via different operations. We can drastically improve our time just by reducing non-value added time or handling time.[13-15]

CHAPTER 3: CASE STUDY

A study was performed at local motor bike developing industry to see how improving facility layout effects energy consumption. There were multiple operations being performed on casted/green part of cylinder head of 70 cc engine. Green part was loaded at CNC machine with twin head and bead. All operations were already loaded on to machine.

3.1 Automotive industry

First a green part enter production line and sequence of operation are performed on it after it leaves machine it moves on to second machine and so on and all process are completed. Green parts and finished parts are shown below.

Figure 9: green parts or casted parts

Figure 10: finished part

As can be seen from images how much work have to be done to accomplish finished state. List of all process and with their value added and non-value added time are shown in table below.

Table 1 : Production data for cylinder head

Model Name CD 70		Part Name Cylinder Head			
Machine Name	Power (Rated)	Operations	Task Time	Value added time	Handling Time
OP-1 A (Twin Spindle)	25KVA	Drilling Reaming Facing Borring Tapping	121.047	98.4	22.647
OP-1 B (Twin Spindle)	25KVA	Drilling Reaming Facing Borring Tapping	122.323	98.4	23.923
OP-1 C (SINGLE Spindle)	20KVA	Drilling Reaming Facing Borring Tapping	136.18	98.4	37.78
OP2-A (Twin Spindle)	25KVA	Drilling Reaming Facing Borring Tapping	118.297	97.6	20.697
OP2-B (Twin Spindle)	25KVA	Drilling Reaming Facing Borring Tapping	122.73	97.6	25.13
OP2-C (Single Spindle)	19KVA	Drilling Reaming Facing Borring Tapping	108.6	97.6	11
OP-3 A (Twin Spindle)	25KVA	Drilling Facing Borring Tapping	118.17	78.2	39.97
OP-3 B (Twin Spindle)	25KVA	Drilling Facing Borring Tapping	129.503	78.2	51.303
OP-4 A (Single	15KVA	Drilling Facing Borring	60.003	39.1	20.903

Spindle)					
OP-4 B (Single Spindle)	15KVA	Drilling Facing Borring	68.337	39.1	29.237
OP-5	33KVA	Drilling Facing Borring	28.37	17	11.37
OP-6 (Rb/Fb)	30.3KVA	Reaming Borring	20.31	10	10.31
OP-7 (Washing)	NIL	Washing	7.893	7.893	0
OP-8 B	2KVA 400VAC 2 TON	Cam Leak Test	37.637	32	5.637

Model Name CD 70		Part Name Cylinder Head			
Machine Name	Power (Rated)	Operations	Task Time	Value added time	Handling Time
OP-8 A	2KVA 400VAC 2 TON	Cam Leak Test	40.167	32	8.167
OP-9 (Seat Guide Press)	11 KVA	Press	37.42	35	2.42
OP-10	15KVA	Reaming Champhering	19.463	10	9.463
OP-11	15KVA	Milling	29.587	10	19.587
OP-12	2KVA	Washing (Hot Water And Air)	55.603	32	23.603
OP-13 Valve	NIL	Manual	8	5	3

Assemble					
OP-14 (Cottor Press)	2KVA	Cottor Press	3	2	1
OP-15 A (Valve Leak Tester)	2KVA	Pressurized Air	42.38	32	10.38
OP-15 B (Valve Leak Tester)	2KVA	Pressurized Air	38.65	32	6.65
OP-16 A (Stud Bolt Tightner)	2KVA	STUD AND BOLT	20.447	17	3.447
OP-16 A (Stud Bolt Tightner)	2KVA	STUD AND BOLT	20.447	17	3.447

Machine Name	**Rated power**	**Operation performed**
OP-1 A (twin spindle)	25KVA	DRILLING REAMING FACING BORRING TAPPING
OP-1 B (twin spindle)	25KVA	DRILLING REAMING FACING BORRING TAPPING
OP-1 C (SINGLE spindle)	20KVA	DRILLING REAMING FACING BORRING TAPPING
OP2-A (TWIN SPINDLE)	25KVA	DRILLING REAMING FACING BORRING TAPPING
OP2-B (TWIN SPINDLE)	25KVA	DRILLING REAMING FACING BORRING TAPPING
OP2-C (SINGLE SPINDLE)	19KVA	DRILLING REAMING FACING BORRING TAPPING
OP-3 A (TWIN SPINDLE)	25KVA	DRILLING FACING BORRING TAPPING
OP-3 B (TWIN SPINDLE)	25KVA	DRILLING FACING BORRING TAPPING
OP-4 A (SINGLE SPINDLE)	15KVA	DRILLING FACING BORRING
OP-4 B (SINGLE SPINDLE)	15KVA	DRILLING FACING BORRING
OP-5	33KVA	DRILLING FACING BORRING
OP-6 (RB/FB)	30.3KVA	REAMING BORRING

OP-7 (WASHING)	NIL	WASHING
OP-8 B	2KVA 400VAC 2 TON	CAM LEAK TEST
OP-8 A	2KVA 400VAC 2 TON	CAM LEAK TEST
OP-9 (SEAT GUIDE PRESS)	11 KVA	PRESS
OP-10	15KVA	REAMING CHAMPHERING
OP-11	15KVA	MILLING
OP-12	2KVA	WASHING(HOT WATER AND AIR)
OP-13 VALVE ASSEMBLE	NIL	MANNUAL
OP-14 (COTTOR PRESS)	2KVA	COTTOR PRESS
OP-15 A (VALVE LEAK TESTER)	2KVA	PRESSURIZED AIR
OP-15 B (VALVE LEAK TESTER)	2KVA	PRESSURIZED AIR
OP-16 A (STUD BOLT TIGHTNER)	2KVA	STUD AND BOLT
OP-16 A (STUD BOLT TIGHTNER)	2KVA	STUD AND BOLT

Table shown above explain each and every step of production of cylinder head of CD 70.

It give details of

1. Operations
2. Handling time
3. Value added time
4. Power rated
5. Total for each machine to machine

From above table it was quite clear some process takes more time and some take less time, some have high energy consumption and some have low or no energy consumption.

At automotive factory they were controlling the flow of product being produce by reducing no. of staff per zone which was help full in reducing cost controlling or reduction total no. of parts being produced. From above table simulated model showed bottlenecks which were even their in production line left by manufacturer and mangers because of limited space capacity. Few bottlenecks were found latter own by balancing machine time like in washing and re-machining at last stage.

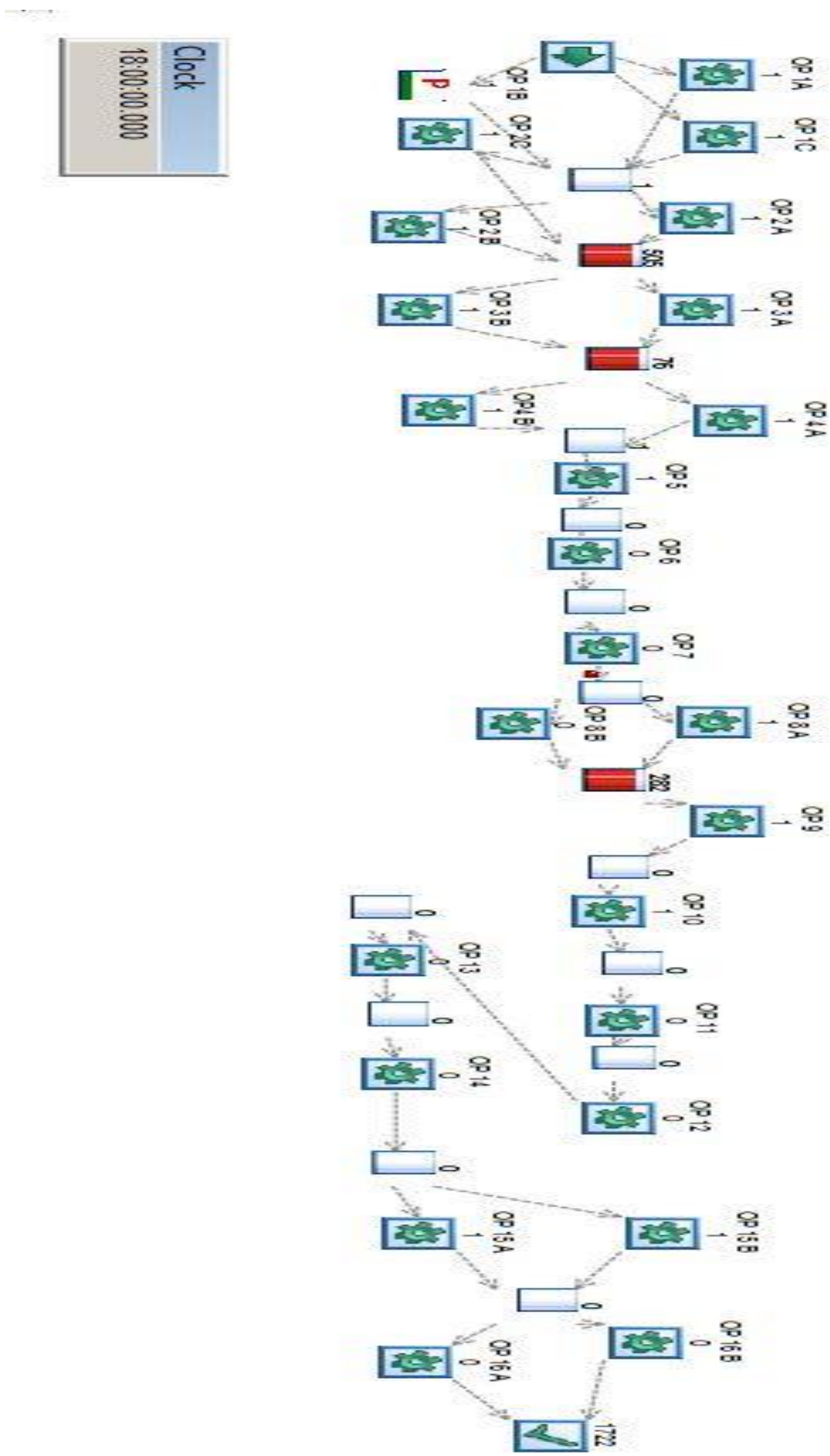


Figure 11: current production model

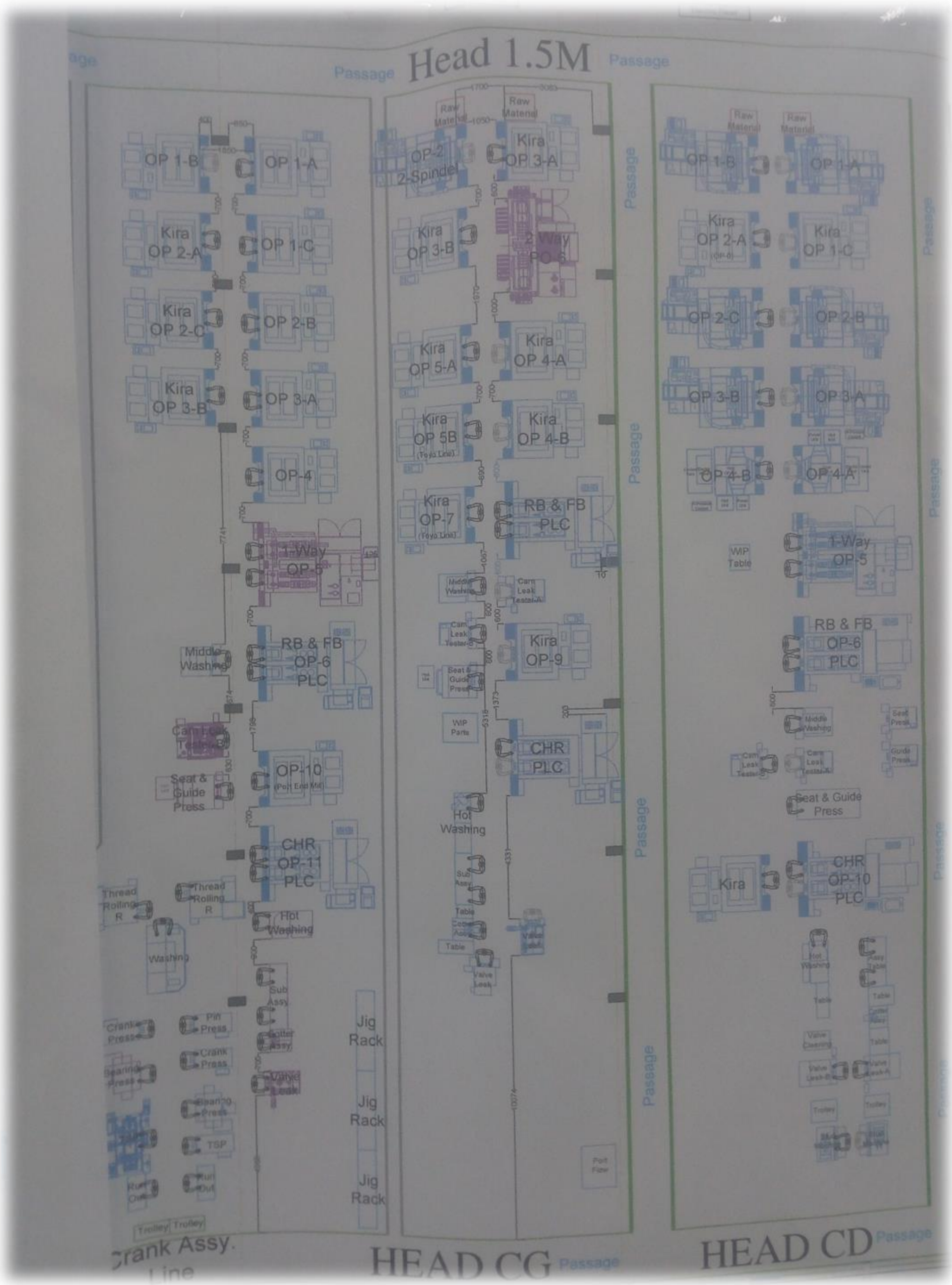


Figure 12: process flow diagram

Figure twelve show machines, workers preforming and process flow diagram.

Chapter 4: Methodology

Methodology are set of rule needed to apply to achieve required results. So to comprehensively study a production line we have to replicate it first. As world has progressed IT has developed many software which helps understand working of industry without going their just with their data provided. So for my research to completely understand automotive industry production line of cd 70 cylinder head are shown below.

1. Simul8 model
2. AHP analysis (equations)
3. Hybrid TOPSIS analysis and ideal point
4. Energy and cost equations
5. Equations for calculating labor handling time (Skill, semi-skilled and new worker)
6. Goal of AHP and TOPSIS

4.1. Simul8

Simul8 is a software used to replicate flow of production, people and work carrier etc. As per my case, CD 70 cylinder head production was replicated up to single person working on any machine. Result obtained were:

i. Machine time,
ii. Handling time
iii. Energy Consumption
iv. Total Part Produced

4.2. AHP (Analytical Hierarchy Process)

Model developed by simul8 were further analyzed by AHP. AHP ranks based on factors specified. As per my case factor specified were:

i. Energy

ii. Running Cost,
iii. Total Production,
iv. Machine Cost
v. Manpower per Zone.

It also helps in eliminating factors which are least effecting system. As study was focused on single end product so each Simul8 model carry equal weightage i.e. 0.25.

In case of multi product, weightage depends on criteria preferred by CEO/Owner It can be running cost, No. of parts, Selling demand etc.

4.3. TOPSIS

TOPSIS is a multi-criteria decision method which optimize result based on factors available. TOPSIS calculation first step utilizes results of AHP for hybridization. TOPSIS gives us positive and negative ideal points which can help us in improving over production line. Productivity of our current production line with optimized/theoretical production can also be calculated using TOPSIS.

STEP 1: Create an evaluation matrix consisting of m alternatives and n criteria.

Table 2: comaprison of Simul8 model results

	Total parts produced	**Energy in kVA actual**	**No. of person per zone**	**Run time hours**
Model 1	1722	0	2	0
Model 2	3266	0.534	0	0
Model 3	2440	0.541	0	4.67
Model 4	2612	0.442	2	0

STEP 2: The matrix evaluation matrix is then normalized to form the normalization matrix using the normalization formula given below:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n$$

Step 3: Calculate the weighted normalized decision matrix

Note: (this step is when AHP and TOPSIS are combined)

Table 3: Weighted Normalized Matrix

Weighted Normalized Matrix				
Model 1	0.083773	0	0.176777	0
Model 2	0.158886	0.151822	0	0
Model 3	0.118703	0.153812	0	0.25
Model 4	0.12707	0.125666	0.176777	0

STEP 4: Determine the worst alternative (S-) and the best alternative (S+)

Table 4: Alternative Ideal Solutions

weighted normalized matrix				
Model 1	0.083773	0	0.176777	0
Model 2	0.158886	0.151822	0	0
Model 3	0.118703	0.153812	0	0.25
Model 4	0.12707	0.125666	0.176777	0
Maximum S+	0.158886	0.153812	0.176777	0.25
Minimum S-	0	0	0	0

STEP 5: Calculate the distance between the target alternative using formula given below for worst and best possible value respectively.

$$d_{iw} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{wj})^2}, \quad i = 1, 2, \ldots, m,$$

$$d_{ib} = \sqrt{\sum_{j=1}^{n}(t_{ij} - t_{bj})^2}, \quad i = 1, 2, \ldots, m$$

D(iw) it is for calculating worst possible solution (S-)

D(ib) it is for calculating best possible solution (S+)

STEP 6: Calculate performance values (Sn) using worst and best possible value for each model using formula

Sn= S-/((S-)-(S+))

Table 5: Performance Value

S+	S-	Performance value (Sn)
0.247233	0.235546	0.487896561
0.173888	0.235546	0.575296431
0.20738	0.20345	0.495216477
0.162041	0.158886	0.495085786

4.4. Handling Time

It is defined as time required by an operator to provide part to machine until machine starts operation. It is different for skilled and semi-skilled operator, similarly it is different for automated and semi-automated machine. Skill level of operator rise by 1% for every hundred part handled with single hand. As for two handed parts number of parts needed to increase skill level decrease by half.

The time necessary to move materials from one work center to the next work center. This time includes waiting for the materials handling equipment (if need) and actual movement time.

Formula for calculating plenty in handling time is:

$$t_{pw} = 0.0125W + 0.011Wt_h$$

Basic handling time 1.13s

Table below Show average handling time for different scenario.

		secured by separate operation or part				secured on insertion by snap fit	
		no holding down required		holding down required			
		easy to align	not easy to align	easy to align	not easy to align	easy to align	not easy to align
		0	1	2	3	4	5
no access or vision difficulties	0	1.5	3.0	2.6	5.2	1.8	3.3
obstructed access or restricted vision	1	3.7	5.2	4.8	7.4	4.0	5.5
obstructed access and restricted vision	2	5.9	7.4	7.0	9.6	7.7	7.7

CHAPTER 5: RESULT AND DISCUSSION

Following production line models were developed on Simul8:

i. Current Production Model of CD 70 cylinder head
ii. Optimized Production Model of CD 70 cylinder head
iii. Target Specific Production Model of CD 70 cylinder head (From optimized Model)
iv. Energy Reduction Model

Abovementioned models provided production line factors which are daily production, bottle neck generated, energy consumed per part and running cost of machines

5.1. Current Production Model

Current model had quite room for improvements. For example

1. Multiple bottle necks
2. Unbalanced machine line
3. High energy cost per part
4. High handling time
5. Low availability of worker
6. Single stage process in multi stage

The above mentioned problems can be seen clearly in image below

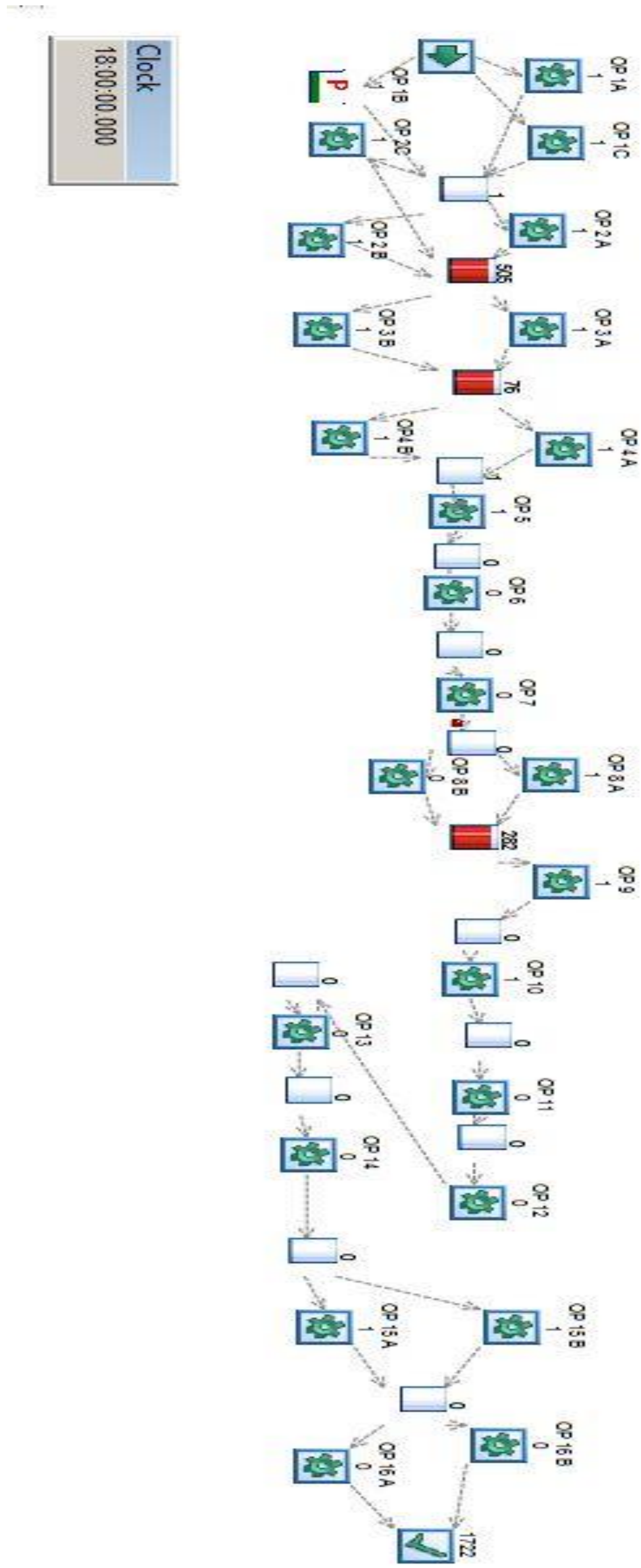
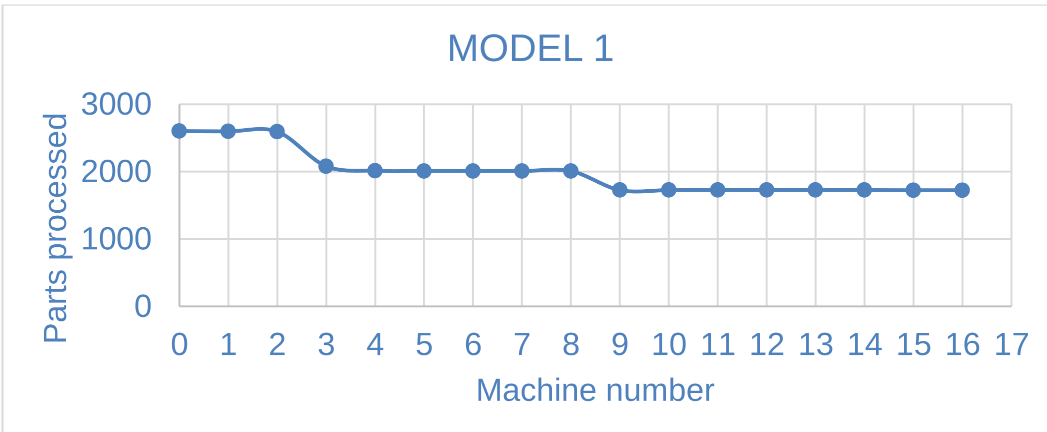


Figure 13: production line (current)

From above image it is quite clear where bottle necks are which are between OP-2 and OP -3 OP-3 and OP -4 OP-4 and OP -5 and OP-8 and OP -9. Existence of multiple bottlenecks are mainly due to unbalanced production line. From task time and handling time mentioned in case study machine time is balanced almost but handling is quite different for each step. In end results are

- Total parts produced per day= 1722
- Energy in kVA= 3.432 per part (rated)
- Energy in kVA= 1.144 per part (actual)
- No. of person per zone= 3
- Run time= 18.00 hours



5.2. Optimized Production Model

The figure below show optimized model. Optimized model have

1. Balanced processes
2. Negligible bottleneck
3. Increased no. of parts produced
4. Decrease energy against part
5. Same run time

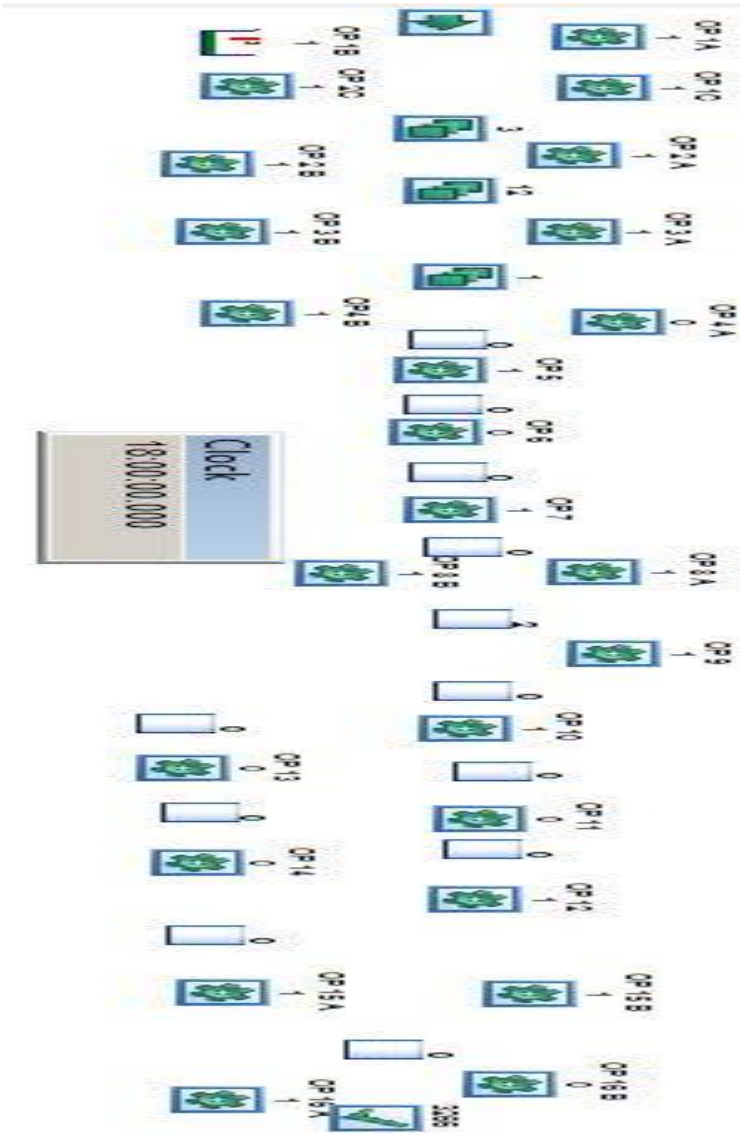
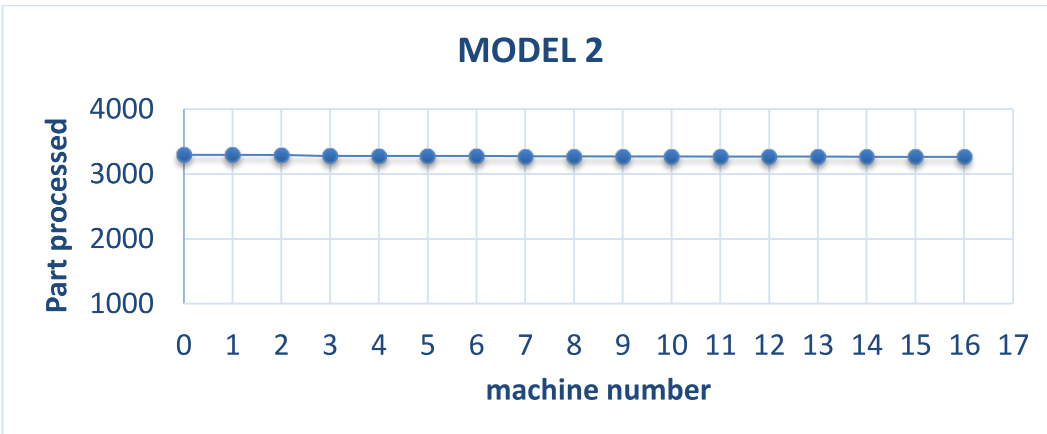


Figure 14: Optimized model

Results for experiment is

- Total parts produced= 3266
- Energy in kVA= 1.81 per part(rated)
- Energy in kVA= 0.61 per part(actual)
- No. of person per zone= 5
- Run time= 18.00 hours



5.3. Target Specific Production Model

Target specified model is shown in image below. Production stops after achieving target of 2440 parts per day.

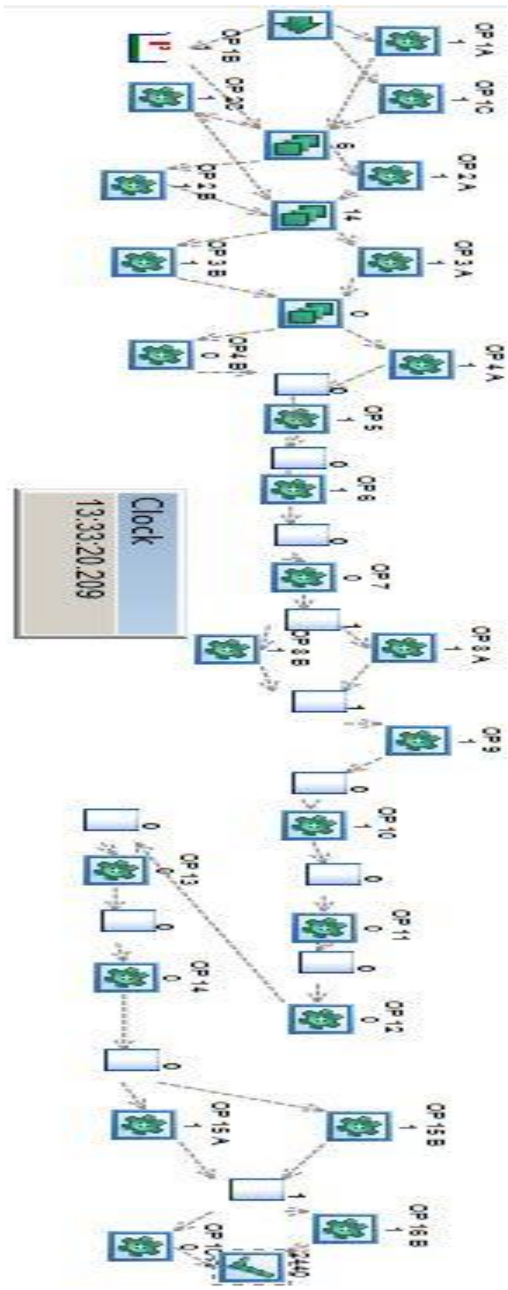
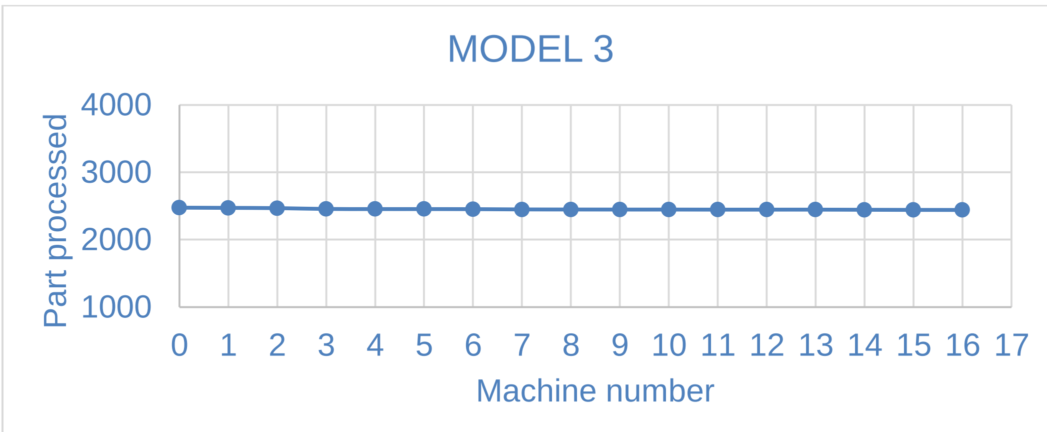


Figure 15: Target model

Results for target models are

- Total parts produced= 2440
- Energy in kVA= 1.81 per part (rated)
- Energy in kVA= 0.6033 per part (actual)
- No. of person per zone= 5
- Run time= 13:33:20 hours



5.4. Energy Reduction Model

In this model OP-1 C and OP-2C was removed total energy per part was changed because of it

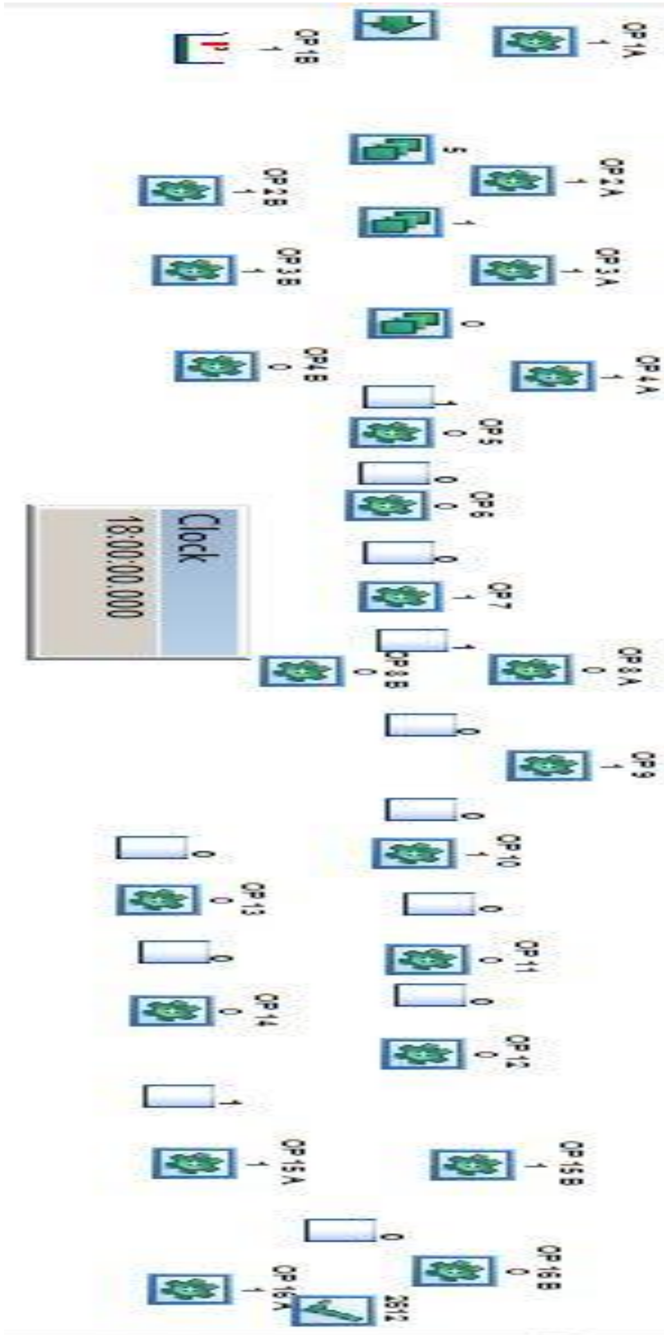
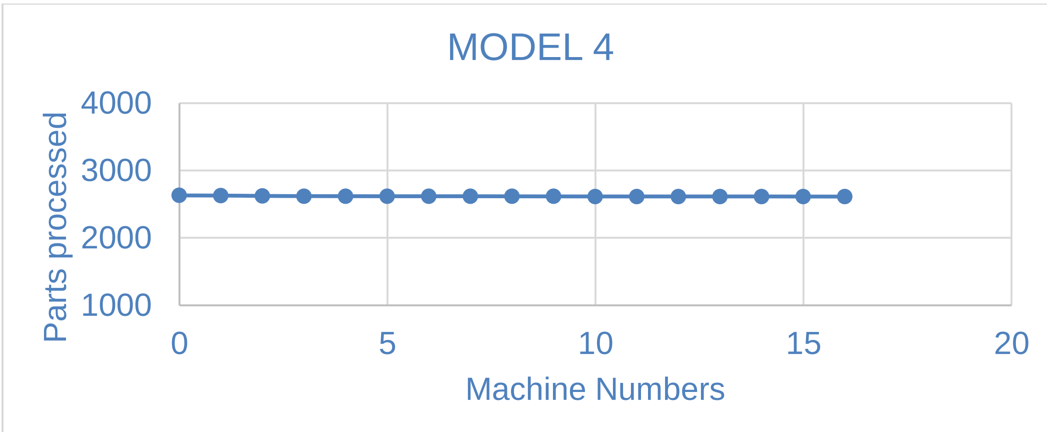


Figure 16: Energy specific model

Results for model four are

- Total parts produced= 2612
- Energy in kVA= 2.102 per part(rated)
- Energy in kVA= 0.702 per part(actual)
- No. of person per zone= 5
- Run time= 18.00 hours



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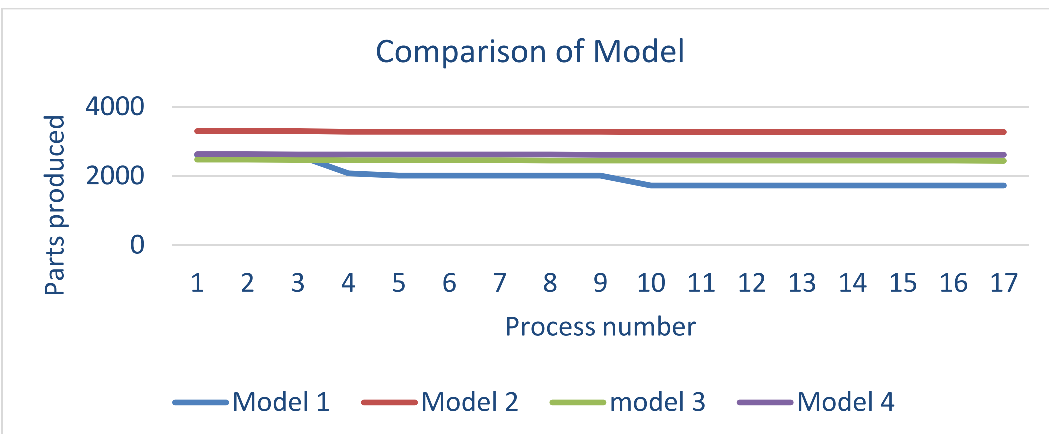
5.5. Comparison of results

Table below show results of all four models in comparison

Table 6: Comparison of models

	Model 1	Model 2	Model 3	Model 4
Total parts produced	1722	3266	2440	2612
Energy in kVA Rated	3.432	1.81	1.81	2.102
Energy in kVA actual	1.144	.61	.603	0.702
No. of person per zone	3	5	5	5
Run time hours	18	18	13.33	18



5.5.1. TAKT TIME

TAKT time is the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand

TAKT time can be first determined with the formula:

$$T = \frac{T_a}{D}$$

Where

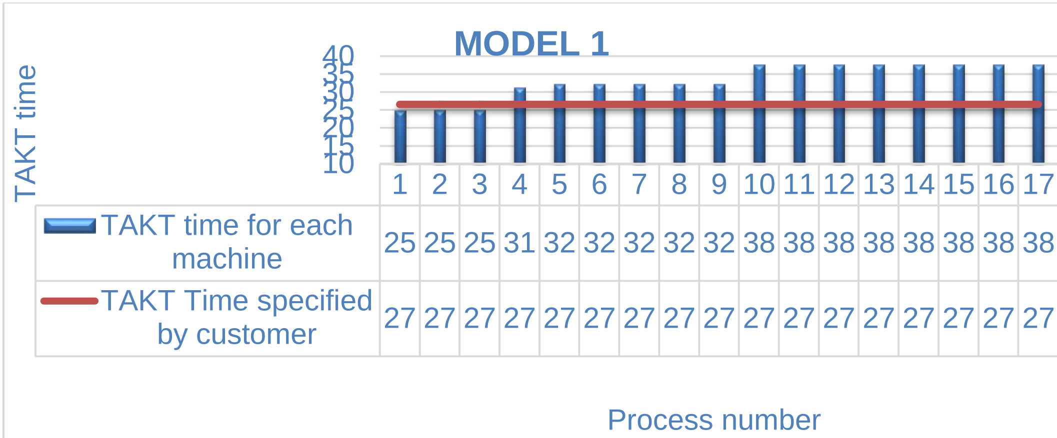
T = TAKT time, e.g. [work time between two consecutive units]

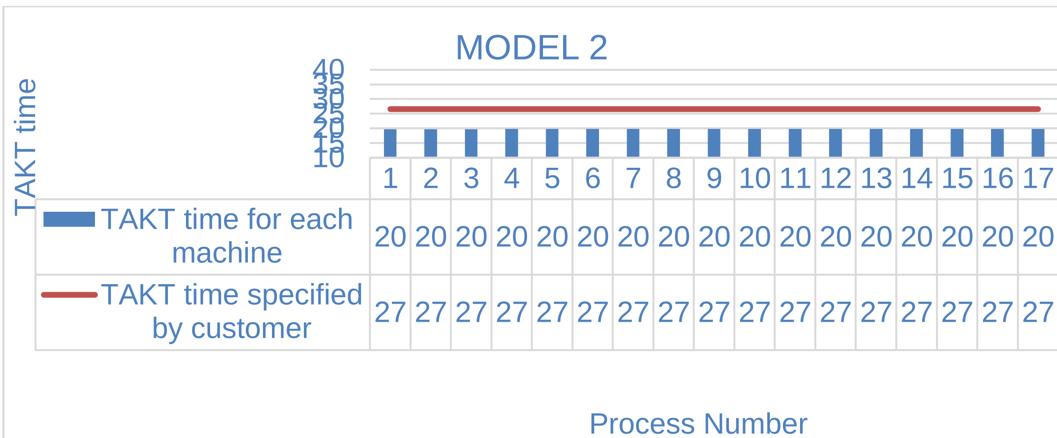
Ta = Net time available to work, e.g. [work time per period]

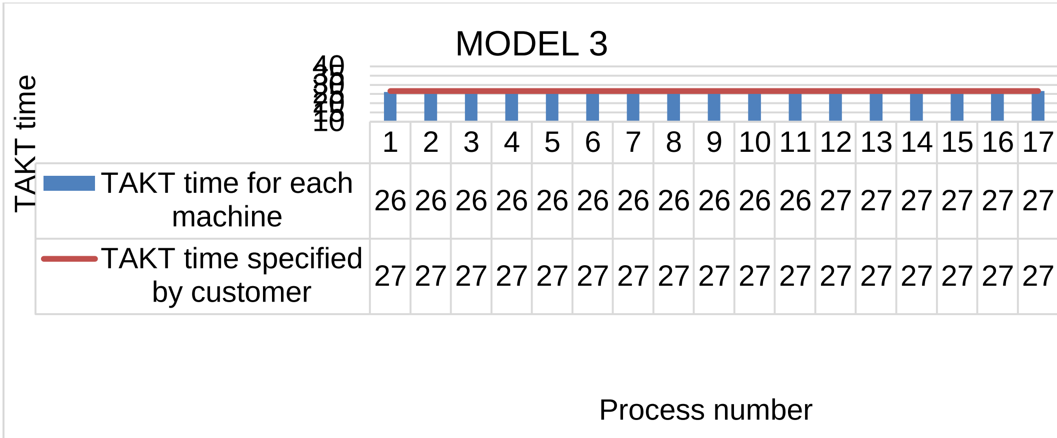
D = Demand (customer demand), e.g. [units required per period]

5.5.1.1. TAKT time for each model

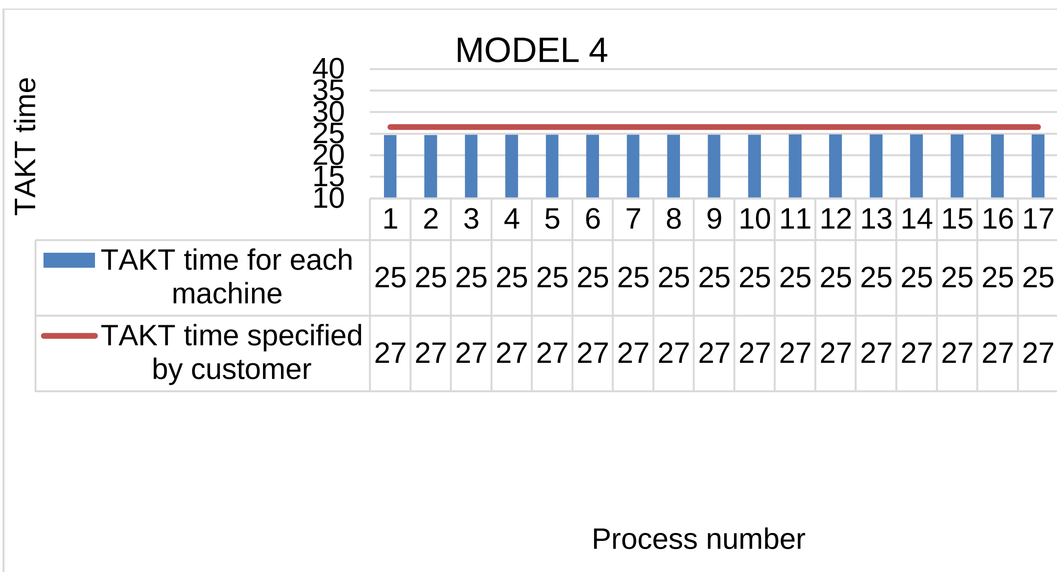
	TAKT	**Desired (below or equal to 26.56)**
Model 1	37.63 s	Above
Model 2	20.25 s	Below
Model 3	26.56 s	Equal
Model 4	24.80	Below


MODEL 1
TAKT time
40
35
30
25
20
15
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
TAKT time for each machine 25 25 25 31 32 32 32 32 32 38 38 38 38 38 38 38 38
TAKT Time specified by customer 27 27 27 27 27 27 27 27 27 27 27 27 27 27 27 27 27
Process number


MODEL 2
TAKT time
40
35
30
25
20
15
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
TAKT time for each machine 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20
TAKT time specified by customer 27 27 27 27 27 27 27 27 27 27 27 27 27 27 27 27 27
Process Number

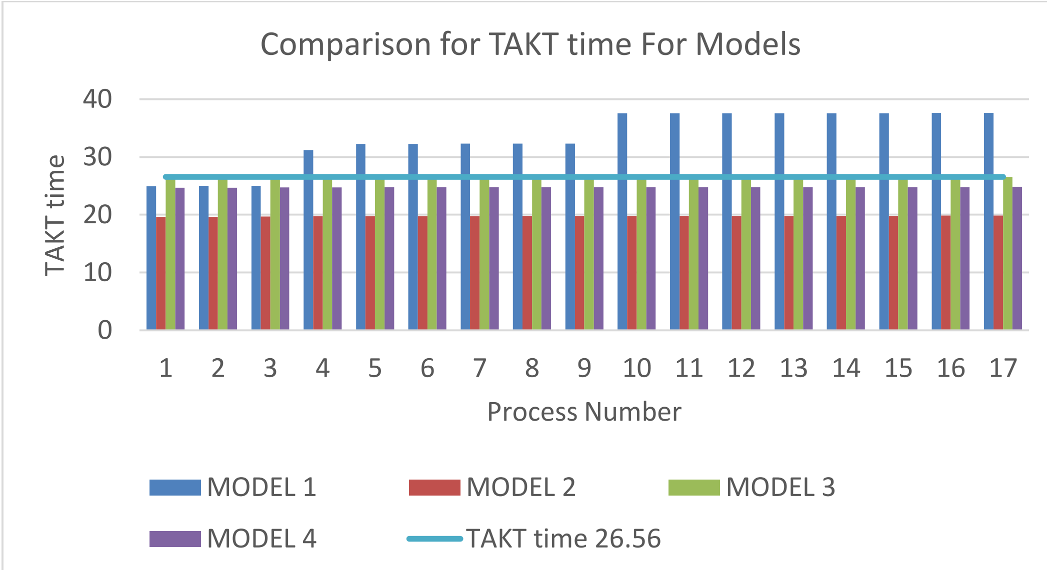


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TAKT time for each machine	26	26	26	26	26	26	26	26	26	26	26	27	27	27	27	27	27
TAKT time specified by customer	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TAKT time for each machine	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
TAKT time specified by customer	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27

5.5.1.2. Comparison of graphs



When a value of TAKT time is lower than desired consumer value to meet demand extra parts are going to be produced. More difference higher extra/spare parts going to be produced.

From results it is clear that more model 2 is going to most extra parts per day which is 826. And model 4 is going to produce

172 extra parts per day. With proper utilization of extra parts daily production and machine running cost can be reduced significantly

CHAPTER 6: CONCLUSION

From results and discussion we can conclude on basis of two things

- Cost
  - Model 2 (optimized model is better for profit)
    - No. of parts will be produced= 901,416 per annum(276)
    - Energy consumption (same as model 1 with no. of parts=475,227)= 1631562.96 kVA (rated)
    - Energy consumption (same as model 1 with no. of parts=475,227)=543854.32 KVA (actual)
- Energy saving
  - Model 3 (optimized for energy saving)
    - No. of parts will be produced=673,440 per annum
    - Energy consumption= 1218926.4 kVA (rated)
    - Energy consumption= 406308.8 kVA (Actual)

For future implementation in production line

- Increase no. of work force per zone to have balanced production line (optimum production)
- Tool and parts inspection and adjustment to be shifted among changing of shifts for more value added time.
- For making any big purchases like machinery, Software like simul8 and TAKT time should be used to see if production line is fully utilized or minor changes can increase production.

When a value of TAKT time is lower than desired consumer value to meet demand extra parts are going to be produced. More difference higher extra/spare parts going to be produced.

From results it is clear that more model 2 is going to most extra parts per day which is 826. And model 4 is going to produce

172 extra parts per day. With proper utilization of extra parts daily production and machine running cost can be reduced significantly

From results and discussion we can conclude on basis of two things; cost and energy saving.

Model 2: Improved model is more cost effective as it fully utilized capability of production line. Part produced per annum 276 days for Pakistan is 901416 parts and energy utilized in terms of KVA per annum is 543854.32 actual.

Model 3: target specific model is more energy efficient as utilize minimum energy for required target of 2440 parts per day and 673440 parts per annum. Energy utilized per annum in terms of KVA is 406286.352

From results, it is clear model 3 is better as developing nation like Pakistan we can't consider possibility of utilizing full production line as of low energy resources and high machine running cost. As model 3 is able to satisfy customer needs with utilizing minimum amount of machine running time and handling time.

Machine are replicated in every model to make a balanced production line. With the help of TAKT time, it was clear that model 2 and model 3 has low no. of working hours per annum per customer demand and every machine is quite close to optimal line which shows high productivity for production line.

Also from MCDM methods, model 3 it better in term of energy saving and cost effectiveness as reduce number of total hours for machines and work handler as both thing is major contributor of overall cost and quite close to positive ideal point..

As for model 2 is better in terms of profit as it utilize maximum amount of machine availability and produce highest no. of parts.

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