Selection of Manufacturing System Based on Their Effectiveness During Covid-19 Pandemic

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ABSTRACT

Manufacturing system effectiveness is the ability of a manufacturing system to process the input resources and convert them into output products to sustain in the global market without losing the manufacturing competency. The effectiveness of a manufacturing system gets affected due to disruption caused by the Covid-19 pandemic. The case company's management has a problem selecting a manufacturing system whose effectiveness remains unaffected in the disruption caused by Covid-19.

An Analytical Network Process (ANP) framework has been developed to select an alternative manufacturing system As a multi-criteria problem.

The ANP-framework for the case company involved in heavy industry business is developed. There are three alternative Manufacturing Systems whose effectiveness depends on various inter-dependent criteria. Based on an effectiveness index obtained from the ANP framework, it favors M1 as the most effective manufacturing system, followed by M2 and M3.

Keywords: Manufacturing System, Flexibility, Effectiveness, Covid-19

1. Introduction

The manufacturing sector plays a significant role in the growth of any nation. The manufacturing sector is also searching for the latest technology to meet customer demand with the lowest price and highest quality in the fluctuating situation. The outcome of a manufacturing system depends on its effectiveness. The effectiveness of any manufacturing system depends upon the various issues which are interdependence to each other. In the present scenario, lockdown is going on at a global level. The main focus is on adaptability to changes in a highly competitive environment and proactively addressing the market and needs of customers. The change in the business environment due to customers' fluctuating demands tends to uncertain in the decision-making. A framework is developing in the chapter for the determination of the effectiveness index. In this model of framework, flexibility (F.L.), Agility (A.L.), and Leanness (L.N.) measure the manufacturing system effectiveness. It explores the relationship between lead time, service and quality of a case company in the automotive sector. The model brings out the justification of this framework which analyzes the influencing issues on manufacturing system effectiveness. In this study, three types of manufacturing systems are considered as Manufacturing system 1 (M1), Manufacturing system 2 (M2) and Manufacturing system 3 (M3).

2. Selecting Alternative Manufacturing Systems M1, M2 and M3: An ANP-based framework

Manufacturing sectors are paying more

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attention to maintaining the competitive advantage over their rivals and fluctuating customer demand. A prominent feature of the business in the present scenario is the idea that the manufacturing system competes in the market. Any manufacturing system's success and failure are evaluated by the end-user of the product in the market. The success and failure of a product depend on single issues, but it depends on various issues. Introducing the right product for the customer targets competitive success and an essential factor to sustainability. Hence, marketplace understanding and satisfaction of customers are the factor in establishing the manufacturing system's strategy. Significant interest has been shown that manufacturing system effectiveness influences various issues. The focus of the flexibility approach has mainly been on adaptability to any change. The concept of flexibility works well when demand is uncertain and changing from time to time. When demand is high and the variety of products is more level of agility is the real challenge. The concept of lean in the manufacturing system has mainly been on the removal of wastage. The advancement of technology is growing at a high rate, and manufacturing sectors need a strategic approach for analyzing the problems in a complex system. The manufacturing sector is also searching for the latest technology to meet customer demand with the lowest price and highest quality. The objective of the present work is to select an alternative manufacturing system using an ANP framework. In the ANP framework, various effectiveness determinants and dimensions of the manufacturing system effectiveness have been compared. The framework considers the interdependence among these effectiveness enablers. These comparative analyses portray the correct linkages and interdependencies of the various enablers. The planning of material is one of the critical issues in a manufacturing system; if material planning is not well, it may influence its effectiveness.

3. Manufacturing System Effectiveness

The case company involved in the heavy industry business wants to improve their competitiveness in the global world. The case company's decision-making authority wants to adopt a manufacturing system with good effectiveness in a situation of Covid-19. The management of the case company has Manufacturing system-1 (M1), Manufacturing system-M2), and Manufacturing system-3 (M3) as the three alternate manufacturing systems. Only three M.S.s have been identified for modeling manufacturing system effectiveness in the present research work, after having a literature review and after four to five meetings with the case company's experts. In the turbulent world type of situations, the effective manufacturing system can play a significant role in optimizing overall cost. The most effective manufacturing system is one of the crucial decisions to be taken by the top management. Lead-time, quality, service level and cost have been identified as performance measures in context to managing the linkages in any system (Christopher et al., 2000, Olhager, J.,1993). With changed objectives, the "qualifier" and "winner" factors may change positions. In this research work, three performance measures, lead time, quality, and service level, have been considered performance measures for a manufacturing system's effectiveness. Flexibility (F.L.), Agility (A.G.) and Leanness (L.N.) have been shortlisted as manufacturing system effectiveness dimensions.

F.L. implies the ability of the system to respond as per market demand. It is characterized by four measures (Koupaei et al., 2016): Materials Planning (M.P.), Capacity Planning (C.P.), Materials Management (MM) and Shop floor control (SFC). A.G. implies the ability to effectively responding to rapidly unexpected changes in the manufacturing system. It is characterized by three measures (Yaghoubi et al., 2010): sensing, perceiving and anticipating changes (SPA), immediate reaction to changes (IRC) and Recovery from changes (RFC). L.N. implies the systematic method for minimization of the wastes in manufacturing system. seven measures characterize it: Overproduction (O.P.), Inventory (IN), Transportation (T.P.), unnecessary movement (U.M.), Waiting (W.T.), Defective outputs (D.O.), and Over processing (OPc).

Nowadays, customers want the various products with the lowest price and good quality. To meet these challenges manufacturing companies need to have agile performance (Foley et al., 2017; Mittal et al., 2017; Meade et al., 1999; Mason et al.,1999; Goyal et al., 2013; Levenshtein, 1996, Venkata R, 2008).

4. Issues Influencing Manufacturing System Effectiveness

From the literature review, case study, opinion from industry and academician, three determinants have been shortlisted as- Lead time, Quality and Service level.

Further from the literature review, case study, opinion from industry and academicians, the barriers influencing the manufacturing system effectiveness have been shortlisted: Flexibility, Agility and Leanness.

Further from the literature review, case study, opinion from industry and academician, the issues influencing flexibility has been shortlisted are material planning (M.P.), Capacity planning (C.P.) and material management (MM).

From the literature review, case study, opinion from industry and academician, the issues influencing agility has been shortlisted are Sensing Perceiving and anticipating changes (SPA), Immediate Reaction to Change (IRC), and Recovery from Change (RFC).

From the literature review, case study, opinion from industry and academician, the issues influencing Leanness has been shortlisted are Over Production (O.P.), Unnecessary Movement (U.M.) and Defective output (D.O.).

5. Decision Environment for Modeling Metric of Manufacturing System Effectiveness

Saaty introduced the concept of AHP for evaluating the most appropriate alternative out of various available alternatives. The appropriate alternative fulfills the entire set of aims in an MCDM problem. AHP allows a set of complex or conflicting influencing issues to be compared with the weightage of each issue compare to its effect on the problem's outcome. ANP is a more generalized form of AHP, including feedback and interdependency relationships between decision variables (Meade et al., 1997; 1999). The modeling result obtained from ANP is more accurate for the complex environment of decision. This approach is designed to consider all the factors and criteria involved that permit the inter-dependency in the system. All probable outcomes that can be observed are joined together in this structure and then evaluate the relative influence from both logical and judgmental.

ANP based framework consider in this case for the selection of best alternatives (Meade et al., 1999). Facts for the selection of ANP based framework as follows:

- Analyzing the manufacturing system's effectiveness is an MCDM problem.
- Various issues, criteria and enablers in the case of the decision-making environment are interdependent to each other.
- Out of these, some of the enablers, dimensions, and criteria are subjected to simple weightage is challenging to achieve.

5.1 Deriving the Interdependence in Manufacturing System Effectiveness

The framework has been developed by considering the interdependence between different manufacturing system levels through the opinion of experts from industry-academic and review of literature on manufacturing systems, which incorporates in the network. Experts involved in providing the response having more than five years of association in the manufacturing system. The experts group consists of four to five. The respondents were made aware of alternative paradigms before capturing the relative weights. Case company selected for study is involved in manufacturing of auto sector, FMCG sector and electronic sector etc. Management of the case company is not very clear to decide which manufacturing system should be given top priority due to influencing effectiveness.

A graphical representation of the ANP model based on the decision environment and related to the manufacturing system effectiveness presented in Figure 1.

5.2 Enablers of Mutual Interdependence

The framework's overall objective is to prioritize the three manufacturing systems based on their effectiveness, which is the measurement of flexibility in meeting volatile market demand. Reduction in lead time, improvement in quality and enhancement in service level are the proposed framework determinants. These determinants dominate the identified dimensions in the framework. The impact of a determinant on manufacturing system effectiveness is affected by other determinants. Saaty (1980) suggested a scale of 1 to 9 for comparison of two elements. On the scale of 1to 9, 1 indicates that equal impact and 9 indicate a strong impact of row element compared to column element. Suppose experts feel that the column element has a more substantial impact than that of the row element, then reciprocal of number from 1 to 9 to be assigned accordingly (Saaty, 1996). Using pair-wise comparison on a scale of 1 to 9, the relative importance of a determinant over other determinants is obtained (Agarwal et al., 2006) and presented in Table 1. The values of relative importance of determinants have been obtained with the help of expert's opinions. The enablers in the framework assist in controlling the dimensions of manufacturing system effectiveness. These enablers are dependent on the dimensions and also have interdependency among them. Enablers under the dimension "Agility" are interdependent to some degree with each other. The interdependencies at various levels of the control hierarchy and interdependencies that are inherited among various hierarchies have been captured in ANP.

5.3 Capture of Relative Weight

For the matrices of ANP, while making a pair-wise comparison of the variables, their relative weights have been obtained by discussion with a group of case company experts. The experts' group consisting of industry experts, academicians from the area of manufacturing sector. For evaluating the relative weight in Table 1, the expert group was asked to respond to various questions. A question will be "What is the impact on lead time towards manufacturing system effectiveness when material planning is compared to capacity planning?". The response "6" in this regard is incorporated in the 2nd row of Table 1.

Table 1: Matrix Showing Comparison Between Flexibility Enablers for Reduction in Lead Time

	Lead time			
Flexibility	**Material Planning (M.P.)**	**Capacity Planning (C.P.)**	**Material Management (MM)**	**e-Vector**
MP	1	6	4	0.69
CP	0.167	1	0.33	0.09
MM	0.25	3	1	0.22

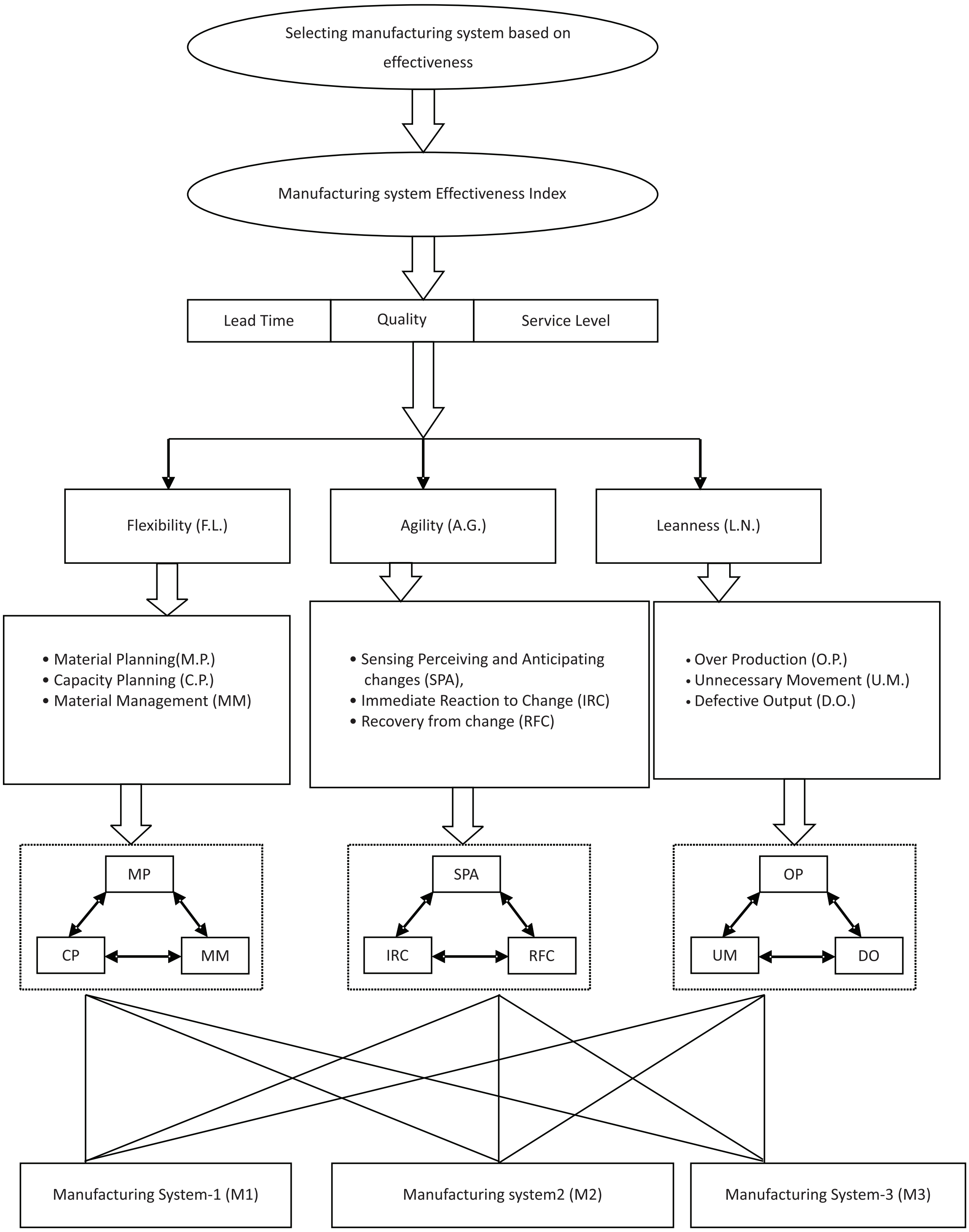

Figure 1: ANP based Model for Selection of Manufacturing System

6. ANP Application

An ANP framework for manufacturing system effectiveness problem is developed as follows:

Step 1: Development of ANP framework

The ANP framework (Figure 1) has sub-criteria and attributes. The attributes at every level have inter-relationships. The framework aims to select the alternative based on their manufacturing systems effectiveness.

Step 2: Pair-wise comparison

The expert is asked to carry out a series of pair-wise comparisons on a scale of 0 to 9 concerning the top-level "control" criterion. Interdependencies among components within the same level are viewed as controlling components for one another. After a pair-wise comparison between the attribute enablers of the dimension flexibility cluster, the weighted priority (e-Vector) is calculated (Saaty, 1980). For example, Table 1 presents the matrix indicating the relative influence of a particular dimension cluster (material planning, capacity planning and material management – which are the cluster of attributes of flexibility) on lead-time.

Similarly, the resultant e-vector of other enablers has been evaluated and presented in Table 5 of column ADkja for determining the weight. The format of the structured question is: "What is the relative impact on flexibility of attribute enabler 'a' when compared with attribute enabler 'b' in terms of reducing lead time?"

Matrices of pair-wise comparison for other dimensions are also required to examine the relative importance in the context of manufacturing system effectiveness. Results of comparison denoted by Pja and in the 2nd column of Table 5.

MSE depends upon the enablers, which are dependent on each other and included in the hierarchy of MSE. In order to see the relative importance of factors involved, improvement of MSE final pair-wise matrices required.

Step 3: Pair-wise comparison matrices of interdependencies

A pair-wise comparison between the enablers has been conducted to examine the reflection of interdependency in the network. Three sub-criteria of flexibility have been considered, such as M.P., CP and MM. In the earlier section, how the sub-criteria of enablers influencing the main criteria has been examined on enablers' main criteria. For obtaining the relative weight in Table 2, the experts were asked the question, "What is the relative impact on flexibility by enablers capacity planning (C.P.) over material management (MM)" for the reduction of lead time"? The answer 1/3 (0.33) is incorporated in Table 2. The relative importance through expert's opinion is similarly obtained and presented in all the ANP framework tables. The e-vector for the remaining enablers is also presented in Table 3.

Table 2: Matrix of Pair-wise Comparison for Enablers under Flexibility, Lead time and Material Planning

Material Planning (M.P.)	CP	MM	e-Vector
Capacity Planning (CP)	1	0.33	0.25
Material Management (MM)	3	1	0.75

Step 4: Formation of Super matrix

A combined pair-wise comparison for all the determinants and their dependencies criteria is evaluated and presented in Table 3, called supermatrix M. The supermatrix deals with the relative importance of each attribute for the cluster of lead time determinant. Further convergence of the super is evaluated and presented in Table 4

Table 3 : Lead time Enablers Super Matrix (M) before convergence

Super matrix Lead time	FL			AG			LN		
	MP	CP	MM	SPA	IRC	RFC	OP	UM	DO
MP	0.00	0.8	0.857						
CP	0.25	0.00	0.143						
MM	0.75	0.2	0.00						
SPA				0.00	0.75	0.83			
IRC				0.8	0.00	0.17			
RFC				0.2	0.25	0.00			
OP							0.00	0.67	0.8
UM							0.67	0.00	0.2
DO							0.33	0.33	0.00

Table 4: After Convergence, Super Matrix

Super matrix Lead time	FL			AG			LN		
	MP	CP	MM	SPA	IRC	RFC	OP	UM	DO
MP	0.45	0.45	0.45						
CP	0.17	0.17	0.17						
MM	0.38	0.38	0.38						
SPA				0.43	0.43	0.43			
IRC				0.39	0.39	0.39			
RFC				0.18	0.18	0.18			
OP							0.42	0.42	0.42
UM							0.33	0.33	0.33
DO							0.25	0.25	0.25

Step 5: Calculation of Desirability Index for Alternatives

The equation for finding desirability index, D_{ia} is given by (Meade et al., 1999):

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

Where i represent factor, and a represents the determinant

P_{ja} is the relative weight of j on determinant a,

$A^{D}{}_{kja}$ represents the relative weight for attribute k, dimension j and determinant a for dependency (D)

AIkja called as stabilized relative weight for attribute k dimension j in determinant a for interdependency (I),

Sikja represents the relative impact of factor i on attribute k, dimension j in determinant a, Kja is the index set of attribute for dimension j in determinant a, j indicates the index set for the dimension j.

Overall, Table 5 shows all the calculations for desirability indices (Di lead time) related to various alternatives based on the Lead time hierarchy using the weights obtained from the pair-wise comparisons of the alternatives, dimensions and weights of factors in the table of supermatrix convergence. These weights are used to calculate the determinant score for the effectiveness of the manufacturing system desirability for each of the alternatives being considered.

For each of the alternatives under lead time determinant, the summation results appear in the final row of Table 5.

Table 5: Lead time Desirability Indices

Dimension	P_{ja}	Attributes	A^{D}_{kja}	A^{I}_{kja}	S1	S2	S3	MS-A	MS-B	MS-C
FL	0.32	MM	0.69	0.45	0.29	0.57	0.14	0.029	0.057	0.014
FL	0.32	CP	0.09	0.17	0.29	0.57	0.14	0.001	0.003	0.0007
FL	0.32	MM	0.22	0.38	0.29	0.57	0.14	0.008	0.015	0.004
AG	0.1	SPA	0.61	0.44	0.51	0.36	0.13	0.014	0.010	0.003
AG	0.1	IRC	0.26	0.38	0.51	0.36	0.13	0.005	0.004	0.001
AG	0.1	RFC	0.13	0.18	0.51	0.36	0.13	0.0012	0.0008	0.0003
LN	0.58	OP	0.57	0.42	0.51	0.36	0.13	0.071	0.050	0.018
LN	0.58	UM	0.24	0.33	0.51	0.36	0.13	0.023	0.017	0.006
LN	0.58	DO	0.19	0.25	0.51	0.36	0.13	0.014	0.010	0.004
Total desirability indices								0.166	0.165	0.051

Step 6: Calculation of Manufacturing System Effectiveness Weighted Index (MSEWI)

By considering the weighted criteria of lead time, quality and service, the e-vector presented in Table 6 for pair-wise comparisons. These results indicate that the lead time determinant (e-vector = 0.55) is the most priority given to improve manufacturing system effectiveness.

Table 6: Pair-wise Comparison of Determinants

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

The overall final results with the consideration of desirability indices and weighted e-vector are presented in Table 7.

Table 7: Overall Weighted Index for Alternatives

Alternatives	Weight			Manufacturing system effectiveness weighted index (MSEWI)
	Lead time	Quality	Service level	
	0.55	**0.17**	**0.28**	
M1	0.166	0.1237	0.1422	0.125
M2	0.165	0.1312	0.1724	0.118
M3	0.051	0.0302	0.0983	0.049

Table 7 indicates that, for the case company, the ANP framework suggests the M1 manufacturing system as the most effective manufacturing system, followed by M2 and M3 manufacturing system.

7. Conclusion

The ANP-based framework developed in this paper is an aid to the decision-makers in selecting manufacturing systems under the scenario of Covid-19. With the restriction of workforce movement and social distancing, the manufacturing system's effectiveness is affected by product quantity, product processing time, product delivery and after-sales service (Solimanpur et al., 2011). An effective manufacturing system makes an enterprise resilient to respond to changes during disruption and sustain itself in a global competitive market. With the help of literature review and interaction with experts from the case, company enablers influencing a manufacturing system's effectiveness have been identified. The enablers have been categorized in determinants and dimensions. There are enablers under each dimension that have interdependence with each other. With the ANP approach's help, three manufacturing systems have been prioritized based on their effectiveness. For the case company, the ANP framework suggests MS-A as the most preferred manufacturing system, followed by MS-B and MS-C. Table 6 shows that the lead time is a top priority, followed by service level and quality (Agarwal et al., 2003, 2007). The result helps the case company's management in making decisions for selecting the most effective manufacturing system to meet the global challenge. The result obtained from the ANP framework is valid for the case company's problem and hence cannot be generalized. The barriers to manufacturing system effectiveness have not been considered. The framework has been developed with eighteen variables. The complexity of the ANP framework increases with an increase in the number of variables. The ANP framework's solution with a large number of variables can be obtained with the help of software.

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