Journal of Engineering Technology
Volume 6, Special Issue on Technology Innovations and Applications
Oct. 2017, PP. 1-10
ORIGINAL ARTICLE

Analyzing manufacturing systems for their effectiveness

Ram Prakash[1], Sandeep Singhal[2], Ashish Agrawal[3]

[1]Research scholar Mechanical Engineering Department, NIT Kurukshetra, Kurukshetra, Haryana India
[2]Associate Professor Mechanical Engineering Department NIT Kurukshetra, Kurukshetra, Haryana India
[3]Associate Professor Mechanical Engineering Department School of Engineering & Technology, IGNOU New Delhi, India

Abstract: Introduction. The effectiveness of a manufacturing system is defined by its ability to transform the input resources into output products using flexible, lean and agile approach in order to sustain in global market without losing the manufacturing competency. One of the difficulties in designing and analyzing a manufacturing system is that its processes are governed by its strategic attributes. **Methodology.**
In order to evaluate the effectiveness of the manufacturing system, an Analytic Network Process (ANP) - based model is developed. **Results and Conclusion.** The ANP-based model for evaluation of manufacturing system effectiveness is illustrated with the help of an example of case company involved in heavy industry business. For the case company, the ANP framework suggests Agile manufacturing system as the most effective manufacturing system followed by Lean manufacturing system and Flexible manufacturing system The framework is an effective tool for analyzing the effectiveness of a manufacturing system. It provides the decision methodology to prioritize these enablers to formulate strategy for top management of the case company to improve the effectiveness of the manufacturing system.

Keywords: Manufacturing System, Flexibility, Effectiveness

Introduction.

In a globally-competitive economy, enterprises must pay continuous attention to increase responsiveness to the changes in customer demand in order to have competitive advantage over their rivals. As part of this constant review and search for manufacturing system effectiveness (MSE) has become an area of study, since it governs flow of material, movement of man power, flow of information, and flow of money in the form of input. Evaluating effectiveness of a manufacturing system is increasingly recognized as a tool for gaining competitive success. Today, lot of new manufacturing technologies is coming into the market. The purpose of this paper is to present a framework for analyzing manufacturing systems for their effectiveness. For this the analytic network process (ANP) approach has been adopted. By using ANP, the influence of various effectiveness determinants and dimensions on the manufacturing system is evaluated. The process also explicitly considers the influence of these effectiveness enablers on one another. These systemic relationships more accurately portray the true linkages and interdependencies of the various determinants [15].

Manufacturing system effectiveness

Survival of any manufacturing company in the global market depends on the effectiveness of its Manufacturing system. From the literature, Flexible manufacturing system (FMS), cellular manufacturing system (CMS), leagile manufacturing system (LaMS), agile manufacturing system (AMS), and lean manufacturing system (LMS) have been considered for analysis of their effectiveness. In the present research work, after having four to five meetings with experts of the case company, only three MSs have been shortlisted for the modeling of manufacturing system effectiveness. These are Agile manufacturing system (AMS), and Lean manufacturing system (LMS) and Flexible manufacturing system (FMS). In the most of the industries, the raw materials cost, material transportation cost and component parts cost, constitutes the major portion of the product cost which might be up to 70% [6]. In such type of situations, the effective MS can play a very significant role in the optimization of overall cost. The selection of the most effective MS is one of the important decisions to be taken by the top management. Quality, cost, lead-time, and service level have been identified as four prime performance measures in context to supply chain management [4]. The four performance measures have been categorized as "market qualifier" and "market winner" in a supply chain and. For an agile supply chain, service level is the market winner, while the other factors are market qualifiers. In case of lean supply quality, lead-time and service level are market qualifiers and cost is the market winner [1]. With changed objectives, the "qualifier" and "winner" factors may change positions. In the present research work, three performance measures lead time, cost and service level have been considered as performance measures for the effectiveness of a manufacturing system. Market sensitiveness (MS), Flexibility (FL), and Waste minimization (WM) have been identified as dimensions of manufacturing system effectiveness.

MS implies quick response to real demand. It is characterized by six measures [2,8]: delivery speed (DS), delivery reliability (DR), new product introduction (NPI), new product development time (NPDT), manufacturing lead-time (MLT), and customer responsiveness (CR). Higher values of DS, DR, NPI and CR or lower values of NPDT and MLT make the supply chain more sensitive towards market forces. FL in manufacturing system involves the use of multiple product line (MPL), cross functional workers (CFW) and use of upgraded technology (UUT). This enables the manufacturing system to become demand driven. WM involve the use of information technology (UIT), Predictive maintenance (PM) and training (TR). In the context of SCM, investments in shared or compatible high technology, investments in shared or compatible manufacturing systems (such as MRPII systems) and common approaches to cycle time reduction are the kinds of routes that may be taken to improved performance[11,12]. The prime focus of agile is on the individual customer. Some parameters are exhorted from lean. One such example includes refinement of mass production in which unilateral producer centered customer-responsive is established. This has been developed as interactive producer-customer relationships in agile [5, 9, and 13].What follows constitutes a framework for considering such alternative approaches to the effective manufacturing system. The measuring of effectiveness in a MSs using the combined approach of analytical network process (ANP) with graph theoretic and matrix approach (GTMA) leading to single numerical index[7]. Some authors developed an integrated approach based on the algorithm and mathematical programming for the cell formation problem (CFP) considering the issues [10,14].The ANP method have applied ANP to analyze the alternative to improve online trust in e-business [3].

The decision environment of ANP

The analytic hierarchy process (AHP) introduced [14] for choosing the most suitable alternative, which fulfils the entire set of objectives in a multi-attribute decision-making problem. The ANP is a more general form of AHP, incorporating feedback and interdependent relationships among decision attributes and alternatives. This provides a more accurate approach when modeling a complex decision environment [15]. The process is designed to provide a holistic approach in which all the factors and criteria involved are laid out in an AHP or in an ANP system that allows for dependencies. All possible outcomes that can be thought of are joined together in these structures and then both judgment and logic are used to estimate the relative influence from which the overall answer is derived. A graphical summary of the ANP model and its decision environment related to manufacturing system effectiveness as shown in Figure 1. The overall objective is to improve the effectiveness of manufacturing system: as an illustration we have considered three criteria are lead time, cost and service level.

ANP Framework application

The ANP methodology is applied to the illustrative manufacturing system effectiveness problem as follows:

Step 1: Model construction and problem structuring: The top most elements in the hierarchy of criteria are decomposed into sub-criteria and attributes. This development of the model requires the identification of attributes at each level and a definition of their inter-relationships. The ultimate objective of this hierarchy is to identify the alternatives that will be most significant in improving the effectiveness of manufacturing system.

Step 2: Pair-wise comparison matrices between component/attribute levels: On a scale of zero to nine, the decision-maker is asked to respond to series of pair-wise comparisons with respect to an upper level "control" criterion. These are conducted with respect to their relative importance towards the control criterion. In the case of interdependencies, components within the same level are viewed as controlling components for one another. Levels may also be interdependent. Through pair-wise comparison between the applicable attribute enablers of performance dimension cluster, the weighted priority (e-Vector) is calculated [14]. For example, Table I presents the comparison matrix used to assess the relative influence of a particular dimension cluster (delivery speed, new product introduction and customer responsiveness – which is the cluster of attributes of market sensitiveness) on lead-time.

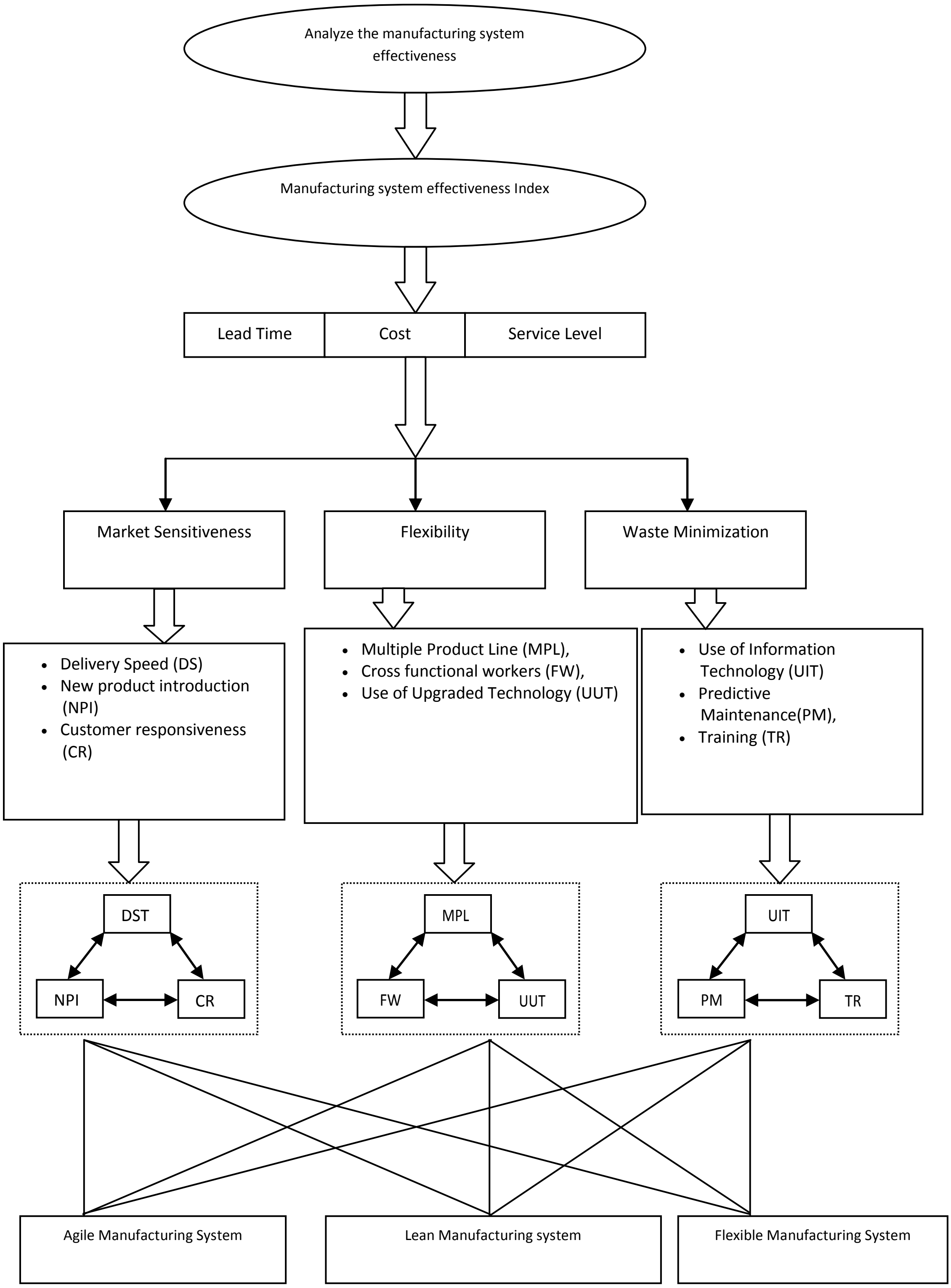

Figure 1: ANP based model for effectiveness of manufacturing systems

Table 1 Pair-wise comparison matrix for Market sensitiveness under Lead time determinant

	Lead time			
Market sensitiveness	Delivery speed (DS)	New product introduction (NPI)	Customer responsiveness (CR)	e-Vector
DS	1	6	4	0.69
NPI	0.167	1	0.33	0.09
CR	0.25	3	1	0.22

Similarly, comparison matrices for other factors/enablers are prepared and the resultant e-Vectors are imported as A^{D}_{kja} in Table II. When determining weightings an illustrative question is: "What is the relative impact on market sensitiveness of attribute enabler, a, when compared with attribute enabler, b, in terms of reducing lead time?"

Additional pair-wise comparison matrices are required for the relative importance of each of the dimensions of MSE clusters (MS, FL and WM) in determining MSE. Results are shown as Pja in the second column of Table II.

The final standard pair-wise comparison evaluations are required for the relative impacts of each of the factors for MSE improvement. (Obviously, the number of pair-wise comparison matrices is dependent of the number of MSE attribute enablers that are included in the MSE improvement hierarchy. There are nine pair-wise comparison matrices required at the level of relationship we have selected for our example.)

Table II Lead time desirability indices

Dimension	P_{ja}	Attributes	A^{D}_{kja}	A^{I}_{kja}	S1	S2	S3	**AMS**	**LMS**	**FMS**
MS	0.32	DS	0.69	0.45	0.29	0.57	0.14	0.029	0.057	0.014
MS	0.32	NPI	0.09	0.17	0.29	0.57	0.14	0.001	0.003	0.004
MS	0.32	CR	0.22	0.38	0.29	0.57	0.14	0.008	0.015	0.002
FL	0.1	MPL	0.61	0.44	0.51	0.36	0.13	0.014	0.01	0.004
FL	0.1	CFW	0.26	0.38	0.51	0.36	0.13	0.005	0.002	0.001
FL	0.1	UUT	0.13	0.18	0.51	0.36	0.13	0.001	0.0004	0.0003
WM	0.58	UIT	0.57	0.42	0.51	0.36	0.13	0.058	0.021	0.018
WM	0.58	PM	0.24	0.33	0.51	0.36	0.13	0.023	0.016	0.007
WM	0.58	TR	0.19	0.25	0.51	0.36	0.13	0.014	0.051	0.0036
Total desirability indices								**0.153**	**0.129**	**0.0538**

Step 3: Pair-wise comparison matrices of interdependencies: To reflect interdependencies in the network, pair-wise comparisons among all the attribute enablers are conducted. Table III illustrates one such case. Market sensitiveness has three sub-factors: DS, NPI and CR. The previous set of comparisons examined how there sub-factors influenced the main factor: now we are examining how each influences the other – the interdependencies. For brevity the final scores of this and the remaining matrices are shown in Table IV.

Table III Pair-wise comparison matrix for enablers under market sensitiveness, lead time and delivery speed

Delivery speed (DS)	NPI	CR	e-Vector
New product introduction (NPI)	1	0.33	0.25
Customer responsiveness (CR)	3	1	0.75

Step 4: Supper matrix formation and analysis: Table IV shows super matrix M, detailing the results of the relative importance measures for each of the attribute enablers for the lead-time determinant of MSE clusters. Since there are nine pair-wise comparison matrices, one for each of the interdependent MSE attribute enablers in the lead-time hierarchy, there will be nine non-zero columns in this super matrix. Each of the non-zero values in the column in super matrix M is the relative importance of the interdependency of two sub-factors. In this example-with three main factors – there are three super matrices, one for each of these main factors, which need to be evaluated.

Journal of Engineering Technology
Volume 6, Special Issue on Technology Innovations and Applications
Oct. 2017, PP. 1-11
ORIGINAL ARTICLE

The super matrix (Table IV) is "converged" in order to arrive at a long-term stable set of weights, in this process; the super matrix is raised to an arbitrarily large power – until the entries are stable. In our illustrative example, convergence is reached at the power of 31. Table V shows the value after convergence.

Step 5: Selection of best alternative

The equation for desirability index, D_{ia} for factor i and determinant a, is defined as (Meade and Sarkis, 1999):

$$D_{ia} = \sum_{j=1}^{J} \sum_{k=1}^{Kja} P_{ja} A^{D}{}_{kja} A^{I}{}_{kja} S_{ikja} \qquad (1)$$

where P_{ja} is the relative importance (weight) of dimension j on the determinant a, $A^{D}{}_{kja}$ is the relative importance (weight) for attribute enabler k, dimension j and determinant a for the dependency (D) relationships between the enabler's component levels, $A^{I}{}_{kja}$ is the stabilized relative importance weight for attribute enabler k of j dimension in the determinant a for interdependency (I) relationships within the attribute enabler's component level, S_{ikja} is the relative impact of factor i on attribute enabler k of dimension j of determinant a, K_{ja} is the index set of attribute enablers for dimension j of determinant a, j is the index set for the dimension *j*.

Table IV Super matrix M for the lead-time enablers before convergence

Super matrix lead-time		MS			FL			WM	
	DS	NPI	CR	MPL	CFW	UUT	UIT	PM	TR
DS	0.00	0.8	0.857						
NPI	0.25	0.00	0.143						
CR	0.75	0.2	0.00						
MPL				0.00	0.75	0.83			
CFW				0.8	0.00	0.17			
UUT				0.2	0.25	0.00			
UIT							0.00	0.67	0.8
PM							0.67	0.00	0.2
TR							0.33	0.33	0.00

Table II shows the calculation for the desirability indices ($D_{i\ lead\ time}$) for various alternatives is based on the lead time control hierarchy by using the weights obtained from the pair-wise comparisons of the alternatives, dimensions and weights of enablers from the converged super matrix. These weights are used to calculate a score for the determinant of effectiveness of the manufacturing system desirability for each of the alternatives being considered.

Journal of Engineering Technology
Volume 6, Special Issue on Technology Innovations and Applications
Oct. 2017, PP. 1-11
ORIGINAL ARTICLE

The second column in Table II is the results from step 2, which are obtained by comparing the relative impact of each of the dimensions on the lead time determinant. The pair-wise comparison matrix for the relative impact of the attribute enablers on the dimensions of MSE is presented in the fourth column. The values in the fifth column are the stable interdependent weights of attribute enablers obtained through super matrix convergence. The relative weight of three alternatives for each dimension are given in the sixth, seventh and eighth columns of Table II. These weights are obtained by comparing three alternatives for every dimension of MSE. The final three columns represent the desirability index ($P_{ja}\ A^{D}_{kja}\ A^{Ikja}\ S_{ikja}$) of each alternative for attribute enablers. For each of the alternatives under lead-time determinant, the summation of these results appears in the final row of Table II.

Table V Super matrix after convergence

Super matrix lead-time	DS	MS NPI	CR	MPL	FL CFW	UUT	UIT	WM PM	TR
DS	0.45	0.45	0.45						
NPI	0.17	0.17	0.17						
CR	0.38	0.38	0.38						
MPL				0.43	0.43	0.43			
CFW				0.39	0.39	0.39			
UUT				0.18	0.18	0.18			
UIT							0.42	0.42	0.42
PM							0.33	0.33	0.33
TR							0.25	0.25	0.25

Step 6: Calculation of Manufacturing system effectiveness weighted index (MSEWI)

Table VI represents pair-wise comparisons of MSE determinants. The results show that the lead-time determinant (Ca = 0.55) as most important for manufacturing system effectiveness improvement. The result indicates that the business enterprise should focus on reducing the lead-time of the whole manufacturing system. The MSEWIi for a factor i is the product of the desirability indices (Dia) and the relative importance weights of the determinants (Ca) of the MSE. The final results are shown in Table VII.

Table VI Pair-wise comparison matrix for the relative importance of the determinants

Determinant	Lead time	Cost	Service level	e-Vector
Lead time	1	2	4	0.55
Cost	0.5	1	0.33	0.17
Service level	0.25	3	1	0.28

Table VII Overall weighted index for alternatives

Alternatives	Weight			Manufacturing system effectiveness weighted index (MSEWI)
	Lead time	Cost	Service level	
	0.55	**0.17**	**0.28**	
AMS	0.153	0.1237	.1422	0.125
LMS	0.129	0.1312	0.1724	0.118
FMS	0.0538	0.0302	0.0983	0.049

Table VII indicates that, for the case company, the ANP framework suggests Agile manufacturing system as the most effective manufacturing system followed by Lean manufacturing system and Flexible manufacturing system.

Discussion and conclusion

The ANP-based model is presented in this paper as an aid to the decision-makers in analyzing manufacturing systems on the basis of their effectiveness. A manufacturing system governs flow of material, movement of man power, flow of information, and flow of money in the form of input. Effectiveness of the manufacturing system is affected by product quantity, product processing time, product delivery and after sales service [16]. An effective manufacturing system helps an enterprise to gain market share and to sustain in a global competitive market. With the help of literature review and interaction with experts from the case company enablers influencing the effectiveness of a manufacturing system have been identified. The enablers have been categorized in determinant and dimensions. There are enablers under each dimension which have interdependence with each other. The model and method allow the consideration of a range of criteria, enablers and alternatives. The ANP approach captures their relationships and interdependencies. It is particularly effective, as both quantitative and qualitative characteristics can be considered simultaneously without sacrificing their relationships [7]. With the help of ANP approach, three manufacturing systems have been prioritized on the basis of their effectiveness. For the case company, the ANP framework suggests Agile manufacturing system as the most effective manufacturing system followed by Lean manufacturing system and Flexible manufacturing system [1,4,7,8,11]. The result helps the management of the case company in taking decision for selecting the appropriate manufacturing system to meet the global challenge. The result obtained from the ANP framework is valid for the problem of the case company and hence cannot be generalized. The barriers of manufacturing system effectiveness have not been considered. The framework has been developed with eighteen variables. The complexity of the ANP framework increases with increase in the number of variables. The solution for ANP framework with large number of variables can be obtained with the help of software.

References

[1] Agarwal A., Shankar R., and Tiwari M.K., (2006), Modeling the Metrics of Lean, Agile and Leagile Supply Chain: An ANP-based Approach, European Journal of Operational Research, (Elsevier Press), Vol. 173, pp. 211-225.
[2] Agarwal A., Shankar R., and Tiwari M.K., (2007), Modeling Agility of Supply Chains, Industrial Marketing Management, Vol. - 36, pp. 443-457.
[3] Agarwal A., and Shankar R., (2003), On-line Trust Building in E-enabled Supply Chain, Supply Chain Management: An International Journal, (MCB Press, U.K.), Vol. 8 No. 4, pp.324-334.
[4] Christopher, M. and Towill, D.R. (2000), "Supply chain migration from lean and functional to agile and customised", Supply Chain Management: An International Journal, Vol. 5 No. 4, pp. 206-213.
[5] Cochran DS et. al (2016) Use of the Manufacturing System Design Decomposition for Comparative Analysis and Effective Design of Production Systems. International Journal of Production Research.;pp 24
[6] Ghobadian, A., Stainer, A. and Kiss, T. (1993) 'A computerized vendor rating system', Proceedings of 1st International Symposium Logistics, pp.321–328.
[7] Goyal, S. and Grover, S. (2013) 'Manufacturing system's effectiveness measurement by using combined approach of ANP and GTMA', International Journal of System Assurance Engineering and Management, December, Vol. 4, No. 4, pp.404–423.
[8] Jayaram, J., Vickery, S.K. and Droge, C. (1999), "An empirical study of time-based competition in the North American automotive supplier industry", International Journal of Operation & Production Management, Vol. 19 No. 10, pp. 1010-33.
[9] Joseph Timothy Foleya et. al (2017) " Manufacturing System Design Decomposition: An Ontology for Data Analytics and System Design Evaluation", 27th CIRP Design Conference, Procedia CIRP vol. 60, pp.175– 180.
[10] Levenshtein, V.I. (1996) 'Binary code capable of correcting deletions insertions and reversals', Soviet Physics Docklady, Vol. 10, no. 8,pp.707–710.
[11] Mason-Jones, T.D.R. (1999), "Total cycle time compression and the agile supply chain", International Journal of Production Economics, Vol. 62, pp. 61-73.
[12] Meade, L. and Sarkis, J. (1999), "Analyzing organizational project alternatives for agile manufacturing process: an analytical network approach", International Journal of Production Research, Vol. 37 No. 2, pp. 241-61.
[13] Mittal, V.K., Sindhwania, R., Kalsariyaa, V., Salrooa, F., Sangwanb, K.S., and Singh., P.L., (2017)" Adoption of Integrated Lean-Green-Agile Strategies for Modern Manufacturing Systems", The 24th CIRP Conference on Life Cycle Engineering, Procedia CIRP ,Vol. 61 ,pp. 463 – 468.
[14] Saaty, T.L. (1980), The Analytic Hierarchy Process, McGraw-Hill, New York, NY.
[15] Saaty, T.L. (1996), Decision Making with Dependence and Feedback: The Analytic Network Process, RWS Publications. Pittsburgh, PA.
[16] Solimanpur, M. and Foroughi, A. (2011) 'A new approach to the cell formation problem with alternative processing routes and operation sequence', International Journal of Production Research, Vol. 49, no. 19, pp.5833–5949