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Structural Flexibility in Supply Chains – A Fuzzy ISM and FMICMAC Approach

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Abstract

Supply Chain (SC) has gained much popularity among the researchers and practitioners from the stage of its infant mortality. Of all, flexibility aspects in supply chains has gained much attention as "Flexibility" supports a firm's supply chain to be more 'Responsive to change'. The supply side also calls for the ability of SCs to respond for rapid changes in the demand. 'Structural flexibility' reflects on the ability of SC to adapt or reconfigure its architecture in response to major changes in the demand side and/or supply sides (Christopher, 2011). Although the research flexibility has reported in literature, the fuzziness in flexibility has observed to be a missing field. While incorporating fuzziness the interactions as well the MICMAC analysis becomes more transparent. This paper represents the results of research undertaken in that direction which is diagnostic in nature.

Keywords: *Supply Chains, Structural Flexibility, Information Sharing, Information flow, Interpretive Structural Modelling (ISM), Fuzzy ISM, Fuzzy MICMAC (FMICMAC - Fuzzy Matrice d'Impacts Croisés Multiplication Appliquée á un Classement)*

Introduction

Supply Chain (SC) as the name indicates is a virtual chain linking customers' customers to suppliers' suppliers. In the current scenario, SC has observed as a essential part to be concentrated to make the organization to be more profitable. Flexibility makes the chain more vulnerable to the rapidly changing industrial environments which ultimately make it more robust and sustainable. While observing the tremendous features of flexible supply chain, this research has been focused to analyze the fuzziness in the flexibility of supply chain. In continuation to this, most of the manufacturing and service sectors adopted these strategies which in succession got dittoed to various service sectors.

Methodology

The research undertaken is diagnostic in nature. The scope of the study was confined to select Indian firms (irrespective sector of operation) in and around select major cities in the state of A.P. The selection criterion for including a firm in to the sample is that the firm should well-defined Supply Chains Systems in place and manage all the activities that are essentially involved in an effective Supply Chain.

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The qualitative data for the study was collected through (i) study of various available documents in the select firms and (ii) semi-structured interviews with the Supply Chain Managers of the firms. Interpretive Structural Modeling (ISM) and FMICMAC (Fuzzy Matrice d'Impacts Croisés Multiplication Appliquée á un Classement) methodology was used. The objectives of the study required qualitative data. The qualitative data was collected through semi-structured interviews with SC Managers in the select firms. Many brain storming sessions and personal interviews were conducted to identify the elements that are supporting the structural flexibility in the Supply Chains and the contextual relationship was established The selection of firms into the sample is based on "Random Sampling". In Random sampling which is also known as "Probability sampling" or "Chance sampling", every item of the universe has an equal chance to be included in the sample. The results obtained by random sampling can be assured in terms of probability. Random Sampling ensures the law of Statistical Regularity which states that "if on an average the sample chosen is a random one, the sample will have the same composition and characteristics as of the universe" (Kothari, 1990).

Analysis using Interpretive Structural Modelling

ISM is based on group judgment on the extent and nature of relationship among elements. The interpretations of the group have been used to draw the overall structure from the complex set of elements. The final structure has been portrayed in a diagraph (Sage, 1977). ISM is an interactive learning process (Pramod and Banwet, 2010). In this a set of different directly and indirectly related elements are structured into a comprehensive systemic model (Warfield, 1974; Sage, 1997). The model so formed portrays the structure of a complex issue, a system of a field of study, in a carefully designed pattern employing graphics as well as words (Thakkar *et al*, 2008). ISM methodology helps to understand the order and direction on the complexity of relationships among elements of the case problem (Sage, 1977). For complex problems, like the one under consideration, a number of elements may be affecting the ICT usage in select banks there by affecting their productivity. The direct and indirect relationships among various elements depict the situation more accurately than the case when an individual factor is considered in a stand-alone mode. ISM develops insights into the collective understanding of these relationships. ISM is interpretive as the judgment of the group of experts decides whether and how the variables are related. It is structural as on the basis of relationship an overall structure is extracted from a complex set of variables. It is a modelling technique as the specific relationships and overall structure are portrayed in a graphical model. It is primarily intended as a group learning process but can also be used individually.

Fuzzy Logic

Fuzzy logic (FL) is well known for providing a cost-effective solution to a wide range of real world problems (Yen *et al.*, 1999) while incorporating the uncertainties. It is based on the perception that there is a third region other than true and/or false. That dimension is defined by a probabilistic figure named as membership function. FL emphasizes on approximate rather than exact images. It poses the ability to mimic the human mind to effectively employ modes of reasoning. With FL, it is possible to specify mapping rules in terms of words rather than numbers. This is because, computing with the words explores imprecision and tolerance. A fuzzy set allows perfect and partial memberships. This is represented by the value of the membership function. It represents the probability that the unit to be a part of that cluster. In other words it is the degree an object belongs to a fuzzy set. Membership function takes a real number value in the interval 0-1. A variable can have membership in more than one cluster with varying or same membership functions.

Structural Self-Interaction Matrix (SSIM)

The scenario was discussed in detail with reference to the study with the concerned experts in the select banks, and also expert opinion was sought from the experts from the academia. ISM methodology suggests use of expert opinions using brain storming, nominal group techniques etc. (which are some of the management techniques for developing the contextual relationship). For analysing the barriers in developing SSIM the following four symbols have been used to denote the direction of relationship between the elements (i and j):

V – Variable i will help achieve variable j

A – Variable j will help achieve variable i

X – Variables i and j will help each other

O – Variables i and j are unrelated

Through detailed discussions with senior mangers of select banks, the following list of key elements were identified for understanding the objectives:

1. Visibility
2. Information flow
3. Information sharing
4. Access to capacity
5. Access to Knowledge & talent
6. Inter-Operability of processes
7. Network orchestration
8. Structural flexibility

These elements were subjected to approval of the interviewees for representation of the study variables in this study. Considering these elements, a Structural Self-Interaction Matrix (SSIM) was developed by determining a contextually relevant subordinate relation among the select elements. Following the consultation and approval of interviewed experts from select banks, the final SSIM representing the pair wise comparison of the elements was developed. The development of SSIM requires depicting dependence among all possible pairs of elements by choosing a contextual relationship showing which elements lead to which other element. Also the derived SSIM was subjected to the consensus of interviewed experts of banks under the population. Based on their feedback, the SSIM was modified and is shown in Table 1.

Table 1: Structural Self-Interaction Matrix (SSIM)

		8	**7**	**6**	**5**	**4**	**3**	**2**
1	Visibility	O	V	V	V	V	A	A
2	Information flow	V	V	V	V	V	A	
3	Information sharing	V	V	V	V	O		
4	Access to capacity	V	V	V	V			
5	Access to knowledge & talent	O	V	A				
6	Inter-operability of processes	A	V					
7	Network orchestration	A						
8	Structural flexibility							

Reachability Matrix

(i) SSIM has been converted in to a binary matrix called "initial reachability matrix". It is developed by substituting V, A, X, and O by 1 and 0. The substitution of 1 and 0 is as per the rules of ISM methodology.

The initial reachability matrix for the relationships among the select elements is made and is shown in Table 2.

Table 2: Initial Reachability Matrix

	1	2	3	4	5	6	7	8
1	1	0	0	1	1	1	1	0
2	1	1	0	1	1	1	1	1
3	1	1	1	0	1	1	1	1
4	0	0	0	1	1	1	1	1
5	0	0	0	0	1	0	1	0
6	0	0	0	0	0	1	1	0
7	0	0	0	0	0	0	1	0
8	0	0	0	0	0	1	1	1

After incorporating the transitivities i.e., if one element A leads to element B (A =>

B) and element B leads to element C (B => C) then element A should also lead to element C (A => C), the final reachability matrix is developed and is shown in Table 3.

Table 3: Final Reachability Matrix with Driver Power and Dependence

Element	1	2	3	4	5	6	7	8	Driving power
1	1	0	0	1	1	1	1	0	5
2	1	1	0	1	1	1	1	1	7
3	1	1	1	1	1	1	1	1	8
4	0	0	0	1	1	1	1	1	5
5	0	0	0	0	1	0	1	0	1
6	0	0	0	0	0	1	1	0	2
7	0	0	0	0	0	0	1	0	1
8	0	0	0	1	0	1	1	1	4
Dependence	3	2	1	5	5	6	8	4	

Classification of Elements

Based on the dependence and driver power, the elements under study are subjected to MICMAC analysis (Duperrin and Godet, 1973) and classified into four sectors, namely autonomous, dependent, linkage and driver/independent. The driver power and dependence of the elements is indicated in Table 4.

Table 4: MICMAC Analysis

Driver Power

8	3							
7		2						
6		IV					III	
5			1		4			
4				8				
3		I				II		
2						6		
1					5			7
	1	2	3	4	5	6	7	8

Dependence

From the table the sector classification is made and is as follows.

I – Autonomous

II – Dependent

III – Linkage

IV – Independent (Driver)

The autonomous elements have a weak driver power and weak dependence relatively disconnected from the system. These elements have few links which may be strong. The dependent elements have weak driver power but strong dependence. The linkage elements on the other hand have strong driver power and dependence. These elements are unstable due to the fact that any action on these elements will affect the other and also a feedback on themselves. The driver or Independent variables condition the rest of the system (Mandal and Deshmuk, 1994). It is observed that the key variables with strong driver power fall into the category of independent or linkage elements (Ravi and Shankar, 2005). The key elements viz., Visibility, Information flow and Information sharing have fallen in the Independent sector in the MICMAC Analysis and proven to be the conditioning elements of the rest of the elements. The linkage elements such as 'Access to capacity' have shown strong driver power and strong dependency on the other elements of the system.

Development of Fuzzy ISM

'Fuzzy ISM' is the plot showing the prioritized matrices with inhibitors on the X and Y Axis and Power on the Z axis. It is shown in Figure 1.It is an advanced model of ISM by conglomerating the fuzziness among the relationships into numerical form. Instead of representing the relationships in boolean numbers, the relationships are expressed in quantified from to make them much vivid. The possibility of interaction is depicted in the reachability matrices thus transforming the model in to a quantitative school of thought. In continuation to the appropriate refinement has to be pursued in the MICMAC.

Development of Fuzzy Initial Reachability Metrics

Initial reachability metrics gives an assessment whether one variable led to another variable or whether one is influenced by other. However, the power by which the variable led to another variable or whether it is influenced by other is a handicap in the analysis. In order to plug the missing link, the attempt for quantification has carried out. By collecting the inputs from ten earlier respondents priority for relationship of each inhibitor was finalized in 1-10 scale. Each decision maker was requested to judge the interpretive characteristics of each inhibitor appraising the contribution degree and importance of it. One indicates very low interrelationship and 10 indicates very high interrelationship. The values showing the fuzzy interrelationship are shown in Table 5.

Table 5: Fuzzy Initial Reachability Matrics

	1	2	3	4	5	6	7	8
1	1	0	0	1	7	1	1	0
2	2	1	0	1	1	9	1	7
3	1	4	1	0	1	1	6	1
4	0	0	0	1	1	1	1	1
5	0	0	0	0	1	0	4	0
6	0	0	0	0	0	1	1	0
7	0	0	0	0	0	0	1	0
8	0	0	0	0	0	5	1	1

Development of Fuzzy Final Reachability Metrics

Similar to the previous case, while considering the transitivity, fuzzy final reachability metrics was made. In this case the values representing transitivity were assumed to be one. The fuzzy final reachability metrics thus constructed is shown in Table 6.

Table 6: Fuzzy Final Reachability Matrics

Element	1	2	3	4	5	6	7	8	Driving power
1	1	0	0	1	1	1	1	0	5
2	2	1	0	1	1	9	1	7	22
3	1	4	1	1	1	1	6	1	16
4	0	0	0	1	1	1	1	1	5
5	0	0	0	0	1	0	4	0	5
6	0	0	0	0	0	1	1	0	2
7	0	0	0	0	0	0	1	0	1
8	0	0	0	1	0	5	1	1	8
Dependence	4	5	1	5	5	18	16	10	

Level Partition

From the final reachability matrix the reachability and antecedent set for each criterion can be attained (Warfield, 1974). The reachability set includes criterion itself and others which it may help to achieve, similarly the antecedent set consists of itself and other criterion which helps in achieving it. There after the intersection between reachability and the antecedent set is attained. If the membership in reachability and the intersection completely agree then the top priority is obtained and the criterion is removed from the subsequent iteration, so on this procedure leads to final iteration leading to the lowest level. The reachability set and the antecedent set for each criteria along with the resultant digraph (Figure 2) are depicted at **APPENDIX – A.**

MICMAC Analysis without Considering Fuzziness

The driving power of an inhibitor is the potency of the inhibitor to cause other inhibitors to emerge. In other words, it is the sum of the elements in the row. Dependence is the measure of how much each variable is leading another variable. It is the sum of the elements in the column. Driving power and dependence of each element without considering fuzziness are shown in Table 6.

Fuzzy MICMAC Analysis

Similar to the previous case, the driving power and dependence of each elements considering fuzziness were calculated. Driving power is the arithmetic sum of the raw ranks whereas dependence is the arithmetic sum of the column ranks. They are shown in Table 6. Based on the driving power and dependence, inhibitors have been classified into four clusters. They are (i) autonomous (ii) dependent (iii) linkage and (iv) independent inhibitors (Mandal and Deshmukh, 1994). The driving power and dependence of each of these inhibitors is found from Table 6. Based on that, a Fuzzy driving power-dependence diagram is constructed as shown in Table 8.

Table 8: Fuzzy Driving Power and Dependence Diagram

Driver Power

24			2						
21		IV						III	
18	3								
15			TRA NSIT					TRA NSIT	
12			TRA NSIT					TRA NSIT	
9					8				
6		1	4, 5						II
3	I		TRA NSIT					7	6
	2	4	6	8	10	12	14	16	18

Dependence

The key elements viz., Information flow has shown highest driving power in the Fuzzy MICMAC Analysis while Visibility, Access to capacity and Access to knowledge & talent have fallen in the Linkage category and proven to be the conditioning elements of the rest of the elements. The element viz., Structural Flexibility, Inter-operability of processes, and Network orchestration have shown highest levels of dependence in order on all other elements.

Fuzzy ISM

Fuzzy ISM gives a pictorial representation of the inter relationships between the elements in the cluster. Instead of representing the relationships by 0 and 1 clear quantified relationships always give a better value addition. A picture that is thousand times worthy than an enumeration. In this regard, a three dimensional view of Fuzzy ISM is plotted using the software MATLAB. The Fuzzy ISM thus is plotted and is shown in Figure 1. X and Y axes indicate the elements. Their interrelationships in terms of intensity on a Liker sale of 0-10 are shown in the Z axis.

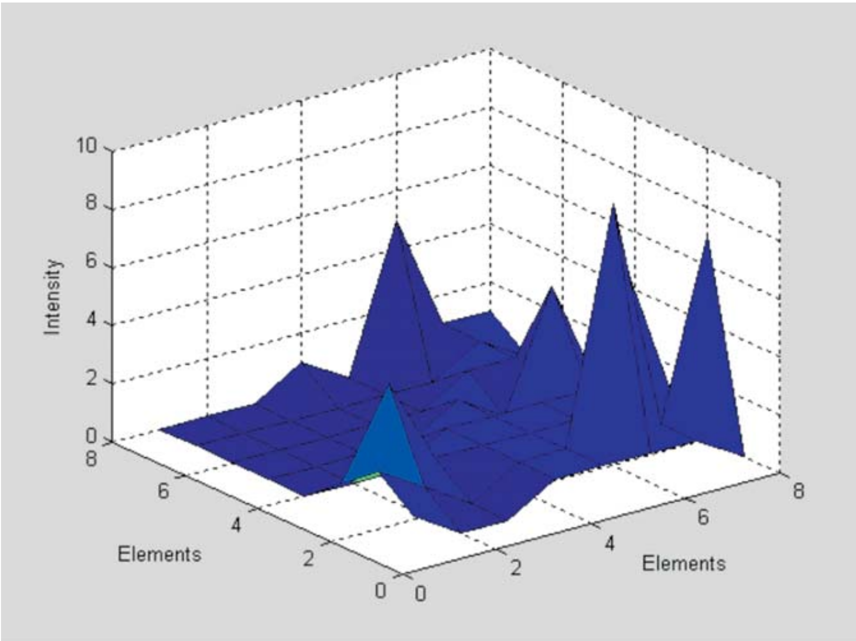

Figure 1: Fuzzy ISM

The interrelationships are expressed by the term intensity in the Fig.1. The places where there is no interrelationship have the intensity values of 0 (zero). In this the max interrelationship is 9 and is for element 2 i.e., Information flow and 6 i.e., Inter-operability of processes. This reflects the reality of efficiency of Supply Chains. The interrelationship between element 2 and element 8 i.e., Information flow and Structural flexibility is 7. This supports the argument that the flow of information across the Supply Chain is resulting in the required levels of structural flexibility in the chain. Thus the intensity gives a vivid representation of the degree of fuzziness among the interrelationships. The intensities of other combinations also can be visualized in Figure 1.

Comparison between MICMAC and Fuzzy MICMAC Approach

Only binary number based inter-relationships between elements are considered by Conventional MICMAC while the fuzzy set theory is used to increase the former's sensitivity. In fuzzy MICMAC an additional input of probable inter-relationships between the elements is introduced. The possibility of inter-relationships is defined by qualitative consideration on 1-10 scale. ISM shows the interpretive behavior of elements influencing the system. However, the degree of interpretiveness is still a question for researchers and practitioners. In this regard, Fuzzy ISM plays a significant role. The MICMAC analysis helps to categorize the elements in to four clusters based on driving power and dependence. In Fuzzy MICMAC, a new region named “transition region” also appears. The transition region is due the influence of fuzziness (Pramod, and Banwet, 2012). In the present study Elements 2,3, 4,5 and 8 i.e., Information flow, Information sharing, Access to capacity, Access to Knowledge & talent and Structural flexibility are in transition region. They will be subjected to higher degree of fuzziness.

Results and Discussion

In the present scenario a paradigm shift has already taken place. The mass production and mass marketing strategies are getting replaced by Global customisation and one-to-one marketing strategies leading to the concept of Extended Enterprise Systems. These facts are being validated by the structural model that has been derived from ISM in the present study. The key element Structural Flexibility has shown high dependence on the other structural elements. The information sharing among all the verticals of the given firm is the driving power of its SC and helps the firm to cope up with the demand uncertainties. For a given firm, its ability to view end-to-end of its SC (from both ends, i.e., from supplier to customer and back to supply side) is its Visibility. According to Chiristopher (2011), information sharing through the channel of information flow provides a powerful plat form for a firm on which it can build collaborative working relationships across its SC. This has been proven by the ISM model.

With the improved Visibility a firm can have an increased access to its capacity and through to its knowledge and talent resources. Visibility helps firms to evaluate its capacity in terms of capacity with every channel partner viz., Raw material procurement, manufacturing, warehousing, packing, inbound and outbound logistics, Marketing, Sales & distribution, reverse logistics etc. Access to the knowledge of the changing market trends and customer priorities is highly essential for a firm to initiate innovation on the product as well as the process using its internal talent. This will help the firm for capacity adjustments there by resulting dyadic relations between the two. The rapidly changing customer priorities call for a firm’s ability to operate multiple SCs to serve for a specific market. This leads to “inter-operability” of the nodal points representing the various channel partners and their linkages with in firm’s SC. As several relevant instruments are used in a way to portray any musical aspect such as melody or harmony, the orchestration of the channel partners for activity synchronisation is becoming more essential for a firm for effective SCs. The ISM Model has proven that the ability of the firm to access market knowledge and firm’s capacity that support in re-engineering its SC network, orchestrating the channel partners and synchronising the activities across the SC resulting the Structural flexibility i.e., the ability of SCs to reconfigure its network design in compliance to the rapid changes on both sides of the SCs.

Conclusion

This research pinpoints the impact of various elements on the structural flexibility. By analyzing the contributions of various elements to the overall system, and incorporating the fuzziness among the interrelationships, it is possible for managers to plan their future strategies in a much precise and deterministic manner. The research undertaken in this case revealed that ‘Access to capacity’ is the most crucial element for which maximum attention has to be focused. Instead of making decision by intrusions and prior judgement, a much better situation can be visualized from this research. Ultimately this adds to the body of flexibility study with a new insight of strategy which is highly useful to the future researchers in the domain of Supply

Chain Management. The findings provide guidelines of importance to the Supply Chain Managers that they should evaluate the identified elements to build flexibility in the structure of their Supply Chains.

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APPENDIX – A

Level partition of Elements

Level - 1 :				
Element	Reachability set	Antecedent Set	Intersection	Level
1	1,4,5,6,7	1,2,3	1	
2	1,2,4,5,6,7,8	2,3,	2	
3	1,2,3,4,5,6,7,8	3	3	
4	4,5,6,7,8	1,2,3,4,8	4	
5	5,7	1,2,3,4,5	7	
6	6,7	1,2,3,4,6,8	6	
7	7	1,2,3,4,5,6,7,8	7	1
8	4,6,7,8	2,3,4,8	8	

Level - 2 :				
Element	Reachability set	Antecedent Set	Intersection	Level
1	1,4,5,6	1,2,3	1	
2	1,2,3,4,5,6,8	2,3,	2	
3	1,2,3,4,5,6,8	3	3	
4	4,5,6,8	1,2,3,4,8	4	
5	5	1,2,3,4,5		2
6	6	1,2,3,4,6,8	6	2
8	4,6,8	2,3,4,8	8	

Level - 3 :				
Element	Reachability set	Antecedent Set	Intersection	Level
1	1,4	1,2,3	1	
2	1,2,3,4,8	2,3,	2	
3	1,2,3,4,8	3	3	
4	4,8	1,2,3,4,8	4	3
8	4,8	2,3,4,8	8	3

Level - 4 :				
Element	Reachability set	Antecedent Set	Intersection	Level
1	1	1,2,3	1	4
2	1,2,3	2,3,	2	
3	1,2,3	3	3	

Level - 5 :				
Element	Reachability set	Antecedent Set	Intersection	Level
2	2,3	2,3,	2	5
3	2,3	3	3	5

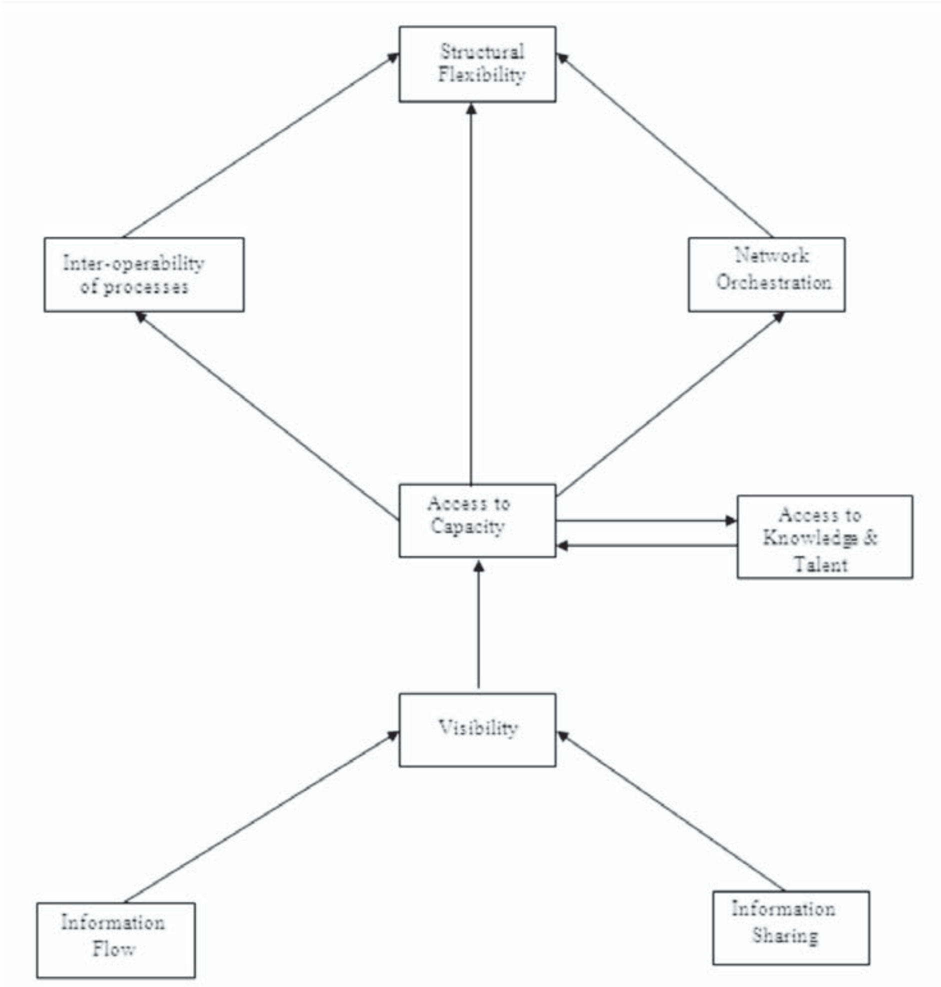

Figure 2: The Element Inter-Relationships in Digraph