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An integrated systematic layout planning, analytical hierarchy process and nonlinear programming approach to facility layout design

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An integrated systematic layout planning, analytical hierarchy process and nonlinear programming approach to facility layout design

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Abstract: This study has three aims: 1) finding alternative layout designs through procedural approach of SLP of a large-scale auto component manufacturer; 2) examine optimality of identified alternatives by using both qualitative and quantitative criteria and ranking them by using AHP method by collecting data from decision-makers of similar 132 manufacturers; 3) identifying most optimal design by using mathematical optimisation model of NLP. Results of SLP provided three prominent quantitative criteria by comparing key performance indicators of four alternative designs with those of existing layout. Informal discussions extracted major qualitative criteria. Rating of all six criteria indicated distance and cost of change being primary influencers. Results of NLP were able to identify one most optimal alternative from feasible four derived from SLP. The study derives its originality by dealing with shortcoming of SLP approach of over emphasis on subjective criteria and of metaheuristic methods of assigning excessive importance to metaheuristic methods.

Keywords: facility layout; systematic layout planning; SLP; analytic hierarchy process; AHP; nonlinear programming; NLP; quadratic assignment problem; QAP.

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Biographical notes: Vikas Singla is currently holding the position of Assistant Professor in the School of Management Studies at Punjabi University, Patiala, India. He has been in teaching profession for last 15 years. He teaches Business Administration and handles subjects in the area of business statistics, research methodology and operations management. His research areas are lean systems. He has contributed in these fields academically by publishing research papers in various national and international journals.

1 Introduction

A significant amount of time is spend in designing facility layout of a manufacturing firm. An appropriate layout streamlines material and man movement within a plant or a shop floor, thus, influencing productivity. An incongruous layout would require rearrangement of facilities causing downtime and cost overruns (Ali Naqvi et al., 2016). Noteworthy emphasis on layout design becomes furthermore important because of its restrictive nature. Once established especially in a manufacturing firm rearrangement of machines and material handling system is challenging to say the least. Thus, suitable layout design is significantly important and is dependent on identification and selection of most important criteria influencing different layout patterns (Perez-Gosende et al., 2021).

Methodologies to design or modify a layout can be primarily categorised as based on qualitative or quantitative criteria. Methods based on qualitative criteria adopt procedural approach wherein a problem is broken down into several steps that are evaluated and examined sequentially. The identification of these criteria depends heavily on experience and judgment of decision makers rather than on some mathematical exact approach (Palominos et al., 2019). Though such an emphasis incorporates important human element into decision-making but lacks scientific scrutiny. This shortcoming is rectified by application of various methods based on quantitative criteria. Algorithmic and approximated approaches involving methods such as simulated annealing, genetic algorithms and ant colony are some of the predominant such approaches (Tosun et al., 2013; Zhou et al., 2017). However, their heavy mathematical orientation makes them difficult to understand for an average manager on the shop floor. Moreover, to cater to the accurate scientific procedure the assumptions and criteria leave behind crucial qualitative criteria effecting reliability of solution (Duffuaa and Fedjki, 2012).

To remove the deficiencies of qualitative method of not providing structured solution and of quantitative method that it lacks focus on human aspects of decision making this study has attempted to integrate both methodologies. Specifically study involved three aims: firstly, to identify feasible alternative layout patterns through systematic layout planning (SLP) method; secondly, to apply a multi-attribute decision making method of analytic hierarchy process (AHP) in order to assign ranks to certain identified qualitative and quantitative criteria for each alternative layout design; and lastly, to evaluate appropriateness of each design by formulating a nonlinear program (NLP) model.

This integration approach is applied in the shop floor of a car component manufacturing company involved in production of emblems of major car manufacturers. The layout of production shop was inefficient, non-standard and had unnecessary material movement. This made it an appropriate candidate for layout modification.

The aims of the study contribute valuably to deficient literature on the topic under study. This was justified by systematic literature review (SLR) done on business management journals in Scopus and Web of Science (WoS) database. SLR depends on selection of appropriate primary keywords. This study involved three major constructs namely SLP, AHP and NLP. First primary keyword included ‘SLP’ OR ‘plant layout’ OR ‘facility layout’ OR ‘layout planning’ OR ‘facility layout problems’ OR ‘facility design’. These were further combined with another set of keywords namely ‘AHP’ OR ‘multi-attribute decision making’ AND ‘nonlinear programming (NLP)’ OR ‘NLP’ OR ‘quadratic assignment problem (QAP)’ OR ‘quadratic programming’ OR ‘metaheuristics’ OR ‘QAP’. This entire query searched for mentioned keywords in title, abstract and keywords of various studies. Furthermore appropriate inclusion and exclusion criteria were determined to select relevant literature. Following inclusion criteria was used:

1 only journals pertaining to business management, operations research and management science were selected

2 recent studies published only after year 2000

3 only published manuscripts

4 studies discussing linkage between SLP, AHP and NLP in automotive component industry.

Exclusion criteria used was:

1 studies presented in conferences, review articles and edited book articles

2 studies presenting only theoretical framework and using only qualitative measures.

The results showed that by applying inclusion criteria of (1), (2), (3) and exclusion criteria (1) 19 and 25 studies were obtained pertaining only to QAP from Scopus and WoS respectively. Title and author examination of these studies revealed that some of them were quoted on both databases. After excluding them total of 37 studies were segregated discussing concept and application of QAP. Similarly, when databases were searched for SLP keywords separately from QAP by applying similar inclusion and exclusion criteria 224 studies were obtained from Scopus and 185 from WoS. Exclusive studies obtained were 317. Abstracts of all these were examined and according to (2) exclusion criteria studies discussing only theoretical framework of constructs under study were only 9 thus reducing studies to 28. Similarly, on the basis of same criteria studies pertaining to SLP were reduced to 108. These abstracts were further analysed by using secondary keywords of 'automotive', 'India' and 'integration' separately. Results showed that none of the studies examined these concepts in Indian automotive industry least the combinatorial approach. In addition, zero studies were found when both SLP and nonlinear programming were searched together.

However, to justify application of integration of SLP, AHP and NLP in this study full examination of extracted studies was conducted. It revealed suitability of these methods in batch production systems wherein facilities are arranged in predefined sequence and in discrete manner. Auto component manufacturing unit under study fulfilled these assumptions. Thus, lack of contribution in literature on assessing combinatorial impact of qualitative and quantitative measures in layout modification in large-scale automotive component manufacturers of India makes this study valuable. Subsequent section discussed certain substantive studies regarding these concepts.

2 Literature review

Layout design has been a very active area of research in both manufacturing and service industry. Principal purpose of an effective layout is to arrange different entities involved in production process to maximise space utilisation and minimise operating cost (Kovacs, 2020). Limited available space and inflexibility in adding more space in case of increased demand or variety poses challenge to layout design. Literature has recorded various formulation and methods to encounter problems in layout (re)arrangement. QAP is a mathematical model that has been extensively used in designing layout of manufacturing system applying batch production method. The assumptions of this method enforce suitability of method where number of facilities and locations are equal focusing on their one to one mapping (Gul et al., 2022). In addition, locations are earmarked as rectangular grids and each of the facility would occupy one of them. The method is considered appropriate for discrete production implying that a process operates in batch and then entire lot moves to another process or facility. The facilities are inter linked and should follow adjacency criteria. This makes it different from continuous method of production wherein units being processed on one facility moves to next without creating batches. The locations in continuous flow system necessarily not to be rectangular shape and they have to be placed essentially according to technological sequence (Hunagund et al., 2021). This study involves modification of an existing layout of a car component-manufacturing shop floor fulfilling conditions of batch system making formulating layout problem as QAP appropriate.

Solving a QAP formulation requires understanding of heuristic or metaheuristic methods. Heuristic methods involve subjective decision making thus lacking precise examination (Mansour et al., 2022). These methods predominantly rely on qualitative criteria such as accessibility, maintenance, flexibility issues to solve layout problems. SLP is one of heuristic methods adopting sequential approach in providing feasible alternative layout patterns. Selection of most optimal alternative is based on experience and judgment of decision maker examining alternatives chiefly from cost perspective (Sagnak et al., 2019). With the ease in computational process, designers have used various algorithms such as ALDEP, COROLAP, CRAFT, etc. to examine feasible alternatives and provide most optimal solution (Xu et al., 2020). This tends to eliminate subjectivity to great extent. On other hand various metaheuristic approaches such as simulated annealing (Tayal and Singh, 2019), genetic algorithm (Pradeepmon et al., 2020), ant colony optimisation (Mohammadnejad and Eshghi, 2019) and tabu search (Silva et al., 2021) are applied as advanced mathematical tools in solving a QAP formulated layout problem. Their procedural complexity makes them difficult to understand and implement in shop floor settings.

Systematic layout procedure (SLP) originally developed by Muther and Wheeler (1994) has been extensively used in identifying the problem area such as distance and time consumed in material movement that caused inefficiencies in existing layout (Flessas et al., 2015). Ojaghi et al. (2016) showed the efficacy of SLP method in suggesting feasible alternative layouts and evaluating them on certain key parameters of travel time, material flow and operating cost. To optimise layout design alternatives provided by SLP the method has been integrated with various mathematical algorithms such as genetic algorithm (Li et al., 2019), simulation methods (Hosseini et al., 2013) and fuzzy constraint theory (Lin et al., 2015). In addition, due to it being influenced by subjective perspective of decision maker the procedure was applicable to various sectors including MSME (Sahoo and Yadav, 2018), workshops (Jia and Huang, 2013) and textile (Suhardi et al., 2019). However, literature lacked recording its execution in car component manufacturing.

Multi-criteria decision models AHP was developed by Saaty (1980) and consisted of defining a hierarchical model that represented complex problems through criteria and alternatives. This procedure was designed to break a complex problem into a set of simpler decisions, thus making problem easier to understand and solve. Various studies have combined AHP with SLP to rank both qualitative and quantitative criteria and prioritise a layout alternative. Primarily studies have used AHP for ranking qualitative attributes in layout design problems. However, their application in ranking both type of attributes has also been highlighted. Hadi-Vencheh and Mohamadghasemi (2013) and Galankashi et al. (2019) for instance identified weights of non-logistics attributes effecting a layout design by using AHP in order to supplement the findings with logistics attributes. On other hand, Jia and Huang (2013) and Qamar et al. (2020) applied AHP to rank quantitative attributes of material travelling distance, total space usage and qualitative attribute of activity relationships in examining possible layout of a manufacturing facility.

Lastly, the study has used NLP method of finding the optimum solution from various layout alternatives by developing a discrete optimisation model. Such model involves discrete decision variables with linear constraints. The model is solved by linearisation of quadratic objective function that results in creating more variables making the problem cumbersome. However, it remains manageable with less than 30 facilities (Drezner et al., 2005). With increase in number of facilities, studies have applied different metaheuristic methods that provide solutions that are more exact. Under similar consideration mixed integer linear programming optimisation technique was applied by Nyberg and Westerlund (2012) for solving a QAP formulated layout problem involving both discrete and continuous variables. As this study also involved mapping of small number of facilities to locations thus NLP method was considered appropriate.

Following is the summary of important studies corresponding to constructs under study.

Table 1 Summary of important studies

SLP	Yang et al. (2000), Goyal and Verma (2019), Wen and Bai (2015) and Hosseini et al. (2013)
SLP and AHP (heuristic methods)	Hadi-Vencheh and Mohamadghasemi (2013), Ma et al. (2014), Qamar et al. (2020) and Jia and Huang (2013)
SLP and metaheuristics methods	Palominos et al. (2019), Li et al. (2019) and Lin et al. (2015)
Optimisation methods like MILP and NLP in layout design	Drezner et al. (2005) and Nyberg and Westerlund (2012)
SLP, AHP or optimisation methods in Indian car component industry	None
SLP-AHP-NLP	None

3 Methodology and results

3.1 SLP

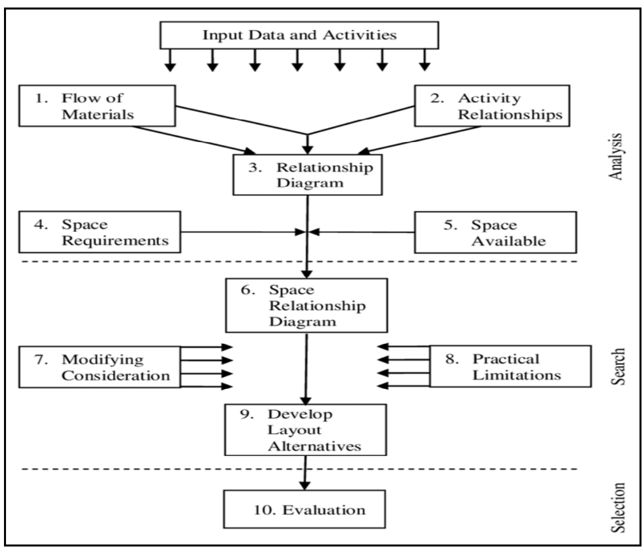
This study has adopted heuristic method of SLP in identifying alternatives to layout problem. It was substantiated through conduct of a pilot survey involving interviews with decision-makers from 56 firms operating in car component industry. Out of 46 interviews 38 (83%) showed their awareness about applicability and suitability of SLP as an alternative providing method. The method was considered as easy to understand and implement due to its sequential approach. Importantly participants deemed SLP to provide relevant quantitative criteria based on experience of managers rather than emphasising only on structured methods. Managers stated that any layout design alternative should be evaluated on certain specific key performance indicators. Any significant improvement from existing layout would entail their selection as quantitative criteria.

Same interview session was used to understand qualitative criteria for evaluation. From exhaustive list of these criteria such as practical constraints, cost of change, accessibility of facilities, their maintenance and flexibility of layout derived from literature participants were asked to provide their viewpoints in open-ended way. Content analysis of their responses would facilitate in identifying the subjective criteria for evaluation of alternatives.

Thus, findings of SLP procedure would provide both quantitative and qualitative criteria for evaluation of proposed alternative designs.

SLP framework required to achieve objective of finding layout alternatives is shown in Figure 1. The procedure is segregated into sequential three steps, namely, analysis, search and selection.

Figure 1 SLP framework



3.1.1 Step 1: analysis

First step in SLP involved understanding the production process. For this study, process of emblem manufacturing in a large-scale auto component company was selected. It was understood by observing the production line in random shifts. It resulted in eight major operations arranged in specific locations. The operations and their sequence is shown in Table 2. The process flowed from 1 to 8.

To examine relationship between different operations/activities and formulate relationship diagram data regarding space occupied to carry out each process; distance travelled by material and total time taken for such travel between each process was collected pertaining to existing layout. Distance data between operations would provide relation between operations. In proposed alternatives endeavour would be to alter this distance under constraints of logical sequence among processes and material movement distance between them. Distance data only does not provide information regarding flow intensity or strength of relationship between two processes. This is indicated importantly by material movement frequency data that was calculated by dividing production quantity in a day by size of the lot. Time between two processes was calculated by multiplying number of times a lot has been moved (material movement frequency per day) and time required to move one lot between two processes. It is important as its understanding would be governing factor in selecting an alternative.

Table 2 List and sequence of processes

Process no.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Process	Raw material store	Injection moulding	Chrome plating	Painting	Assembly	Final inspection	Packing	Finished goods store

Table 3 Input data and activities

Production quantity/day = 2,640 units							
#	*From*	*To*	*Distance (feet)*	*Lot size*	*Time taken to move one lot (mins.)*	*Material movement frequency per day = production quantity/lot size*	*Total time consumed in material movement/day (mins.)*
1	Injection moulding	Chrome plating	60	972	1	3	$3 \times 1 = 3$
2	Chrome plating	Painting	500	324	8	9	$9 \times 8 = 72$
3	Painting	Assembly	50	480	1	6	$6 \times 1 = 6$
4	Assembly	Final inspection	50	240	1	11	$11 \times 1 = 11$
5	Final inspection	Packing	400	240	7	11	$11 \times 7 = 77$
6	Packing	Finished goods store	400	240	7	11	$11 \times 7 = 77$
			Total				*246 minutes*

Table 4 Existing space covered by each process

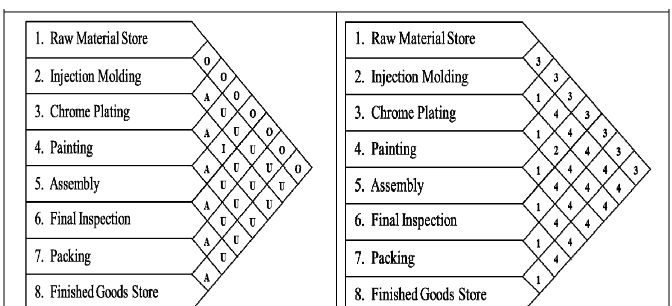
Process no.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Process	Raw material store	Injection moulding	Chrome plating	Painting	Assembly	Final inspection	Packing	Finished goods store
Area (sq. feet)	2,000	6,355	9,800	1,150	3,000	200	200	1,400

Last aspect in step 1 of SLP is to observe the quantity of floor space allocated to each work station. Existing space covered by each facility is shown in Table 4. The data when compared with available indicated lack of extra floor space implying any new arrangements to be carried out within existing available space.

Relationship diagram: The importance of analysing material movement frequency per day is further highlighted in understanding relationship between processes that is depicted in drawing of relationship diagram. The purpose is to identify relative positioning of various operations in order to understand relationship between functions/processes based on material movement frequency. The diagram indicates proximity and thus importance between operations. This information is necessary in designing layout alternatives. Relationship diagram shows that some of the processes are unimportant for one-another due to no frequency of use while some of the processes are absolutely necessary for one-another due to high frequency of use.

Relationship diagram gives directions to finalise adjacency of the processes implying that which processes should be closer to one another based on material movement or frequency of use between the processes. In this case, relationship diagram shows (Figure 2) that relationship of raw material store can be ordinary (O) closer to moulding, plating and painting. Relationship of injection moulding is absolutely necessary (A) to chrome plating. Relationship of chrome plating is (A) to painting and assembly. Relationship of painting is (A) to assembly. Relationship between assembly and final inspection, final inspection and packing, packing and FG store is also (A). While designing the alternate layout we need to keep in mind that those processes which have absolutely necessary and important relation must be closer to one another as much as possible.

Figure 2 Relationship diagram of processes

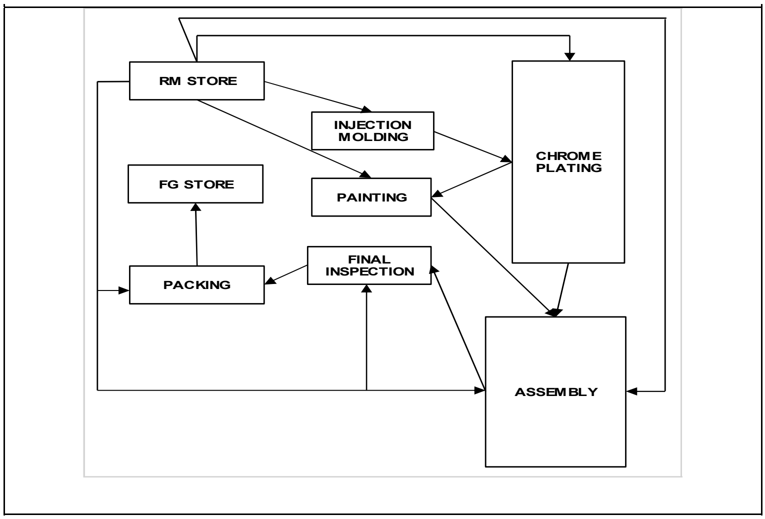


Rating	Definition	Reason	Code
A	Absolutely Necessary	Frequency of use high	1
I	Important	Frequency of use medium	2
O	Ordinary Closeness OK	Frequency of use low	3
U	Unimportant	No Frequency of use	4

3.1.2 Step 2: search

Space relationship diagram: Relationship diagram in step 2 provided sequence of processes by considering intensity of workflow between each one of them. Synchronising that information with space occupied by each process and distance between processes furnishes a very important pictorial representation of existing layout termed as space relationship diagram (Figure 3). This diagram importantly indicated the relationship between processes of whole facility in terms of distance irrespective of sequence of operations. It also facilitated highlighting of deficiencies and scope of improvement in existing layout.

Figure 3 Space relationship diagram



Numerous arrows in the diagram clearly allow inferring that existing layout causes too much travel among the processes. Thus, existing layout provides an opportunity of improvement. Next section is devoted to provision of alternative layouts by considering information observed in step 1.

Layout alternatives: based on from-to chart, relationship diagram of the processes, and space relationship diagram four feasible alternate layouts (Figure 4) were developed by converting relationship chart into block layout. At this stage, feasibility was examined by observing movement constraints of facilities such as moulding, painting and plating machines that are fixed at specific locations and cannot be moved. Proposed alternatives involve rearrangement of remaining five facilities.

In alternate 1, raw material store was kept in centre of all processes and other processes like assembly, final inspection, packing and FGS stores were kept near to each other. In alternate 2 all the processes were arranged in line so that material movement could be minimised. In alternate 3 raw material store, final inspection, and packing processes were kept near to each other processes because in these three processes material movement was more from other processes like moulding, plating and painting. In alternate 4, only assembly, final inspection, packing and FG store were shifted near to each other because distance and material movement was high between these departments.

3.1.3 Step 3: layout evaluation

Human element is predominant in this stage of SLP as even; for instance, quantitative data indicated high workflow intensity between two processes but manager considered their adjacency to be not convenient for cost considerations thus overriding the quantitative attribute. According to this aspect when four alternatives were evaluated on aspects of practical constraints, cost of change and management approval alternative 4 was considered as most feasible (Table 5).

Figure 4 Layout alternatives

However, for more robust and scientific approach of evaluation alternatives were evaluated on both quantitative and qualitative criteria. Thus for effective examination it is necessary to select these criteria appropriately.

Interviews revealed that performance indicators of distance travelled, total time consumed in material movement and process lead times between two processes were important in layout evaluation. Their role as quantitative criteria of layout evaluation was established by conducting a before-after study. Data regarding these indicators were collected for existing layout and for alternative 4. To calculate the distance and time data facilities in the shop floor were rearranged according to block diagram pertaining to alternative four. All eight operations were carried out and data collected (Table 6). Positive improvement in three criteria indicated their appropriateness in layout evaluation.

Table 5 Evaluation of alternatives

Alternative	*Major change*	*Practical constraints*	*Cost of change*	*Management approval*
Alternative 1	Raw material store was kept in centre of all process and paint, assembly, final inspection, packing, FGS kept adjacent to each other.	Raw material store could not be shifted because it must have been roadside in order to have easy transport/logistics flow from suppliers. Could be considered but shifting cost of paint and assembly was high.	High	No
Alternative 2	Moulding, plating and paint shop were shifted and all processes were tried to keep adjacent to each other.	Moulding shop and plating shop could not be shifted due to huge investment.	Very high	No
Alternative 3	Raw material store, final inspection, and packing processes were kept near to each other processes.	Raw material store can not be shifted because it must be roadside in order to have easy transport/logistics flow from suppliers. Could be considered but shifting cost of paint and assembly was high.	High	No
Alternative 4	Assembly, final inspection, packing and FG store were kept adjacent to each other. All other processes were on their same location.	Could be implemented but plant shut down was needed to change the layout.	Low	Yes

For identifying qualitative criteria majority of responses under content analysis revealed cost of change (49%), accessibility of facilities (38%) and their flexibility in event of variation in demand and product variety (35%) as predominant concerns in layout evaluation. Due to lack of responses, practical constraints and maintenance of layout attributes were not contemplated.

Therefore, four proposed alternatives were evaluated by using these six criteria. For this however firstly these criteria would be ranked by applying AHP method as explained in next section

3.2 AHP

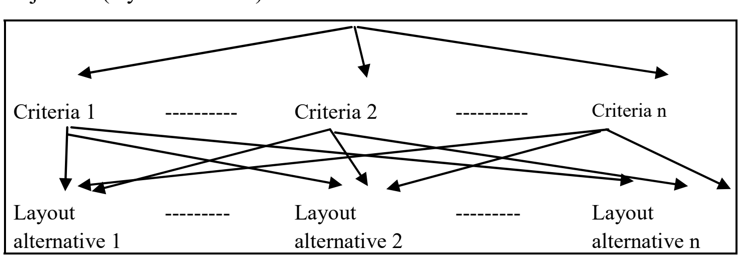
AHP method involved formulation of a model containing sub-criteria, criteria and final objective. This study focussed only on finding weights to criteria forming only one level. However, the method was appropriate as it allowed comparison of each attribute with all other separately (Figure 5). To gather responses a structured questionnaire was designed by using paired comparison scale where criteria were compared in pairs and respondents had to select one considered relatively more important for layout design. Importantly, to evaluate a layout design participants were first shown pictorial representation of all the alternatives. The participants needed to select one most appropriate design and then examine it on different criteria. The rating scores were recorded on five-point scale where

'5' meant extremely important and '1' meant equally important. Pairwise comparison matrix would lead to calculation of weights assigned to each criteria. These would be further applied in NLP equation.

Table 6 Selection of quantitative criteria

Production quantity/day = 2,640 units					
From	*To*	*Distance (feet)*		*Time taken to move one lot (mins.)*	
		Before	*After*	*Before*	*After*
Injection moulding	Chrome plating	60	60	1	1
Chrome plating	Painting	500	500	8	8
Painting	Assembly	50	50	1	1
Assembly	Final inspection	50	0	1	0
Final inspection	Packing	400	0	7	0
Packing	Finished goods store	400	20	7	0
Total		*1,460*	*630*	*25*	*10*
Percentage reduction		*56.85%*			
Production quantity/day = 2,640 units					
From	*To*	*Total time consumed in material movement/day (mins.)*		*Process lead time (days)*	
		Before	*After*	*Before*	*After*
Injection moulding	Chrome plating	3	3	1.251	1.251
Chrome plating	Painting	72	75	1.170	1.170
Painting	Assembly	6	5	0.266	0.266
Assembly	Final inspection	11	0	2.449	2.448
Final inspection	Packing	77	0	0.310	0.306
Packing	Finished goods store	77	4	0.310	0.306
Total		*246*	*87*	*25*	*5.756*
Percentage reduction		*64.63%*		*0.173%*	

Figure 5 Objective (layout decision)



The respondents of the study were the decision makers from large-scale auto component manufacturers forming a homogeneous group in terms of their operations, scale, managerial experience and knowledge about layout modification methods. According to Auto Component Manufacturer Association report (https://www.acma.in/annual-report.php) of 2020, out of total 832 auto component manufacturers in India 30% firms (approx. 250 nos.) are large enterprises. Out of these 250 suppliers 132 (52.8%) agreed to be part of this study. One manager each from every firm participated in the study.

3.2.1 Ranking of attributes that influences a layout's selection (AHP model)

Responses from structured questionnaire designed on a pair-wise comparison scale involved both quantitative and qualitative criteria for rating by managers.

The results showed (Table 7) that out of three quantitative attributes distance to be traversed between two facilities is given maximum importance. Similarly, from three qualitative attributes decision makers considered cost of change as influencing their choice of evaluating a layout design. NLP model was formulated by using these criteria along with their weights.

Table 7 Weights assigned to each criteria w.r.t. four layout designs

	Distance	*Total time consumed in material movement/day*	*Process lead times*	*Cost of change*	*Accessibility of facilities*	*Flexibility*
FLP 1	0.23	0.17	0.10	0.21	0.16	0.13
FLP 2	0.20	0.16	0.15	0.22	0.13	0.14
FLP 3	0.17	0.19	0.18	0.14	0.15	0.17
FLP 4	0.20	0.18	0.14	0.24	0.14	0.10

3.3 NLP

This section provides results for a weighted NLP model formulated by using ranking weights of both quantitative and qualitative criteria. SLP results provided four feasible alternative layouts. NLP model would examine optimality for all these models. Objective function of the model is of maximising the performance of particular FLP under the maximum applicability of criteria. The performance measure of a criteria are examined on a scale of 0–1 where '0' implies least and '1' maximum performance. The notations used in this model are:

x_{mn} performance measure of *n*th criterion of *m*th FLP where *n* goes from 1 to 6 and *m* from 1 to 4.

w_n indicates weights assigned to each respective criterion.

So, performance measure relating to criteria and weights pertaining to FLP 1 would be:

x_{11} distance criterion with weight w_1

x_{12} total time consumed in material movement/day with weight w_2

x_{13} process lead time criterion with weight w_3

x_{14} cost of change criterion with weight w_4

x_{15} accessibility of facilities criterion with weight w_5

x_{16} flexibility criterion with weight w_6.

$$\text{Objective function:Maximise} \quad \sum_{n=1}^{6} w_n x_{nm} \quad \text{for } m = 1, 2, 3, 4$$

s.t.

$$\sum_{n=1}^{6} w^2{}_n = 1;$$

$$0 <= x = x_{nm} <= 1$$

This nonlinear model is solved by using Microsoft Excel Solver software package. The model with non-negative weights is solved for all four FLPs separately. Results pertaining to performance measure of criteria and objective function are shown in Table 8.

Table 8 Performance measures of different criteria w.r.t. four layout designs

	Distance	*Total time consumed in material movement/day*	*Process lead times*	*Cost of change*	*Accessibility of facilities*	*Flexibility*	*Objective function score*
FLP 1	0.257	0.365	0.403	0.584	0.311	0.286	0.3710
FLP 2	0.437	0.431	0.347	0.519	0.409	0.357	0.4257
FLP 3	0.325	0.421	0.361	0.524	0.374	0.205	0.3645
FLP 4	0.724	0.655	0.314	0.827	0.276	0.311	0.5748

The results of NLP model (Table 8) showed that objective function of maximising performance of an alternative layout was much better of FLP 4 (0.5748) than other three alternatives. The interpretation becomes more relevant by inferring the contribution of each individual criterion. Distance to be travelled (0.724) and time taken for material movement (0.655) between facilities rated much higher as compared to corresponding scores of other layout designs. FLP 1, FLP 2 and FLP 3 were not identified as good alternative designs due to its low rating primarily on these attributes. Importantly, cost of change was predominant (0.827) among all criterions in all layout designs and especially in FLP 4 implying that layout modification is considered as costly and time-consuming proposition.

4 Conclusions

The proposed approach in this study amalgamates qualitative and quantitative approach to layout design in a manufacturing facility. Such combination was lacking in the literature though few studies (Yang et al., 2000; Wen and Bai, 2015) have combined systematic sequential approach involving subjective criteria with mathematical algorithms. However, literature combining the advantages of SLP method with advanced quantitative tools was lacking. This study thus has intended to provide a wholesome approach by firstly finding alternative layout designs through procedural approach of SLP bringing in the human element of decision-making. Secondly, to examine optimality of identified alternatives both qualitative and quantitative criteria were identified and ranked by using AHP method. Lastly, by using these weights a mathematical optimisation model of NLP was formulated. Thus, this approach of SLP-AHP-NLP made study unique.

Informal interview and discussions with design experts of various auto component manufacturers revealed application of SLP method in layout modification. It was considered to be easy to understand and apply based on sequential approach and involving subjective judgement of decision makers. However, subjectivity does not provide consistent and scientifically robust outcomes. Thus, to mitigate effects of human factors research on layout design has tilted towards application of pure mathematical models like simulated annealing, fuzzy constraint theory, etc. Ease of computation with availability of software algorithms have also encouraged adoption of more scientific procedures. However, due to they being complex, difficult to comprehend and unyielding to experts' acumen are difficult to embrace. Due to these reasons especially lack of flexibility interviews highlighted lack of adoption willingness to such structured models. Thus, this study integrated benefits of both methods in order to provide an optimal layout design.

This study derived three prominent quantitative criteria by comparing key performance indicators (distance travelled, time consumed in such travel and process lead times between two processes) of four alternative designs (obtained from SLP) with those of existing layout. A significant improvement ensued their selection. Informal discussions also extracted major qualitative criteria (cost of change, accessibility and flexibility of facilities) on which decision makers intend to evaluate a layout design. Rating of all six criteria by AHP method indicated distance and cost of change being primary influencers. Weighted NLP optimisation model also signified that these attributes have a significant role in examining performance of proposed layout alternatives. Results of NLP were able to identify one most optimal alternative from feasible four derived from SLP.

4.1 Theoretical implications

As indicated by SLR of two primary databases of Scopus and WoS this study would have valuable contribution to literature on layout design. Though the review showed subject of layout modification to be actively researched with focus on both subjective and mathematical approaches, but, it lacked contribution on a specific aspect. Studies did not provided a complete integration from identifying of alternative designs to ranking evaluation attributes and lastly examine optimality of alternative by using a mathematical approach. Studies either have combined a sequential approach such as SLP with AHP or have entire focus on scientific algorithms by formulating layout design as a QAP model. This study thus intends to combine all three aspects in layout design and support extant literature.

4.2 Managerial implications

Short product life cycles have forced manufacturers to be agile to capricious requirements of customers. Flexibility and responsiveness inbuilt of layout design significantly reduces material handling cost and improves other measures of productivity such as transportation cost and lead-time (Brochner, 2017). Original equipment manufacturers in car industry have accrued benefits responsive layout designs. However, to achieve full potential they are encouraging suppliers in the entire supply chain to adopt these methods. Thus, approach of this study can be helpful to firms in large component industry in implementing layout standardisation process. Linking of subjective with scientific approach will prove beneficial in performance measures and managers can take cue from this study.

4.3 Future research

The study has limited its scope to understanding application of SLP as sequential approach in providing layout alternatives and AHP as multi-criteria decision-making tool. Future studies can apply and compare other such tools like TOPSIS, data envelopment analysis (DEA) and fuzzy decision-making. Furthermore, the study constrained its findings with only six criteria. Other criteria especially in qualitative category such as maintenance, management approval, etc. could be focussed on in solving layout design problem. The approach in this study applied to single floor layout without any scope for expansion. Future studies can examine appropriateness of it in multi-floor facility and with other constraints. This would provide generalisation to the proposed framework in its applicability to different facilities. Lastly, examine aptness of the approach by evaluating impact of performance of different alternative layout designs on productivity improvement. Role of layout in improving productivity of a shop floor would be further substantiated.

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