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Productivity improvement using facility layout analysis and optimization – A case study

S Saravanan
PG Student, Department of Mechanical Engineering, PSG College of Technology, Coimbatore.
19mf09@psgtech.ac.in

V Jaiganesh
Associate Professor, Department of Mechanical Engineering, PSG College of Technology, Coimbatore.
vj.mech@psgtech.ac.in

Abstract—

The facility layout problem (FLP) is an intrinsic part of facilities planning. It helps in systematic arrangement and location of all production units within a facility with an aim of improving the production operations of an industry. The work reported in this paper aims to propose a solution to a realtime facility layout problem based on an integrated approach for increasing the productivity. Initially Murther's Systematic Layout Planning (SLP) is used to generate alternate layouts. Simulation software was used to determine quantitative measures of the production process. By using Analytic Hierarchy Process (AHP) qualitative measures of material handling were determined. A weighted Non Linear Programming (W-NLP) model is formulated to model the facility layout problem considering both quantitative and qualitative aspects. Hence by selecting the optimal layout alternative, productivity can be increased. This paper provides organizations a way to devise and refine adequate criteria and alleviate the risk of selecting optimal solutions

Keywords— Facility layout problem, Systematic LayoutPlanning, simulation, Analytic Hierarchy Process, Weighted NonLinear Programming.

I. INTRODUCTION

Today, there is a speedy change in corporate environments. Due to ever-changing strategic goals the manufacturing facilities are going through periods of expansion and decline in their production. Many industries are fast swapping from one product line to another and stopping the existing production lines. To keep up with the pace, the facility layout, an important element of facilities planning, has to be malleable to changes [Chen, 2013].

A facilities layout procedure emerges from the overall strategic plan of an industry and its benefit is dependent on having an effectual production system, therefore, it is essential that the design of product , the selection of process, and the schedule design be mutually workable and benevolent [Tompkins, 2010].

Frequently, industries forget to consider strategic planning for their facilities. Rather, they focus on other factors such as maintenance, quality assurance, and marketing. In the current times, facilities planning has become more and more essential and researchers have suggested several new layout design strategies to upgrade the performance of manufacturing systems. The facility designers choose these layouts based on the degree of uncertainty in the product mix, the sound data for future requirement and redrafting the layout costs [Maryam Hamedi, 2012].

The facilities layout problem (FLP) is an intrinsic part of facilities planning. Habitually, FLP features two approaches; qualitative or quantitative [Sahin, 2010]. The qualitative approach focus to increase closeness rating scores between work centers based on a closeness function acquired from a relationship chart . The quantitative approach focus to reduce the total material handling costs between work centers based on distance function [Jia Zhenyuan, 2011].

As reported by Keragu, (1999), a facility designer endeavor either to increase the adjacency measure, reduce the total cost of material handling or optimize a combination of the two. Hence, FLP can be expressed uniquely but it is usually considered as an optimization problem (Poormostafa, 2011). An important element during the FLP design process is the design of an efficient and effective material handling system. Material handling decisions have an important effecton the effectiveness of a facility layout. In this note, the layoutdesign and the material handling system should be examinedaltogether [Tompkins, 2010].

Most of the researchers try to discourse material handling cost cutting as an essential aspect because it is approximated that the cost of material handling provides up to 20-50% of themanufacturing cost of a product. Moreover, it is commonly accepted that efficacious facilities planning can reduce thesecosts from 10 to 30% [Tompkins, 2003]. When the location ofthe workstations alters, a trimming in material handling cost can be brought about by reducing the distance moved by the material handling equipment between the facilities.

From literature, there are more approaches focused at generating facility layouts. Most of these approaches are progressive algorithmic techniques such as genetic algorithm[Resende, 2015], and ant colony optimization [Chen, 2013]. Algorithmic approaches often involve only quantitative input data and they are complicated, thus need advanced educationin mathematical models [Chien, 2004].

However, procedural approaches, such as Systematic Layout Planning(SLP) proposed by Murther, can be used in connecting both qualitative and quantitative factors together in the facility design process [Apple, 1977]. Furthermore, [Sharp, 1999] proposed that more research effort has been onthe facility layout design problem and there is an insufficientsolution in the analysis stage.

The generation of a model for the layout design is a crucial step because of its unorganized and broad nature. Yang and [Kuo,2003] proposed a merged approach of AHP and Data Envelopment Analysis (DEA) to solve a facility layout problem. A computer aided layout planning software called 'Spiral' is used to make a substantial numbers of layoutalternatives as well as to create quantitative Decision Making Unit (DMU) outputs. Then Data Envelopment Analysis isapplied to solve the multiple objective layout problem.

To solve the layout design problem some researchers haveapplied DEA and AHP [Ertay, 2006]. Shang and Sueyoshi (1995) made a blended framework to smoothen the decision- making design and planning stage for the problem of choosingthe most suitable solution of Flexible Manufacturing System(FMS). This framework contains three models namely an AHP model, a simulation module and an accounting stratagem. These modules are unified through DEA. Both AHP and simulation models are used to create the needed outputs for DEA, whereas the accounting stratagem finds the needed inputs, such as expenditures and resources for realizing the potential benefits. There is a less number of literature on the concurrent usage of both AHP and DEA methodologies for the facility layout design.

Foulds and Partovi (1998) used AHP to analyze the closeness relationship among arranging departments for a layout problem. Their aim was to create a block plan based on the outcome of closeness relationship. Cambron and Evans (1991) proposed a varied computer-aided layout design method to create a set of design alternatives and then these alternatives were analysed by AHP according to a set of design criteria. Yang et al. (2000) used AHP to verify multiple-objective layout design alternatives created from Muthers' SLP algorithm.

This study uses Systematic Layout Planning (SLP) as a procedural tool for creating alternate layouts. Then quantitative data like utilization percentage, average waiting time and material handling effort can be extracted fromcomputer aided simulation software called Flexsim. The qualitative data is extracted from AHP procedure. To integrate qualitative and quantitative data, a weighted NLP approach is proposed. Thus based on the weight comparison from NLP approach the one with highest weight is suggested. This paper aims to demonstrate that integration of SLP, AHP, simulation and W-NLP procedure can be used to improve an existing layout for better productivity.

II. Systematic Layout Planning

Systematic layout planning (SLP) is a procedure used to set the layout of workstation in a manufacturing plant. Here the workstations that has higher logical relationship are placed close to each other. SLP procedure is applied to optimize the existing layout. The application of this procedure is expected to make the fastest material flow with the lowest amount of material handling. Systematic layout planning consists of four stages as follows:

Step1 – PQRST analysis (Product, Quantity, Routing, Supporting and Time).

Step 2 – Activity relationship analysis.

Step 3 – Flow of materials analysis.

Step 4 – Relationship diagram.

Step 5 – Space requirements/availability analysis.

Step 6 – Layout alternatives practical constraints.

Step 7 – Generating combination of different layouts.

Thus it is a procedural approach permitting the users to, identify, picturize and rate the various activities, relationships, and alternatives employed in a facility layout problem. It is done based on input data, the flow of materials, activity of relationships and relationship diagrams. The framework representation of systematic layout planning is shown in Fig.1.

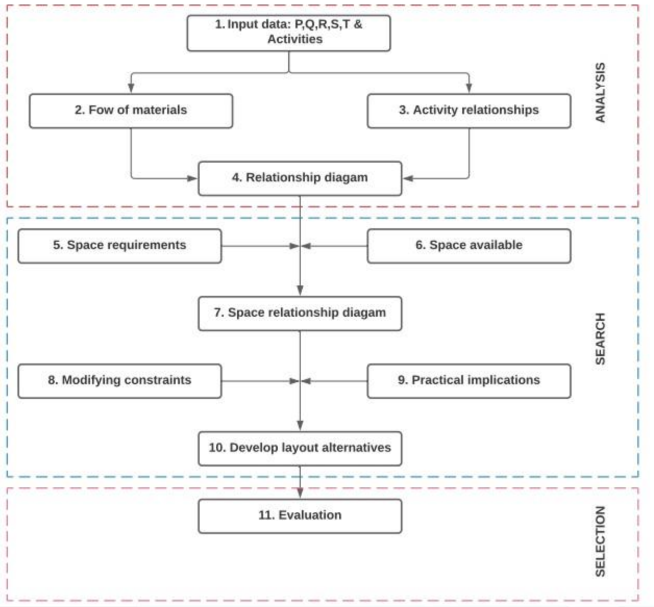

Fig.1. Framework of SLP

III. Simulation

Simulation has been frequently used to investigate the behavior of real world manufacturing systems to acquire better understanding of fundamental problems. Simulation modeling is extensively used in manufacturing systems [Azadeh et al., 2008]. Main reason for this is the competitive environment prevailing in many organizations have resulted in a greater instance on automation to increase productivity and quality. As automated systems complicated, they typically can only be studied using simulation.

Another important factor is the equipment cost and facilities that can be very large, thus comparatively small disbursement on simulation can decrease the risk of failure after implementation. Thus the process organizations with their advanced automation and capital investment would seem an ideal chance for the exertion of simulation technique [Saeheaw et al., 2009].

Despite their extensive occurrence, available examples of the application of simulation modeling are very few, and those existing focus on the analysis of production planning and control issues. White and Tsai (1999) applied simulation to study the logistics of solvent recovery in a chemical processing industry. Therefore, a simulation model is an easier way to build up models to mimic real life scenarios, to find out bottlenecks, to increase system performance in terms of productivity, waiting queues, utilization, cycle times, takt time and lead times.

Some of the benefits of computer simulation are that they provide feasible solutions within a short time span, cuts inventory cost and throughput time, optimizes system including buffer sizes, maximizes the use of manufacturing resources, improves line performance and schedule, increases productivity of existing facilities, reduces disbursement in planning new facilities and lowers investment risks by early proof of concept [Law and Kelton, 2000].

IV. Analytical Hierarchy Process

In general, there exist a total of 18 MADM methods, e.g., AHP, GRA, TOPSIS, ELECTRE and outranking methods [41]. Among these MADM techniques AHP is one of the most

popular technique in which problem is converted to a hierarchic structure and then based on the decision-maker's

judgments the alternatives are ranked [Saaty TL, 1980].

The hierarchy of a usual AHP model is as follows: the overall decision objective (the best alternative) is at the top level, criteria (if required, sub-criteria) comes in the middle level(s), and alternatives are placed at the bottom level. The main reason of applying AHP especially for the qualitative performance data is the reality that qualitative criteria are not stateable as quantitative data. Also, the decision-maker confidence in the evaluation provided by the AHP methodology is more when it is compared with other multi-attribute decision making approaches [Zakarian A, 1993].

The other advantages of the AHP include: providing a systematic procedure for subjective decision, applying sensitivity analysis, representing information about the evaluation criteria weights and providing better understanding and involvement among the members of the decision-making group and hence engaging to the selected alternative [Shang JS,1993].

In this study, the aim of the AHP application is to attain the weights showing the relative importance of the FLPs under each criterion. Decision maker will be finding a comparison matrix by comparing pairs of the FLPs against the criteria at the bottom level. Analytic aspect of rating method permit decision-makers to analyze a huge number of alternatives easily. Since in this work, the performance measures of the qua chy stru

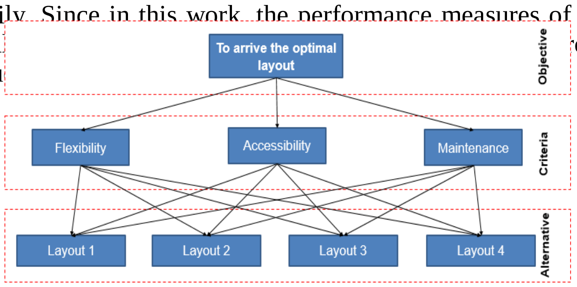

Fig.2. A hierarchical structure of AHP for FLD

Following are the steps involved in AHP procedure developed by Saaty (1990):

Step 1 – Define the problem and determine its objective.

Step 2 – Construct the hierarchy from the top (Goal) through the intermediate levels (criteria) to the lowest level (alternatives).

Step 3 – Generate a matrix of pairwise comparison for each criteria and alternatives mentioned priory. The pairwise comparison matrix showing the importance of intensity is shown in Table 1.

Step 4 – The next step is to see whether the obtained criteria weights are consistent. This is done by determining the consistency index using the eigenvalue (λ_{max}) as in equation (1):

$$\text{Consistency Index } (CI) = \frac{\lambda_{max} - n}{n-1} \qquad (1)$$

where n is the matrix size, after that consistency is checked by the consistency ratio (CR) as:

$$\text{Consistency Ratio (CR)} = \frac{\text{Consistency index}}{\text{Random index}} \qquad (2)$$

where Random Index is average random consistency (Table 2), CR is acceptable only if it is less than 0.1, if it is more than, the judgement should be revised and improved.

Table 1. Pairwise comparison scale.

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	For compromise between the above values

Table 2. Random index table

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	0.12	1.24	1.32	1.41	1.45	1.49

V. A Weighted NLP Model for Ranking FLPs

In this section, a weighted NLP model for ranking the FLPs against the performance measures of each qualitative and quantitative criteria is projected.

Let P be the number of alternative layouts generated by SLP procedure. Also, let X_{pc} denotes the performance measure of p^{th} FLP (p = 1,.., P) under c^{th} criterion (c = 1..., M). Then, the performance measures of criteria are transformed within a 0 – 1 scale using the below formula.

$$\text{Transformation formula} = \frac{X_{pc} - \min(X_{pc})}{\max(X_{pc}) - \min(X_{pc})} \qquad (3)$$

To facilitate the ranking, let W_c (decision variable) be the relative importance weight attached to the c^{th} criterion (c = 1,..., M). The proposed model is as follows:

$$\text{Maximize } Z = \sum_{c=1}^{M} W_c X_{pc} \qquad (4)$$

c=1 c

$$\text{Subject to } \sum^{M} W^2 = 1 \qquad (5)$$

$$W_1, W_2 \ldots \ldots W_6 \geq 0 \qquad (6)$$

For example, the criteria may be ranked in a decreasing order such that $W_1 \geq W_2 \geq . . . \geq W_M$. Note that since the objective function of the applied model is maximization, hence for criteria such as material handling effort, average waiting time we can consider negative or by using the reciprocal of the actual value.

To obtain the score of each FLP the following steps are carried out:

1. Transform the performance measure X_{pc} using transformation formula (3) on a scale of 0 - 1

2. Solve the preferred model for each FLP using nonlinear programming optimizer.

3. Sort the scores Z_{max} values in the decreasing order.

VI. PROPOSED METHODOLOGY

The study proposed here initailly uses systematic layout planning for generating alternative layouts. In addition to the alternative layouts, material handlimg effort (a quantitative measure) is also extracted. Then the current state of the production process is simulated with the help of simulation software called FlexSim 2019.

The quantitative data obtained from simulation are throughput, aversge waiting time, avearge work in process inventory. Next AHP methodology is applied to get the weights of qualitative data. Flexibility, accessability and maintenance are considered as qualitative data.

An weighted NLP approach is then used thereby considering both qualitative data and quantitative data simultaneously. Here the objecteive function, constraints and non negative restrictions are framed for each alternative. Each equation is solved using Microsoft Excel Solver.

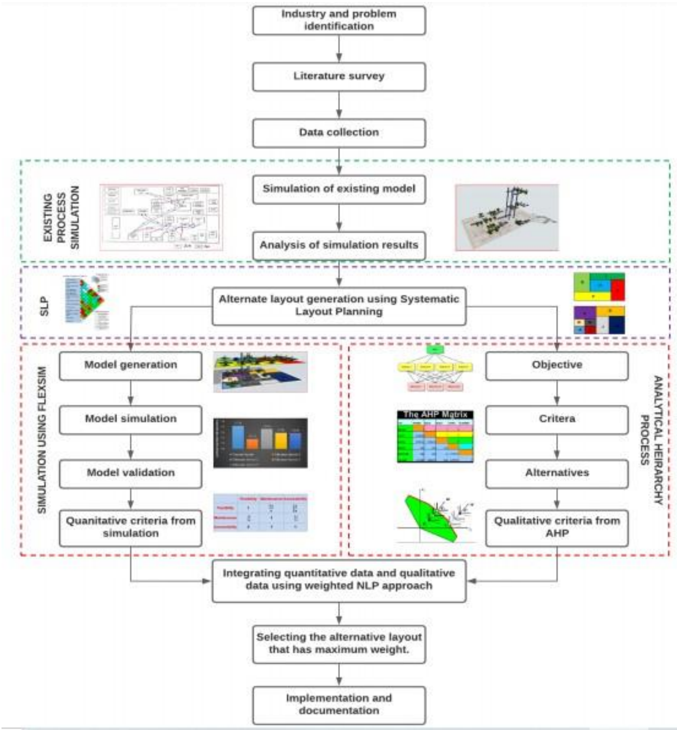

Fig.3. The proposed methodology

VII. CASE STUDY

An automobile parts manufacturing industry, located in Kakkalur industrial estate, Chennai, Tamil Nadu providing parts to various Tire 1 companies in Tamil Nadu. They have facilities like gravity die casting, Aluminum and zinc cathodic protection anode.

The industry has been facing the problem of poor flexibility in the system, floor area utilization was not effective, lower production. Because of this, management of the industry looking to redesign the existing facility layout for increased production, for better floor area utilization and for improved flexibility in the system.

There were near about 12 departments with 18 machines of various types and the floor space available is 453.58 feet. The current layout is shown in Fig.4.

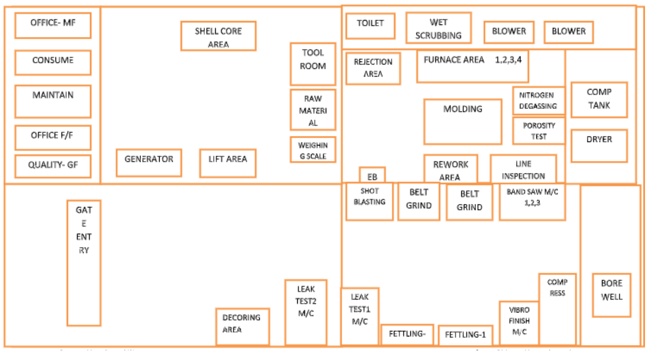

Fig.4. Existing layout

For easy notation the departments are coded as shown below.

A – Shell core making.

B – Raw material storage area.

C – Gravity Die Casting.

D – Decoring.

E – Cutting.

F – Grinding.

G – Fettling.

H – Leak testing,

I – cutter.

J – Shot blasting.

K – Quality and control.

L – Final storage.

1. *Data collection*

Gathering and analyzing the data is the initial step in the proposed methodology. The basic input variables were product, process, routing, time, spacing. Product is the material that to be processed on the production line and it is the most important input for any facility layout design problem.

The industry currently manufactures tank, pipe for radiators and intercoolers. Time study is conducted for the selected products that needs enhanced productivity. The current layout is shown in Fig.4.

The first process is shell core making where the core for casting process is made. Next the aluminum gravity die casting process is used to produce the casting product tank and pipe. Then secondary operation is carried on. It consists of sequence of process namely cutting, grinding, fettling, cutter and shot blasting.

The secondary operation is followed by final inspection and dispatch. To visualize the flow of material, spaghetti diagram is used which is shown in Fig.5.

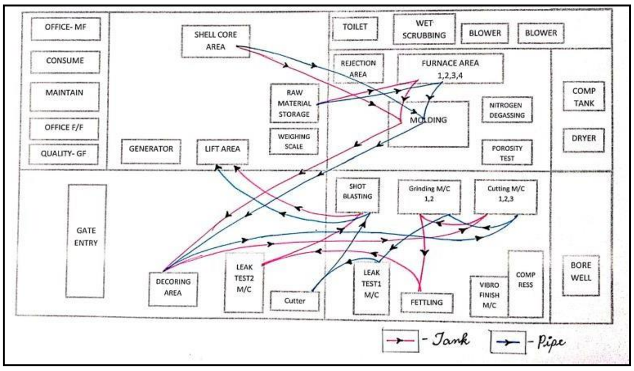

Fig.5. Spaghetti diagram.

2. *Simulation of existing process*

The focus of modeling and simulation process is on formulating and solving a real system such as facility layout problem. Furthermore, the system being studied is simulated, verified and validated. The simulation model has following assumptions:

- The production process line is never starved.
- The set up times are not taken considered, since in a real system the setup process is usually made at the end of the working time.
- Eight hours working time does not include breaks.
- No maintenance process is performed during the working period.
- All process times for operations include insignificant breakdowns.
- Transportation of raw materials is performed by workers who are assigned for operations.

Here the current model is being modeled in the computer assisted software called FlexSim 19. The simulation is carried out for one shift of production.

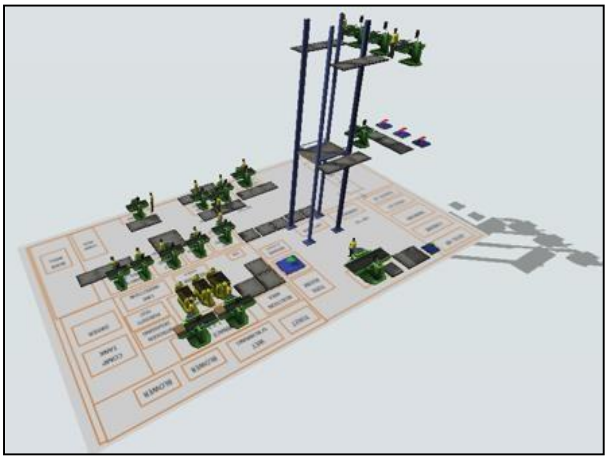

Fig.6. Existing layout modeled using FlexSim'19

The Fig.14 shows the output generated from the simulation of the current layout.

2.1 Throughput

Manufacturing throughput time is the actual amount of time required for a product to pass through a manufacturing process, finally converting from raw materials into finished goods.

Here from the simulation results it is clear that during the as is scenario the throughput of pipe is found to be 170 units and tank (RH & LH) is found to be 78 units and 82 units respectively.

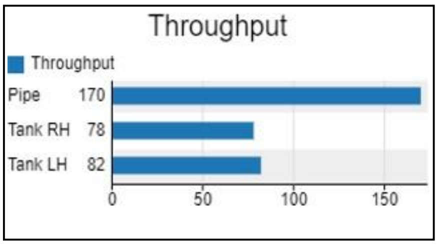

Fig.7. Throughput of Existing layout

Average waiting time

The time a job is made to wait before processing is called queue or waiting time. As queue time increases at various work stations in an industry.

Waiting time has a significant impact on manufacturing process. Longer the process is in waiting, higher are the expenses incurred. Due to extended waiting time, workmen becomes idle and utilization of production processes decreases, which eventually results in a decrease in the overall performance of the company. The results from simulation represents an average waiting time of 2.19 minutes.

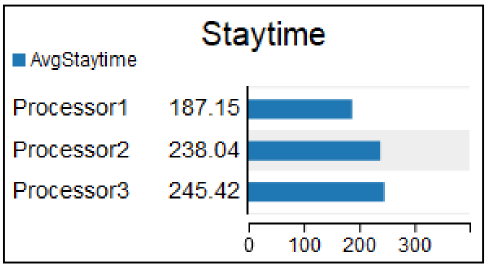

Fig.8. Average waiting time of existing layout

2.3 Utilization percentage

Utilization is the available machine time that's used for manufacturing processes. The machine utilization rate is an important metric for manufacturing organizations to monitor. For the existing state the utilization percentage is 74%.

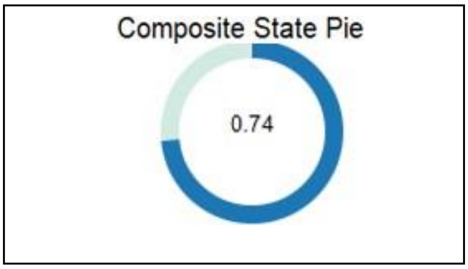

Fig.9. Utilization of existing layout

By simulating the current layout using FlexSim we can get valuable insights (existing throughput, waiting time and utilization %) on production process. For the existing process the performance measures obtained are shown in Table 4.

Table 4. Performanve measures from simulation of existing process

PERFORMANCE MEASURE		
Throughput	Pipe	170 units
	Tank RH	78 units
	Tank LH	82 units
Average waiting time		2.19 minutes
Utilization %		74%

3. Generation of alternate layouts

In production shop floor one of the well-known methods for determining the facility arrangement is systematic layout planning (SLP), as proposed by Muther (1973). SLP is a step by step approach used for layout generation.

The procedure of applying SLP is relatively straightforward. However, in recent times it has been addressed as a common approach in providing layout design guidelines. The steps involved in SLP are projected below.

Step 1 – PQRST analysis

It includes product (P), quantity (Q), routing(R), supporting (S), and time (T), which should be reviewed in order to ensure the validity of the input data at the design stage.

The study is made for three products namely Tank LH, Tank RH, Pipe that undergo similar processes. Based on the history of data collected, for past three months the average demand is found to be 140 units, 140 units and 180 units respectively. Here they have been following process layout that is similar machines are grouped together and called as one work station. The schedule requirement is shown in the form of pallet loads per shift in table

Step 2 – Flow of material analysis

This step clearly picturizes the flow of material among different functional areas. The flow is This aggregates all material flows from the whole production line into a from-to chart that represents the flow intensity among different tool sets or departments. The from to chart is shown in the Table 5 that is followed by distance matrix in the Table 6.

Here the material handling effort is also calculated using the below formula

$$\text{Material handling effort} = \text{load} \times \text{distance travelled} \quad (7)$$

This is found by combining the from to chart and distance matrix. It is considered as one of the quantitative criteria for further evaluation. The material handling effort for current layout is shown in Table 7.

Table 3. Processing sequence

PRODUCT	PROCESSING SEQUENCE
PIPE (LH)	Shell core (A) → Gravity die casting (C) → Decoring (D) → Cutting (D) → Grinding (F) ↓ Quality check (k) ← Shot blasting (J) ← Cutter (I) ← Leak testing (H) ←
TANK(LH)	Raw material (B) → Gravity die casting (C) → Decoring (D) → Cutting (D) → Grinding (F) ↓ Quality check (k) ← Shot blasting (J) ← Leak testing (H) ← Fettling (G) ←
TANK (RH)	Raw material (B) → Gravity die casting (C) → Decoring (D) → Cutting (D) → Grinding (F) ↓ Quality check (k) ← Shot blasting (J) ← Leak testing (H) ← Fettling (G) ←

Table 4. Flow rate of products per shift

FLOW RATE OF PRODUCTS	
Products	Flow rate
Pipe (LH)	15 pallet loads per shift
Tank (LH)	11 pallet loads per shift
Tank (RH)	11 pallet loads per shift

Table 5. From – To chart

	A	B	C	D	E	F	G	H	I	J	K	L
A			15									
B			22									
C				37								
D					37							
E						37						
F							22	15				
G								22				
H									15	22		
I										15		
J											37	
K												37
L												

Table 6. Distance chart

	A	B	C	D	E	F	G	H	I	J	K	L
A		40	60	55	50	85	87	45	95	54	60	63
B	40		50	20	35	30	34	30	45	25	45	48
C	60	50		58	52	72	74	52	90	56	110	113
D	55	20	58		68	40	42	25	27	25	55	58
E	50	35	52	68		4	8	60	55	54	110	113
F	85	30	72	40	4		7	32	15	25	98	101
G	87	34	74	42	8	7		35	13	15	105	108
H	45	30	52	25	60	32	35		12	10	40	43
I	95	45	90	27	55	15	13	12		3	80	83
J	54	25	56	25	54	25	15	10	3		45	48
K	60	45	110	55	110	98	105	40	580	45		3
L	63	48	113	58	113	101	108	43	583	48	3	

The material handling effort is then calculated for the alternative layouts generated from SLP. By comparing the value, one with lower material handling effort can be selected.

Table 7. Material handling effort

	A	B	C	D	E	F	G	H	I	J	K	L	Total
A			900										900
B			1100										1100
C				2146									2146
D					2516								2516
E						148							148
F							154	480					634
G								770					770
H									180	220			400
I										45			45
J											1665		1665
K												111	111
L													0
Total	0	0	2000	2146	2516	148	154	1250	180	265	1665	111	10435

Step 3 – Activity relationships

This step performs qualitative analysis towards the closeness relationship decision among various departments. Here the relationships between each department is analyzed. The activity relationship chart is shown in figure 10. The notations used inside the activity relationship diagram is shown in Table 8.

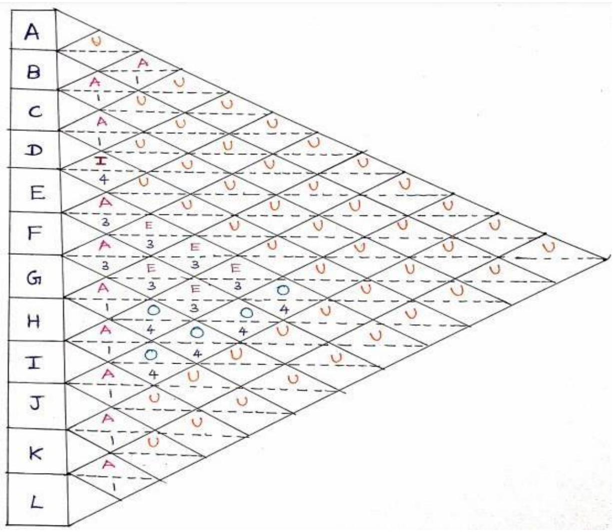

Fig.10. Activity realtionship chart.

Table 8. Activity realtionship notations I

A	Absolutely
E	Essentially important
I	Important
O	Ordinary closeness
U	Unimportant
X	Highly undesirable

Table 8. Activity realtionship notations II

1	Flow of material
2	Ease of supervision
3	Contact necessary
4	Convenience

Step 4 – Relationship diagram.

The relationship diagram locates departments spatially. Those departments that have strong interactions and/or close relationships are placed in proximity with one another. It reveals a potential good relative positioning decision among the functional department.

It provides a wide picture of potential closeness relationship for making better decision. The activity relationship diagram is shown in Fig.12.

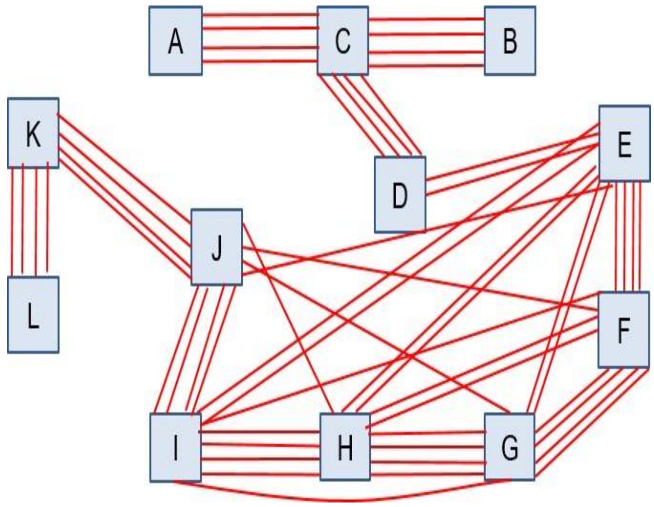

Fig.12. Activity relationship diagram.

Table 9. Activity reationship diagram notations

	A
	E
	I
	O
	U

Steps 5 & 6 – Space requirement and space available.

It helps to determine the amount of floor space to be allocated to each department. It depends on the total foot prints needed to achieve planned production.

Here initially the production space actually needed is calculated. Next the amount of non-production space required is then determined. Then by summing these two we can get the total space requirement.

$$\text{Total space requirement} = \text{Production space required} + \text{non production space required.} \quad (8)$$

Table 9. Production space requirement.

PROCESS	EQUIPMENT	NUMBER OF EQUIPMENTS AVAILABLE	MACHINE CENTRE DIMENTION PER MACHINE (ft) Depth x width	MACHINE CENTRE AREA PER MACHINE (ft^2)	TOTAL PROCESS AREA (ft^2)
Shell core making	Shell core shooter	1	14.21 X 3.96	56.27	56.27
Gravity die casting process	Die	3	3.8 X 2.6	9.88	29.64
Decoring	Hand Drill	1	3 X 3	9	9
Cutting	Cutting machine	4	3 X 2	6	24
Grinding	Grinding machine	3	3.58 X 2.5	8.95	26.85
Fettling	Fettling work bench	2	5 X 4.17	20.85	62.55
Leak testing	Leak testing machine 1	1	6.92 X 3.08	21.31	21.31
	Leak testing machine 2	1	5 X 4.17	20.85	20.85
Cutter	Hand cutter machine	1	4 X 4	16	16
Shot blasting	Shot blasting machine	1	13.17 X 5.58	73.49	73.49
				Total square feet required	**339.99**
				40% aisle space	**135.99**
				Production space required	**475.98**

Thus the Table 9 clearly shows the production space required. Here the aisle that is the space for movement is considered as 40% of the total space utilization. Thus by summing up we get a total production space of 476.98 sq ft.

Table 10. Non-Production space requirement

ACTIVITY		Area (ft^2)
Storage	Raw material	42
	Finished goods	80
Office	Main office	1080
	Quality room	780
	Rest room	720
Stores		300
Core parting line painting area		300
Final Quality check		21
Receiving and shipping		760
Total non-production space required		**4083**

Total space requirement

$$= \text{Production space required} + \text{non production space required} \quad (9)$$

$$= 453.58 + 4083$$

$$= 4536.58\ sq\ ft$$

Step 7 – Space relationship diagram.

The space relationship diagram adds departmental size information into the relationship diagram of step 4. Thus it gives the viewers a good visualization of various departments. The space relationship diagram is shown in fig.14.

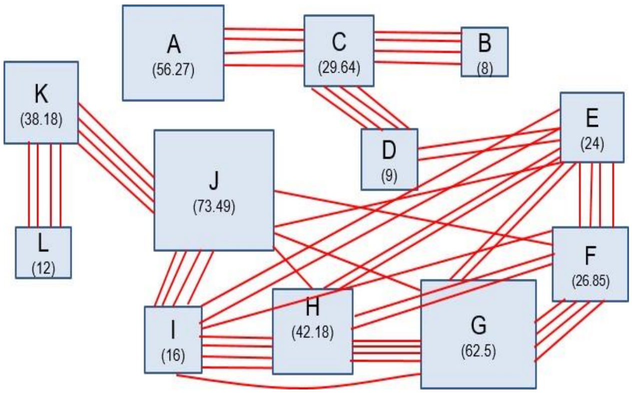

Fig.14. Space relationship diagram

Step 8 – Generating alternative layouts.

By rearranging the space relationship diagram we can get different combinations of layout. Here we consider four alternate layouts.

Different colors were used to represent different departments as shown in below Table.11

Table 11. Production space requirement

A	Shell core
B	Raw material storage
C	Gravity die casting
D	Decoring
E	Cutting
F	Grinding
G	Fettling
H	Leak testing
I	Cutter
J	Shot blasting
K	Quality and control
L	Final storage

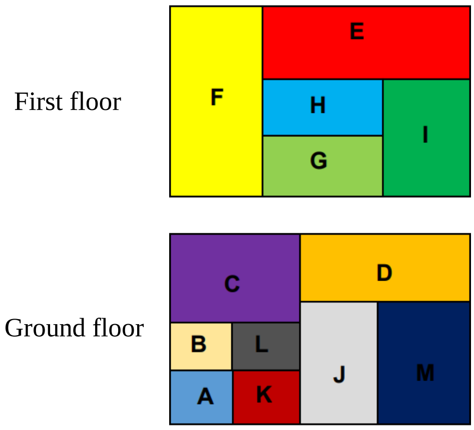

Fig.15. Alternate layout 1

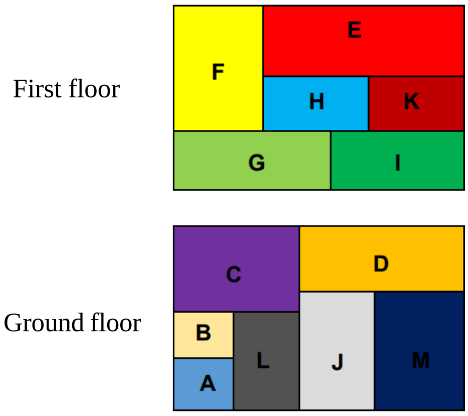

Fig.16. Alternate layout 2

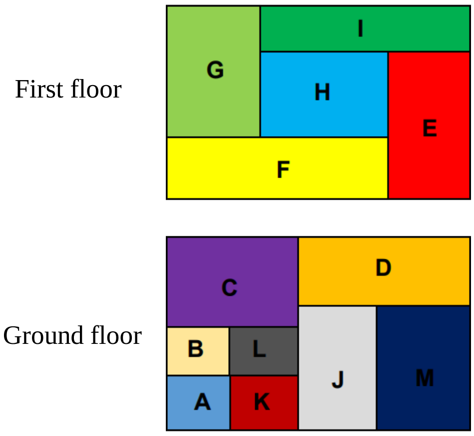

Fig.17. Alternate layout 3

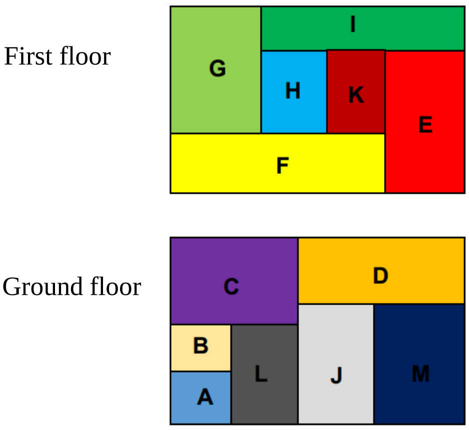

Fig.18. Alternate layout 4

4. *Analysis of simulation results*

Here the layouts generated from SLP are simulated and the results are analyzed.

Throughput

Now considering the throughput of pipe we can see that for the current layout it is 170 units but for layout 3 the throughput is increased to 171 units per shift. When considering Tank LH for current layout it is 82 units whereas for alternate layout 1, 2, 3 it is found to be 146 units. For Tank RH current layout yields 78 units but for layout 3 it is 129 units per shift. Thus alternate layout 3 is found to have higher throughput.

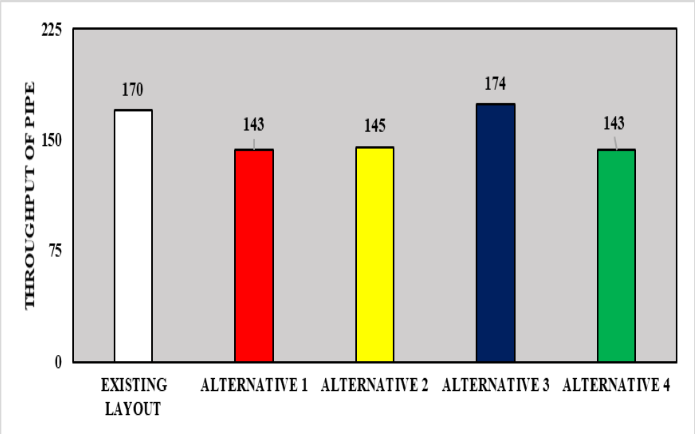

Fig.19. Throughput comparison for pipe

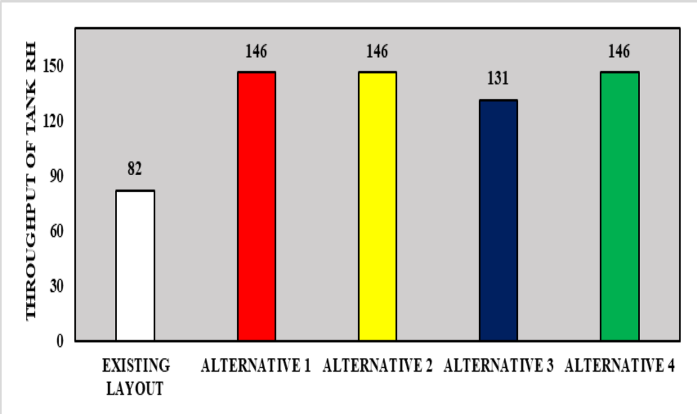

Fig.20. Throughput comparison for Tank RH

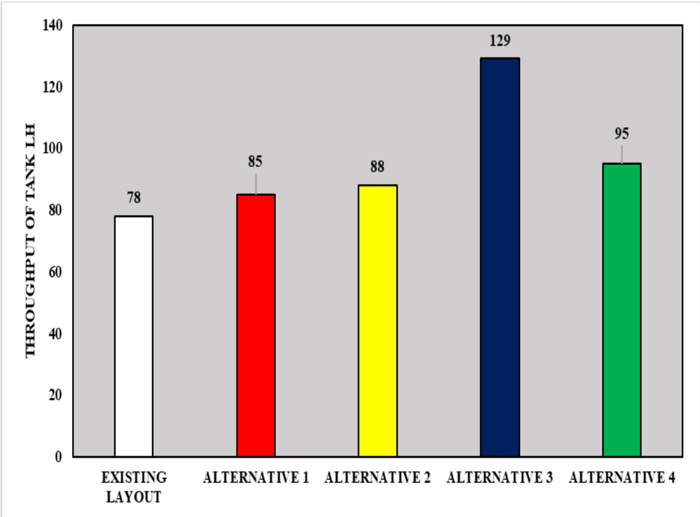

Fig.21. Throughput comparison for Tank LH

Inference from throughput comparison

From the above graphs we can infer that by changing the layout the throughput also changes. This is because, when the layout is altered the material movement time reduces which finally results in increased throughput. Here the alternate layout 3 is preferred as it shows increased throughput for pipe and tank LH.

Utilization % of current layout vs alternate layouts

The utilization % of current layout is found to be 74%. On comparing the alternative layouts, layout 3 is found to have about 89 %.

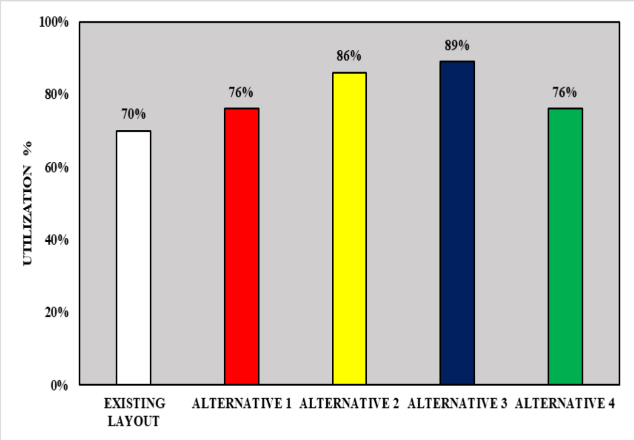

Fig.22. Comparison of utilization %

Inference from utilization % comparison

In the Fig.21. alternate layout 3 has higher utilization %. Hence it can be preferred.

Average waiting

The average waiting time of current layout is found to be 177.21 seconds. Here our focus is on finding the minimum waiting time. On comparing the alternative layouts, layout 2 is found to have about 174.76 seconds.

Hence by considering the average waiting time, layout 2 can be preferred. Layout 3 is found to have higher throughput

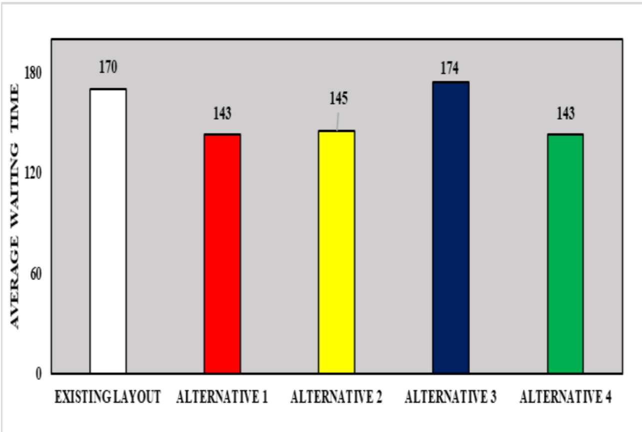

Fig.23. Comparison of average waiting time

Inference from average waiting time comparison

From the above graphs we can infer that waiting time is an essential parameter for increased productivity. Here alternate layout 3 is preferred as it has a higher utilization %

Material handling effort

The material handling effort of current layout is found to be 10435 loads of material handling trips per shift. Here our focus is on decreasing the material handling effort.

On comparing the alternative layouts, layout 3 is found to have about 7643 loads of material handling trips per shift.

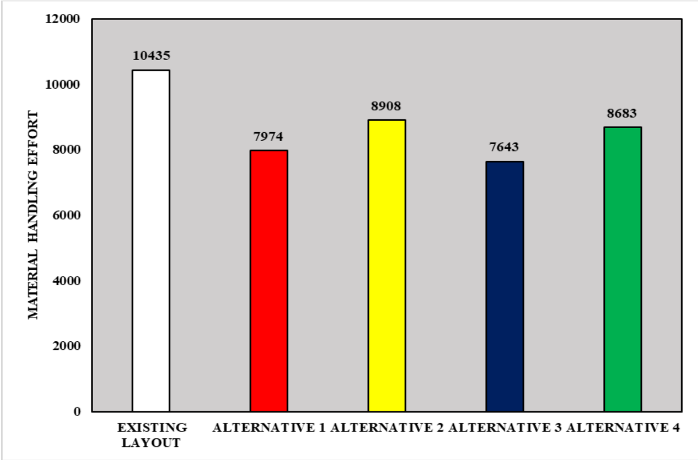

Fig.24. Comparison of material handling effort

Inference from material handling effort comparison

From the above graphs we can infer that material handling effort is more for current layout. The following table clearly depicts the values of quantitative data which is obtained from SLP and simulation.

Table 12. Quantitative data obtained from simulation and SLP

		ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE .3	ALTERNATIVE 4
CRITERIA	Material handling effort	7974	8908	7643	8683
	Average Waiting time	174.76	176.64	175.91	175.86
	Utilization %	0.74	0.86	0.89	0.76

5. *Analysis using AHP*

The purpose of the AHP approach is to tolerate vagueness and ambiguity of information and to provide a vector of weights expressing the relative importance of the layout alternatives with respect to each criterion. Qualitative measures are weighted by AHP.

Qualitative data includes aspects of flexibility, accessibility and maintenance. Flexibility here means the capability to perform a variety of tasks under variety of operating conditions. Accessibility refers to the material handling and operator's ability access things easily. Here the maintenance means the space required to carry out maintenance activity.

Initially a pairwise comparison matrix is constructed based on the decision maker's choice. The pairwise comparison matrix is shown in Table 13.

Then criteria weights are obtained. For all stages of the hierarchy, the consistency index (CI) of the judgment matrix is calculated. If our CI value is less than 0.1 we can justify that the obtained criteria weights are consistent

Table 13. Pairwise comparison matrix

	Flexibility	Maintenance	Accessibility
Flexibility	1	3	1/5
Maintenance	1/3	1	1/7
Accessibility	5	7	1

Table 14. Normalized pairwise matrix

	Flexibility	Maintenance	Accessibility
Flexibility	0.16	0.2727	0.1489
Maintenance	0.05	0.0909	0.1064
Accessibility	0.79	0.6364	0.7447

Table 15. Criteria weights

	Flexibility	Maintenance	Accessibility	Criteria weight
Flexibility	0.16	0.2727	0.1489	0.1932
Maintenance	0.05	0.0909	0.1064	0.0833
Accessibility	0.79	0.6364	0.7447	0.7235

Table 16. Criteria weight multiplied with each criteria

	Flexibility	Maintenance	Accessibility
Flexibility	0.1932	0.2499	0.14
Maintenance	0.0644	0.0833	0.10
Accessibility	0.9660	0.5831	0.72

Table 17. Consistency calculation

	Flexibility	Maintenance	Accessibility	Weighted sumvalue
Flexibility	0.1932	0.2499	0.14	0.5878
Maintenance	0.0644	0.0833	0.10	0.2511
Accessibility	0.9660	0.5831	0.72	2.2726

Table 18. Ratio of weighted sum value to criteria weight

	Flexibility	Maintenance	Accessibility	Weighted sum value	Criteria weight	Ratio
Flexibility	0.1932	0.2499	0.14	0.5878	0.1932	3.0427
Maintenance	0.0644	0.0833	0.10	0.2511	0.0833	3.0136
Accessibility	0.9660	0.5831	0.72	2.2726	0.7235	3.1411

$$\lambda_{max} = \frac{3.0427 + 3.0136 + 3.1411}{3} = 3.0658 \qquad (10)$$

$$\lambda_{max} = 3.0658$$

$$\text{Consistency Index (CI)} = \frac{\lambda_{max} - \text{n}}{\text{n} - 1}$$

$$= \frac{3.0658 - 3}{2} \qquad (11)$$

$$\text{Consistency Index (CI)} = 0.0329$$

$$\text{Consistency Ratio} = \frac{0.0329}{0.58} = 0.0567 \qquad (12)$$

Thus from the above calculations the consistency ratio is found to be 0.0567 which is < 0.10. Therefore, we can conclude that the obtained matrix is reasonably consistent. Here the AHP procedure is shown for Alternative layout 1. In the similar manner we can obtain the criteria weights of other alternative layouts.

Table 19. Criteria weights obtained from qualitative data

	CRITERIA WEIGHT			
	ALTERNATIVE1	ALTERNATIVE2	ALTERNATIVE.3	ALTERNATIVE4
Flexibility	0.1932	0.2311	0.5679	0.1307
Maintenance	0.0833	0.1038	0.0982	0.1925
Accessibility	0.7235	0.6651	0.3339	0.6768

6. Integration of quantitative data and qualitative data using W-NLP approach

Initially the criteria weights obtained from both qualitative and quantitative analysis is clubbed together into one matrix. This is shown in Table 19. The table values are changed in such a way that the values obtained are between 0 – 1. This is done using the transformation formula priory mentioned in this paper.

Then to convert this matrix into a NLP problem, we need an objective function, decision variable and constraints. The objective function here is of maximization type that is we are interested in finding the numerically largest weights.

Table 20. Overall transformed criteria weights of the qualitative data and quantitative data

	MATERIAL HANDLING EFFORT	AVERAGE WAITING TIME	UTILIZATION %	ACCESSABILITY	MAINTENANCE	FLEXIBILITY
ALTERNATIVE 1	0.71	1	0	1	0	0.14
ALTERNATIVE 2	0	0	0.77	0.85	0.19	0.23
ALTERNATIVE 3	1	1.39	1	0.00	0.14	1
ALTERNATIVE 4	0.16	0.41	0	0.88	1	0

Here the material handling effort and the average waiting time are to be minimized. As our objective function is of maximization type we use the reciprocal of these two criteria. Equation (4) is our objective function.

A) Defining the decision variables

Let us first define the decision variables used in solving the NLP.

W_1 – Material handling effort

W_2 – Average waiting time

W_3 – Utilization percentage

W_4 – Accessability

W_5 – Maintenance

W_6 – Flexibility

B) Formulation of objective function

The objective function is framed based on the transformed matrix value in table (18)

$$Z_{max} = 0.71\,W_1 + W_2 + W_4 + 0.14\,W_6 \quad (13)$$

$$Z_{max} = 0.77\,W_3 + 0.85\,W_4 + 0.19\,W_5 + 0.23\,W_6 \quad (14)$$

$$Z_{max} = W_1 + 1.39\,W_2 + W_3 + 0.14\,W_5 + W_6 \quad (15)$$

$$Z_{max} = 0.16\,W_1 + 0.41\,W_2 + 0.88\,W_4 + W_5 \quad (16)$$

Here the equation (13) indicate the objective function of alternative layout 1 and for the respective alternative layout each equation is framed. Now, we are going to solve this nonlinear model for each FLP using Microsoft Excel Solver software package.

C) Formulation of constraints

We know that transformed matrix consist of values that lies between 0 – 1. In order to avoid negative values in the objective function the square of the decision variables are considered

$$W_1^2 + W_2^2 + \cdots + W_6^2 = 1 \quad (17)$$

Based on decision maker's comparing material handling effort and average waiting time,

$$W_1 - W_2 = 0 \quad (18)$$

Equation (19), (20), (21) is based on decision maker's decision on material handling effort, average waiting time and utilization percentage. Here they are considered as similar. That is $W_1 = W_2 = W_3$,

$$W_1 - W_3 = 0 \quad (19)$$

$$W_2 - W_3 = 0 \quad (20)$$

$$W_4 - W_6 = 0 \quad (21)$$

On comparing maintenance and feasibility, the later would be more (greatly significant)

$$W_5 - W_6 < 0 \quad (22)$$

On comparing accessibility and material handling effort, the later would be more (greatly significant) so the following constraint equation is framed

$$W_4 - W_1 < 0 \quad (23)$$

D) Non negativity restriction (NNR)

Either it may be a throughput or machine utilization, it need not take negative value. Since non negative weights don't have significance meaning Thus NNR is shown below,

$$W_1, W_2 \ldots\ldots W_6 \geq 0 \quad (24)$$

The excel solver solution for alternative layout one is shown in upcoming figures.

DECISION VARIABLE	W1	W2	W3	W4	W5	W6
VALUES						
DECISION VARIABLE	0.71	1	0	1	0	0.14

CONSTRAINTS	EQUATION	LHS	<=>	RHS
1	W1 - W2 = 0	0	=	0
2	W2 - W3 = 0	0	=	0
3	W1 - W3 = 0	0	=	0
4	W4 - W6 = 0	0	=	0
5	W4 -W1 < 0	0	<	0
6	W5 - W6 < 0	0	<	0
7	W1.W1 + W2.W2 + W3.W3 + W4.W4 + W5.W5 + W6.W6 = 1	0	=	1

Z (MAX)	0

Fig.24. Solution of NLP

Here the problem is of nonlinear type. From the drop down menu the GRG non – linear is selected and solved. Here the GRG stands for "Generalized Reduced Gradient". In its most basic form, this solver method looks at the gradient or slope of the objective function as the input values (or decision variables) change and determines that it has reached an optimum solution when the partial derivatives equal zero. Of the two nonlinear solving methods, GRG Nonlinear is the fastest.

DECISION VARIABLE	W1	W2	W3	W4	W5	W6
VALUES						
DECISION VARIABLE	0.71	1	0	1	0	0.14

CONSTRAINTS	EQUATION	LHS	<=>	RHS
1	W1 - W2 = 0	0	=	0
2	W2 - W3 = 0	0	=	0
3	W1 - W3 = 0	0	=	0
4	W4 - W6 = 0	0	=	0
5	W4 -W1 < 0	0	<	0
6	W5 - W6 < 0	0	<	0
7	W1.W1 + W2.W2 + W3.W3 + W4.W4 + V	=((C6^2)+(D6^2)+(E6^2)+(F6^2)+(G6^2)+(H6^2))		

Z (MAX)	0

Fig.25. Formula for constraints

DECISION VARIABLE	W1	W2	W3	W4	W5	W6
VALUES						
DECISION VARIABLE	0.71	1	0	1	0	0.14

CONSTRAINTS	EQUATION	LHS	<=>	RHS
1	W1 - W2 = 0	0	=	0
2	W2 - W3 = 0	0	=	0
3	W1 - W3 = 0	0	=	0
4	W4 - W6 = 0	0	=	0
5	W4 -W1 < 0	0	<	0
6	W5 - W6 < 0	0	<	0
7	W1.W1 + W2.W2 + W3.W3 + W4.W4 + W5.W5 + W6.W6 = 1	0	=	1

=SUMPRODUCT(C7:H7,C6:H6)

Fig.26. Formula for Objective function

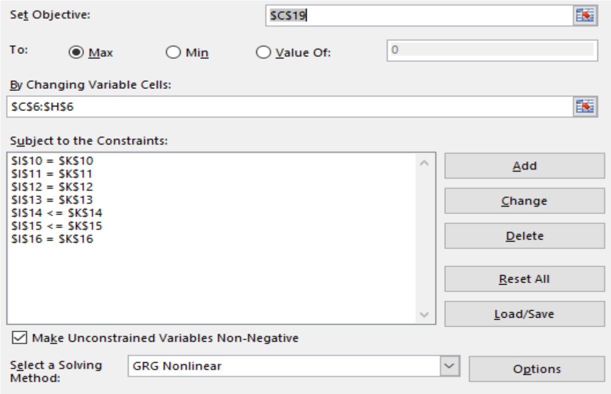

Fig.27. Solver parameter

DECISION VARIABLE	W1	W2	W3	W4	W5	W6
VALUES	0.447214	0.447214	0.447214	0.447214	0	0.447214
DECISION VARIABLE	0.71	1	0	1	0	0.14

CONSTRAINTS	EQUATION	LHS	<=>	RHS
1	W1 - W2 = 0	0	=	0
2	W2 - W3 = 0	0	=	0
3	W1 - W3 = 0	0	=	0
4	W4 - W6 = 0	0	=	0
5	W4 -W1 < 0	0	<	0
6	W5 - W6 < 0	-0.44721	<	0
7	W1.W1 + W2.W2 + W3.W3 + W4.W4 + W5.W5 + W6.W6 = 1	1	=	1

Z (MAX)	1.274559

Fig.28. Solver solution for Layout alternative 1

Thus in the similar way other three equations are solved and it can be visualised with help of a bar diagram shown in Fig.29.

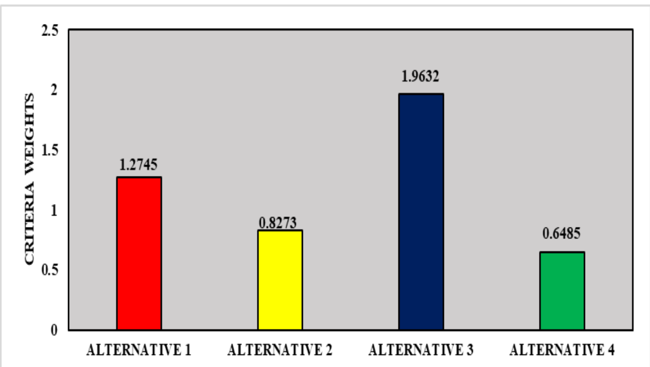

Fig.29. Comparison of criteria weights obtained from W-NLP

From the comparison of the criteria weights are shown in the form of pie chart in Fig.28. Thus it clearly depicts that alternative 4 has higher weightage as our NLP is of maximization type. The industry X is now suggested to implement the layout 3 that is optimal. By implementing the layout 3 they can see and increased throughput of 174 units of pipe, 130 units of LH tank and 130 units of RH tank and their utilization percentage can be increased up to 89%.

Table 21. Comparison of existing layout vs proposed layout

PERFORMANCE MEASURE		EXISTING LAYOUT	PROPOSED LAYOUT
Throughput	Pipe	170 units	174 units
	Tank RH	78 units	130 units
	Tank LH	82 units	129 units
Average waiting time		2.19 minutes	1.82 minutes
Utilization %		74%	89%

VII. Discussion and Conclusions

The suggested approach in this study gives an NLPmodel to Facility Layout Design problem in the area of prioritizing the FLPs generated by SLP. This model simulataneously takes into account opinion of experts with regard to weights obtained by the AHP for qualitative criteria, as well as performance measures of quantitative criteria.

The data required for comparing the FLPs regarding to the qualitative criteria for constructing the pair wise comparison matrix and determining the ranking order of criteria on a real case study are drawn out through interviewing with design experts of the industry. It is also possible to consider the ranking order of criteria. It depends severely on judgments of designers for the ranking order of criteria and it might temporarily be resulted in uncertain and conflicting knowledge.

The criteria under consideration in this study according to considerations of experts participating in assessment include three quantitative criteria (material handling effort, average waiting time and utilization %) and three qualitative criteria (accessibility, maintenance and flexibility). However, if required, design experts can consider other qualitative and quantitative criteria in FLD problem, depending on nature of FLD problem, type commercial software used for simulation or proper explanation by experts.

For example, (Ertay et al, 2006) consider another quantitative criterion (material handling vehicle utilization) besides the above criteria together with the qualitative criterion such as quality instead of accessibility and maintenance for judging the FLPs. Also, we can see that the other criteria like layout change cost of FLPs, speed of helping, facility of handling, etc., also available in FLD problem. But in spite of all these drawbacks, with the help of proposed robust facility layout framework, the company can provide significant solutions for their layout problem. Moreover, the framework presented in this case study can be implemented on a personal computer without any restrictions as the flexSim software and excel solver are available and offers a step by step guidance to the decision makers in planning the layout design.

VIII. FUTURE SCOPE

This work uses the traditional AHP for comparing the FLPs with respect to each qualitative criterion in the pair wise comparison as proposed by [Saaty,1980]. But in real world, evaluating and comparing qualitative criteria are expressed as linguistic expressions and judgments, it is better to use fuzzy AHP approach that gives more accurate decisions. Moreover, the NLP can be solved using advanced software like MATLAB or any other coding language that may yield an accurate objective function value.

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