

## Minimization of Cellular Layout Complexity Index Using TRIZ

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**Abstract:** Industries consist of different types of layouts to meet dynamic demands for various production strategies. Layout formulation depends on the production requirements as job shop, flow shop or cellular manufacturing. The layout operation and performance in manufacturing systems is significantly influenced by layout complexity. Currently layout complexity index is obtained using mathematical techniques for different layouts. In this article a cellular layout is considered for minimizing layout complexity index. Theory of inventive problem solving (TRIZ) technique is implemented to reduce cellular layout complexity index without trading off automation and flexibility of the layout. Layout complexity assessment methodology is adopted for quantifying the layout complexity. Subsequently contradiction matrix and inventive principles of intermediary is applied to obtain the optimum solution. As a result the new layout is designed to achieve 27.80% of reduction in layout complexity.

**Key words:** Cellular Layout • Layout Complexity Assessment • Layout Complexity Index • TRIZ

### INTRODUCTION

The dynamic nature of market demands striving for proper layout design to achieve optimum productivity and profit. The competitive strategies of a firm are driven by flexibility and automation of the layout. Subsequently, this leads to an increase of complexity in layout. The entities are proposed [1] as facilities of machine tool, shop, work centre, manufacturing cell, department and warehouse. The redesign of layout is discussed [2] as time consuming and it hinders the workers activities and material flow considerably. The static complexity is defined as expected amount of information necessary to describe the state of a system. Similarly dynamic complexity depends on probability of resources being in a certain state and deviation from schedule due to uncertainty by measuring the difference between the actual and scheduled system performance [3]. Complexity is further defined [4] as a measure of uncertainty in achieving the specified Functional Requirements (FR) and also as a logarithmic function of probability of fulfilling functional requirement. In turn a heuristic was proposed [5] to quantify structural and operational system complexity based on series of system complexity metrics, it measure relationships between system components,

number of elements and complexity of each element. However, neither relative importance of individual metrics was discussed nor they combined into a single system complexity index. For multi-state mixed-model assembly systems and multi-echelon assembly supply chains the manufacturing complexity induced by product variety in assembly systems and supply chains, by generating models to characterize the propagation of complexity [6].

The investigation [7] focused on internal static manufacturing complexity, based on product line complexity, product structure and process complexity components. The measuring complication of complexity in layout was discussed due to lack of evident quantifiable elements. Further [8] revealed various complexities associated in technical system. The overall complexity of a system identified as inborn complication of customer needs and external constraints, acquired complexity associated with uncertainty in satisfying the functional requirements of design decisions. Subsequently [9] proposed chain type manufacturing system structural classification and coding system (SCC) for various types of equipment found in manufacturing systems that determines its structural complexity. Some more contributions to this domain were made by a number of authors [10-19].

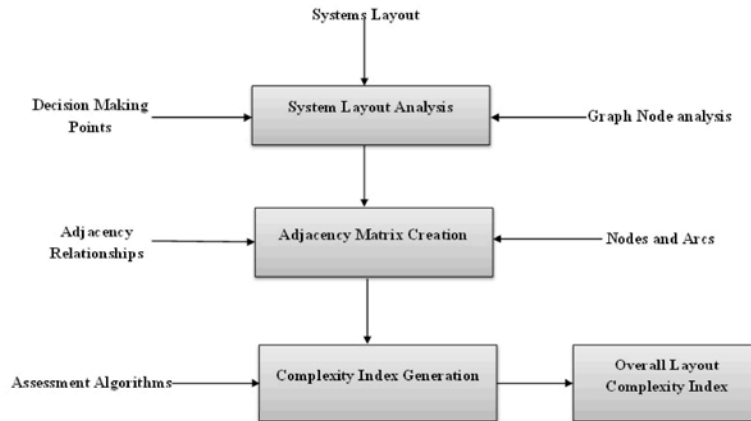


Fig. 1: Layout Complexity Assessment Model

Recently a new method of layout complexity assessment in manufacturing systems has introduced [20] for assessing structural complexity. In these work physical structural characteristics is proposed with six complexity indices in a layout. The indices include layout density, path, cycle, decision points, redundancy distribution and magnitude and used to calculate overall layout complexity index (LCI). This complexity makes a barrier of constraints to designer's vista hence tradeoff exists between automation and complexity. In this context this article focuses to develop various layout models and further reduce the layout structural complexity. Theory of Inventive Problem Solving (TRIZ) is used to optimize the contradicting factors. The subsequent chapters focus on layout complexity, TRIZ implementation, results discussion and conclusion.

**Layout Complexity Index:** The newly proposed layout complexity assessment model in manufacturing system [20] has five node layout and six indices. The layout complexity assessment model deals with the information flow, functional nodes and decision points between various departments along with input / output nodes. It also determines the method of decision making in these facilities. The assessment model mentioned in Figure 1, it consists of system layout analysis, adjacency matrix creation and complexity indices generation. System layout analysis is governed by graphical analysis, decision making points and manufacturing system layout. The layout is analyzed and a diagram is generated with nodes and arrows representing the decision making points and the connections in the system respectively. Adjacency matrix creation takes the inputs of system layout analysis, nodes & arcs and adjacency relationships. A layout adjacency matrix is created to represent nodes and relationships between them in the

diagram. In third step overall complexity indices generation is performed based on adjacency matrix creation, assessment algorithms and layout complexity index. An overall layout structural complexity index (LCI) has also been developed to combine the individual indices.

Layout complexity indices of density, paths, cycles, decision points, redundancy distribution and magnitude have separately quantified. The density index show how dense the system could be with the presence of nodes, arrows and redundancy. Path index describes the complexity associated with each path starting from initial to final node. Complexity associated with loops and cyclic paths described by cycle index. Decision point index exhibits the difficulty in assigning a particular path for a product especially for multiple product lines. The redundancy indices of Distribution and Magnitude deals with the distribution frequency, magnitude, pattern of redundant arrows and nodes. The density and number of decision point's indices in a layout correspond to number and location of joint interfaces between its modules. The paths, cycles, redundancy, distribution and magnitude indices capture the pattern of material flow between nodes. The model also reveals the practical capability of the system along with all its features.

The cellular layout of [20] and mentioned in Figure 2 is preferred for further complexity reduction.

In this layout A is a Washing Centre, B and C are the manufacturing centers and D and E are the Assembly Centers. Also there is an input node and two output nodes. The values of Individual complexity indices are calculated as

$$\text{Density Index, } D = \frac{k}{n(n-1)} \quad (1)$$

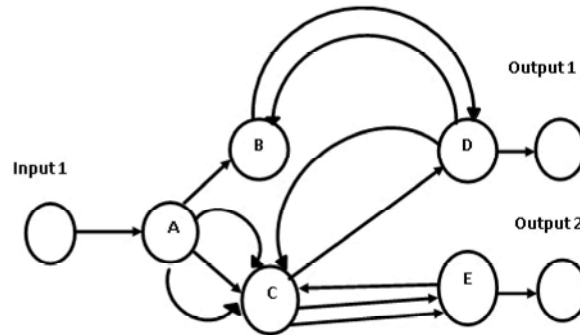


Fig. 2: Existing Layout

where '**k**' is the actual number of connections and '**n**' is the number of nodes.

$$\text{Path index, } P = 1 \frac{P}{N} \quad (2)$$

where '**p**' is the minimum theoretical number of paths and **N** is the number of existing paths calculated from the paths finder algorithm.

$$\text{Cycle Index, } CL = \frac{C}{MG} \quad (3)$$

where **C** is the actual number of cycles calculated from the cycles finder algorithm.

$$MC = \sum_{i=1}^n C_i^n \quad (4)$$

where **MC** is the theoretical maximum number of cycles and  $C_i^n$  is the combination of '**n**' nodes

$$\text{Decision Point Index, } DS = 1 - \frac{SP}{LP} \quad (5)$$

where **SP** is the number of nodes on the shortest path in the layout graph, representing the theoretical minimum number of decision points in one sequence and **LP** is the number of nodes on the longest path, representing the actual number of decision points in one sequence.

$$\text{Redundancy Distribution Index, } RD = \frac{r}{a} \quad (6)$$

where '**r**' is the number of locations where there are redundant arrows and '**a**' is the theoretical maximum number of locations in the graph representation where redundancy may exist.

$$\text{Redundancy Magnitude Index, } RM = \frac{pr}{w} = \frac{w - a}{w} \quad (7)$$

Where '**pr**' is the total number of redundant parallel arrows; '**w**' is the total number of forward arrows, representing the theoretical maximum number of redundant arrows, while '**a**' is the number of adjacent nodes.

$$\text{Overall layout Complexity Index, } LCI = \left( \sum_{i=1}^n C_i \right)^2 - \sum_{i=1}^n C_i^2 \quad (8)$$

where,  $C_i$  be the individual complexity indices

**TRIZ:** Theory of Inventive Problem Solving (TRIZ) was developed between 1950 and 1980 by the Russian patent expert and scientist Genrich Altshuller (1926-1998) along with his staff members. He determined that 90% of engineering problems posed had been solved somewhere else in very similar ways and by altering it can be used to solve a particular problem. He screened over 200,000 patents and observed that rather than seeking a trade-off, the most innovative solutions eliminated or resolved the contradiction. In contrast to the common "trial and error" problem solving methods such as brainstorming, lateral thinking etc., TRIZ only relies on the unbiased laws of evolution of technical systems and therefore enables a focused search for possible solutions [21-23]. TRIZ determines [24] problems and offers direct solutions along with confidence and consist of a set of conceptual solutions to technical problems. This set of solutions consists of various inventive principles; trends of technical evolution and standard solutions [24]. To apply any of these solutions the problem is reduced to its conceptual format. Now, the problem can be matched with one or more of the conceptual solutions. The identified conceptual solution can afterwards be transformed into a specific, factual solution that answers to the original problem. This is a distinctive feature of TRIZ, distinguishing it from other conventional problem solving methods [25].

In TRIZ Contradictions are mutually opposing requirements aroused in a system at a particular time as technical contradictions or physical contradictions. The TRIZ is implemented in this work based on contradiction matrix and inventive principles. This is a 39×39 matrix in which the 39 Engineering parameters like weight of moving object, speed, force, tension, pressure, shape etc. are arranged horizontally and vertically. It gives the possible solutions using 40 inventive principles. The ‘improving feature’ of the problem is given on one axis usually y axis, while the other axis give the ‘worsening features’. On the intersection cell of each improving feature and worsening feature, several reference numbers are given corresponding to the inventive principles which is to be used. There are altogether forty inventive principles includes segmentation, skipping, blessing in disguise, local quality, asymmetry, intermediaries etc. These principles are used to obtain the proper solution for the problem. Applying the principles obtained from the contradiction matrix creatively into the specific problem to achieve an innovative solution. Some times more than one solution is obtained. Then the designer has to choose the optimum solution according to his required criteria.

**New Layout Model:** The cellular layout mentioned in Figure 2 [20] selected for complexity reduction. TRIZ is implemented to develop various layouts using Intermediary principle. This problem can be solved by using the Contradiction Matrix with 39 engineering parameters. Further problem contradictions are identified, improving feature as extend of automation (38) and

worsening feature as device complexity (36). The number in the feature bracket shows corresponding number in the engineering parameters table. The intersection of 38<sup>th</sup> and 36<sup>th</sup> parameters gives a common cell in which certain numbers inscribed on it. Here the following inventive principles were obtained; Dynamics (15), Intermediary (24) and Preliminary Action (10). The number in the bracket shows the corresponding number among the forty inventive principles. Among these principles, intermediary principle instructs in using an intermediary carrier article or intermediary process holds good for reconfiguring the layout with less complexity. Dynamics principle usually applied to the problems related to moving objects and movement it has only feeble influence in the structural complexity of the layout and for an existing layout preliminary actions are not possible. Intermediary principle is applied over the existing layout, a buffer station ‘X’ is introduced between node ‘E’ and ‘C’. The buffers station ‘X’ serves to store products in the layout with minimum investment rather than a manufacturing cell. This buffer station makes ease the decision making process and influence the layout complexity.

## RESULTS DISCUSSION

The newly developed eight types of layout is analyzed to identify the minimum complexity index. The overall complexity is arrived using the Eq 8 and it is influenced by individual indices value. The complexity indices value for each model using Eq1 to Eq8 and mentioned in the Table 1. The detailed calculation for new layout of E→C mentioned in Figure 3 is as follows.

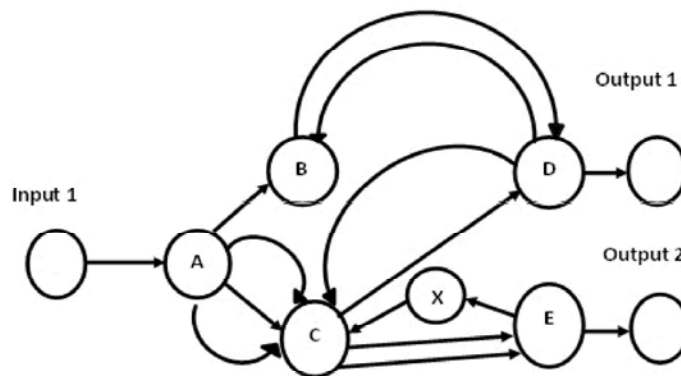


Fig. 3: New Layout

Similarly, intermediary principle applied to modify the existing layout for eight possible new layouts as between A→B, A→C, B→D, D→B, C→D, D→C, C→E and E→C.

Table 1: Complexity indices for different model

Layout Model → Index ↓	Complexity Indices Value 'c'							
	1 A→B	2 A→C	3 B→D	4 D→B	5 C→D	6 D→C	7 C→E	8 E→C
D	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
P	0.5	0.667	0.5	0.5	0.5	0.5	0.667	0.5
CL	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
DS	0.5	0.4	0.5	0.4	0.4	0.5	0.5	0.4
RD	0.33	0.33	0.33	0.33	0.33	0.33	0.167	0.33
RM	0.33	0.33	0.33	0.25	0.33	0.25	0.33	0.25
LCI	3.42	3.60	3.42	2.85	3.11	3.15	3.32	2.85

Table 2: Comparison of complexity of existing and new layout

Index	ElMaraghy. <i>et al.</i> , (2013)	Kanthavel and Hemanth Sivan (2014)
Density Index (D)	0.40	0.30
Path index (P)	0.33	0.50
Cycle Index (CL)	0.27	0.10
Decision Point Index (S)	0.40	0.40
Redundancy Distribution Index (RD)	0.40	0.33
Redundancy Magnitude Index (RM)	0.38	0.25
Overall layout Complexity Index (LCI)	3.95	2.85
LCI Reduction in %	Nil	27.80

- Density Index (D): number of connections 'k' (including input and output nodes) is 9, number of nodes 'n' is 6 and  $D = \frac{9}{6(6-1)} = 0.3$ .

$$= (0.3+0.5+0.1+0.4+0.33+0.25)^2 - (0.3^2+0.5^2+0.1^2+0.4^2+0.33^2+0.33^2) = 1.88^2 - 0.68 = 2.85$$

- Path index (P): minimum theoretical number of paths 'p' is 2, number of existing paths calculated is 'N' is 4 and  $P = 1 - (\frac{2}{4}) = 0.5$ .

- Cycle Index (CL): actual number of cycles calculated from the cycles finder algorithm 'C' is 6, theoretical maximum number of cycles 'MC' is 6,  $nC_i$  is 57,  $C_i^n$  is the combination of '6' nodes and  $CL = \frac{6}{57} = 0.1$ .

- Decision Point Index (DS): number of nodes on the shortest path in the layout graph 'SP' is 3, the number of nodes on the longest path 'LP' is 5 and  $DS = 1 - (\frac{3}{5}) = 0.4$ .

- Redundancy Distribution Index (RD): number of locations for redundant arrows 'r' is 2, theoretical maximum number of locations in the graph representation for redundancy exist 'a' is 6 and  $RD = \frac{2}{6} = 0.33$ .

- Redundancy Magnitude Index (RM): total number of redundant parallel arrows 'pr' is 3, total number of forward arrows 'w' is 9, number of adjacent nodes 'a' is 6 and  $RM = \frac{3}{9} = 0.33$ .

- Overall layout Complexity Index (LCI)

$$= (\sum_{i=1}^n C_i)^2 - \sum_{i=1}^n C_i^2$$

The Complexity indices for different model mentioned in the Table 1 reveals the overall complexity index under various layout modifications. The existing layout model based on (ElMaraghy. *et al.*, 2013) is having LCI of 3.95. In this new layout, two insertions of D→B and E→C have produced lowest complexity value of 2.85 and complexity is reduced about 27.8%. The Comparison of complexity of existing and new layout is presented in Table 2.

## CONCLUSION

A good layout design is an inevitable aspect for any industry. But now a days the facility complexity increases considerably with increasing flexibility demands or automation factors. The significance of complexity reduction is really a need of the hour as the scientific world has not given much attention to it. Here through this endeavor it can be inferred that the complexity can be reduced considerably (about 27.8%) by the application of TRIZ and once again proved that it is sound tool for overcoming the technical contradictions. The prime objective of reducing complexity is achieved without any sacrifice on flexibility. The new layout is very much feasible since it can be incorporated with very little changes and of course with very less time and money. This approach can be extended to other layouts too for

reducing complexities. Also if the problem definition is somewhat different then inventive principles and obtained solutions could be different.

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