Modeling Soft Dimensions of FMS and Their Interrelationship Using ISM and MICMAC Analysis

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Abstract

India is emerging as a major manufacturing hub next to China for a large number of industrial products due to the availability of resources, large qualified workforce, emerging new markets, and low cost of production. The objective of the present study was to identify the interrelationship and links between soft dimensions of a flexible manufacturing system, whose richness plays a vital role in successful FMS implementation. Thorough literature review is presented on a flexible manufacturing system. Not only do the latest technologies involving automation and robotics in manufacturing drive operational excellence and improve productivity, but the role of human factors or soft dimensions is also crucial, and needs to be considered for the successful implementation of a flexible manufacturing system. Its implementation would enable any manufacturer to survive in this competitive environment where sustainability is achieved by adopting a flexible manufacturing system. A flexible manufacturing system reduces set up time, provides more flexibility, and leads to standardization of processes. An efficient manufacturing system rooted in sustainability is the key to improve profitability in this uncertain business environment. The present study employed ISM methodology and MICMAC analysis to identify the contextual interrelationships between soft dimensions of FMS. The dependent and independent factors identified from the study will help managers and decision makers in enhancing productivity and profitability.

Keywords: flexible manufacturing systems (FMS), soft dimensions, measures, ISM, MICMAC

JEL Classification: C65, M11, M12

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Manufacturing companies in the 21st century face uncertain, high-frequency market changes driven by global competition. To stay competitive, these companies must possess new types of manufacturing systems that are cost-effective and very responsive to all these market changes (Koren, Heisel, Jovane, Moriwaki, Pritschow, Ulsoy, & Van Brussel, 1999). The concept of flexible manufacturing systems evolved during the 1960s when robots, programmable controllers, and computerized numerical controls brought a controlled environment to the factory floor in the form of numerically controlled and direct numerically controlled machines (Kostal & Velisek, 2010).

The concept of the flexibility of manufacturing systems is contemporary and important for three reasons. First, the instability and volatility of the environment, in which manufacturers operate, has forced many firms to re-organize their production, if only to reduce the overall scale of their operations. Second, developments such as flexible manufacturing systems and robotics mean that flexibility is being explicitly promoted as a desirable attribute of production equipment. Third, the relatively recent interest in the nature of production management objectives has widened the scope of production aims beyond cost and productivity issues, to include the flexibility of production systems (Slack, 1983). World leading automobile companies such as Toyota and Honda

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are following flexible manufacturing systems. Toyota is practicing FMS so as to flexibly respond to changes in market and enhance customer satisfaction (Masuyama, 1995). FMS is emerging as a key strategic advantage for Honda. Honda's manufacturing flexibility is almost as important to its success as its product lineup. To respond to changes in economic conditions, Honda is able to shuffle production among different plants as well as make different models in one plant.

Literature Review

The present study adopted a systematic literature review approach for review of published papers and articles. It was found that past researchers have mostly used traditional review; however, systematic literature review is a recent trend adopted by researchers for conducting literature review (Lightfoot, Baines, & Smart, 2013 ; Pittaway, Robertson, Munir, Denyer, & Neely, 2004 ; Van Aken, 2005) to synthesize and organize the findings. Therefore, the present review is done based on the technique of systematic literature review approach as recommended by Tranfield, Denyer, and Smart, (2013). This eradicates the issues related to the application of correct methodology and easily helps to develop the later sections of the study. In this process, we adhered to the principles that are an integral part of a systematic literature review. We made an attempt to understand which studies have been conducted in the past on flexible manufacturing systems. For literature review, scholarly works from databases such as Science Direct, Compendex, Ebsco, Emerald, and Scopus were studied.

The literature review is limited to only include: scientific research from the last 20 years in flexible manufacturing systems, performance measures, and soft dimensions. Moreover, each reviewed paper needed to match the filtering criteria such as : The research study must be written in English language and published in peer reviewed journals between 1984 and 2014 and manuscripts with a non managerial focus were excluded from the review process.

The objectives of literature review are:

- To study the evolution of (a) FMS, (b) its definition, and (c) soft dimensions of FMS,
- To identify the literature gaps related to FMS implementation in a firm and its relationship with firm performance,
- To identify the various soft dimensions, which help in successful implementation of FMS.

✷ **Definition of Flexible Manufacturing System (FMS) :** Numerous definitions have been given on FMS by management gurus, practitioners, and academicians. The definitions from various literature sources are further presented in a tabulated form in the Table 1. It can be concluded from the Table that FMS is a philosophy and a systematic activity to improve the value and efficiency of the product and services offered to the customers through the maximization of potential of all stakeholders.

✷ **Review of Tools and Mathematical Models :** Mathematical models and tools are techniques employed to assess, appraise, and to provide solutions for manufacturing issues. They are helpful in troubleshooting issues related to a flexible manufacturing system. The review of mathematical models applied in FMS studies are listed in the Table 2.

✷ **Performance Measurement of a Flexible Manufacturing System :** FMS has been a major component of competitive advantage for manufacturers to enhance profitability. Existing literature on performance measures are vast, varying from industry to industry. Performance measures and metrics have received focus from practitioners due to its wide importance. The role of these measures and metrics in the success of an organization cannot be overstated because they affect strategic, tactical, and operational planning and control. Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and

Table 1. Table Definitions/Concepts of FMS

Author (Year)	Definitions
Kostal and Velisek (2010)	A flexible manufacturing system is a system that is able to respond to changed conditions.
Shivan, Benal, and Koti (2006)	A flexible manufacturing system is an arrangement of machineries interconnected by a transport system. A flexible manufacturing system consists of a group of processing work stations interconnected by means of an automated material handling and storage system and controlled by integer computer control system.
Liu, Wires, Lamping, Fischer, & Miller (2003)	A flexible manufacturing system includes at least one module, an operational unit mounted to said at least one module and a local controller operating connected to the operational unit. The local controller is adapted to control the operational unit. At least one module and the local controller together are capable of operating in a standalone operation or are integrated into a flexible manufacturing system.
Parker and Wirth (1999)	A flexible manufacturing system comprises of machine flexibility, process flexibility, product flexibility, routing flexibility, volume flexibility, expansion flexibility, operation flexibility, and production flexibility.
Boer (1994)	A flexible manufacturing system is widely regarded as a major step towards "the factory of the future". They combine several items of hardware, software applications, and controls based on a number of technological developments for flexible manufacturing.
Mizoguchi, Momoi, & Nakamura (1994)	A flexible manufacturing system is one which includes a stack yard, a machine tool, and a stacker crane.
Tetzlaff (1990)	A flexible manufacturing system can be defined as a computer controlled production system capable of processing a variety of parts.
Stecke (1986)	A flexible manufacturing system is an integrated system of computer numerically controlled (CNC) machine tools, each having an automatic tool interchange capability, all connected by an automated material handling system.
Browne, Dubois, Rathmill, Sethi, & Stecke (1984)	A flexible manufacturing system is an integrated, computer controlled complex of automated material handling devices and numerically controlled (CNC) machine tools that can simultaneously process medium single sized volumes of a variety of part types.

Table 2. Mathematical Models Applied in FMS Studies

Mathematical models	Area of application	Author (Year)
Linear Programming	Prescribe production plans and adaptive control	Wilhem and Shin (1985)
DEA	Most appropriate flexible manufacturing system for manufacturing organizations	Sheng and Sueyosh (1995)
Simulation models	Develop scheduling mechanism	Kim and Kim (1994)
Stockhastic models	Develop flexible manufacturing system	Buzacott and Shantikumar (1993) ; Zhou and Venkatesh (1998)
Decision support system	Develop flexible manufacturing system	Suri and Whitney (1984)
Integer programming	Problem of part type selection, machine loading, part input sequencing and operation scheduling	Sawik (1990)
AHP	Flexible manufacturing system, machine grouping, and loading problem	Stecke (1986)
Heuristic methods	Scheduling problem in Flexible manufacturing system (minimization of system unbalance and the no. of late jobs)	Shanker and Tzen (1985)
Petri nets	Measuring and analysis of performance measures of FMS	Petri (1962); Petri (1976) El- Tamimi, Abidi, Mian, and Aalam (2012)

Table 3. Performance Measures of FMS

Measures	Author (Year)
Productivity	Son and Park (1987)
Quality	Son and Park (1987) ; Adler (1988)
Flexibility	Son and Park (1987)
Cost	Adler, Goldoftas, & Levine (1999)
Time	Adler, Goldoftas, & Levine (1999)

Table 4. List of Benefits of FMS

Author, Year	Benefits
Dubey and Ali (2013)	Reduced lead time; reduced work in progress inventory; increased throughput
Kostal and Velisek (2010)	Achieve high flexibility in management of production facilities and resources (time, machines, and their utilization)
Stecke and Solberg (1981)	Improve the systems production rate
Boer (1994)	Improved market performance; Reduces cost/time of operations; improved operations management
Kim and Kim (1994)	Effectively use scheduling mechanism
Sarin and Chen (1987)	Minimize overall machining cost; Improve response time to various problem on shop floor
Avlonitis and Parkinson (1986)	Competitive advantage
Suri and Whitney (1984)	Improve productivity

Table 5. Soft Dimensions of FMS

Author (Year)
Graham and Rosenthal (1986) ; Narain, Yadav, & Antony (2004) ; Belassi and Fadlalla (1998); Maffei and Meredith (1994)
Soft Dimensions
Relationship between in-house team and vendor ; Skills of flexible manufacturing system workforce ; Experience of flexible manufacturing system workforce ; Cross training ; Cross functional cooperation ; Job rotation; Team building ; Continuous experimentation ; Adaptation ; FMS workforce commitment ; FMS workforce motivation

determining future courses of actions (Gunasekaran, Patel & Gaughey, 2004). Performance measures identified after conducting the review of FMS literature are tabulated in the Table 3.

✷ **Flexible Manufacturing Systems and Firm Performance :** FMS implementation will have a positive effect on a firm's market share and profits, although mediated through customer satisfaction. The benefits of FMS are given in a tabulated form in the Table 4.

✷ **Soft Dimensions of a Flexible Manufacturing System :** An attempt was made to understand the key soft dimensions of FMS - identified by different research scholars - that are crucial for successful implementation of FMS. The Table 5 lists the soft dimensions required for successful implementation of FMS. Each of the dimensions identified were further used an input in ISM technique keeping the research objectives in mind.

Figure 1. Flowchart for the ISM Methodology

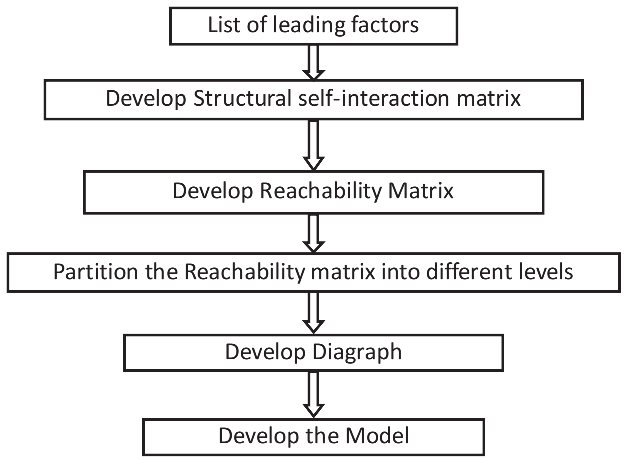


Table 6. List of Leading Factors

No.	Identified Factors
1	Relationship between in-house team and vendor
2	Skills of flexible manufacturing system workforce
3	Experience of flexible manufacturing system workforce
4	Cross training
5	Cross functional cooperation
6	Job rotation
7	Team building
8	Continuous experimentation
9	Adaptation
10	FMS workforce commitment
11	FMS workforce motivation

Theoretical Framework

ISM is a proven and popular methodology for understanding relationships among specific items that define a problem. ISM is useful to achieve the objectives in the presence of a large number of directly and indirectly related elements and complex interactions among them, which may or may not be expressed in a proper manner. ISM plays a vital role in this kind of situation and helps in understanding a structure within a system. The ISM model depicts the structure of a complex problem in a carefully designed pattern. ISM has been used in the past by several researchers due to multiple benefits. It guides and records the results of group response on complex issues in an efficient and systematic manner (Attri, Dev, & Sharma, 2013; Dubey & Ali, 2013; Sushil, 2005a, 2005b, 2009, 2012 ; Warfield 1974, 1994, 1999). The ISM steps are presented in the Figure 1.

✷ **Identifying the Leading Factors :** The Table 6 depicts the leading factors identified from the existing literature.

✷ **Developing the Structural Self Interaction Matrix (SSIM) :** For developing the SSIM (Table 7), the below mentioned symbols have been used to denote the direction of relationships between the variables (*i* and *j*):

Table 7. Structural Self Interaction Matrix

	11	10	9	8	7	6	5	4	3	2	1
1	V	V	V	V	A	A	A	A	A	A	
2	O	O	O	A	A	A	A	A	A		
3	O	O	X	A	A	A	A	A			
4	V	V	V	V	O	A	A				
5	V	V	V	V	A	A					
6	V	V	V	V	V						
7	V	V	V	V							
8	A	A	A								
9	A	A									
10	A										
11											

V : *i* leads to *j* , but *j* does not lead to *i* ,
A: *i* does not lead to *j*, but *j* leads to *i*,
X: *i* leads to *j* and *j* leads to *i*,
O: *i* and *j* are unrelated to each other.

✷ **Develop a Reachability Matrix :** The SSIM was converted into a binary matrix, that is, the reachability matrix (Table 8) by substituting *V, A, X,* and *O* by 1 and 0. The substitutions of '1' and '0' are done as below:

(1) If the *(i, j)* entry in the SSIM is *V*, then the *(i,j)* entry in the reachability matrix becomes '1' and the *(j,i)* entry becomes '0',

(2) If the *(i, j)* entry in the SSIM is *A*, then the *(i,j)* entry in the reachability matrix becomes '0' and the *(j,i)* entry becomes '1',

Table 8. Initial Reachability Matrix

	1	2	3	4	5	6	7	8	9	10	11	DRIVING POWER *(Y)*
1	1	0	0	0	0	0	0	1	1	1	1	5
2	1	1	0	0	0	0	0	0	0	0	0	2
3	1	1	1	0	0	0	0	0	1	0	0	4
4	1	1	1	1	0	0	0	1	1	1	1	8
5	1	1	1	1	1	0	0	0	1	1	1	8
6	1	1	1	1	1	1	1	1	1	1	1	11
7	1	1	1	0	1	0	1	1	1	1	1	9
8	0	1	1	0	1	0	0	1	0	0	0	4
9	0	0	1	0	0	0	0	1	1	0	0	3
10	0	0	0	0	0	0	0	1	1	1	0	3
11	0	0	0	0	0	0	0	1	1	1	1	4
DEPENDENCE POWER *(X)*	7	7	7	3	4	1	2	8	9	7	6	

Table 9. Final Reachability Matrix

	1	2	3	4	5	6	7	8	9	10	11	DRIVING POWER *(Y)*
1	1	0	0	0	0	0	0	1	1	1	1	5
2	1	1	1*	0	0	0	0	0	0	0	0	2
3	1	1	1	0	0	0	0	0	1	0	0	4
4	1	1	1	1	0	0	0	1	1	1	1	8
5	1	1	1	1	1	0	0	1*	1	1	1	8
6	1	1	1	1	1	1	1	1	1	1	1	11
7	1	1	1	0	1	0	1	1	1	1	1	9
8	0	1	1	0	1	0	0	1	0	1*	0	4
9	0	0	1	0	0	0	0	1	1	1*	0	3
10	0	0	0	0	0	0	0	1	1	1	0	3
11	0	0	0	0	0	0	0	1	1	1	1	4
DEPENDENCE POWER *(X)*	7	7	7	3	4	1	2	8	9	7	6	

(3) If the *(i, j)* entry in the SSIM is *X*, then the *(i,j)* entry in the reachability matrix becomes '1' and *(j,i)* entry also becomes '1'

(4) If the *(i, j)* entry in the SSIM is *O*, then the *(i,j)* entry in the reachability matrix becomes '0' and the *(j,i)* entry also becomes '0'.

✷ **Transitivity Principle :** In this step, the concept of transitivity is introduced so that some of the cells of the initial reachability matrix are filled by inference. Transitivity can be explained with the following example. If element *"I"* relates to element *"j"* and element *"j"* relates to element *"k,"* then transitivity implies element *"I"* relates to element *"k"*. Transitivity is the basic assumption in ISM and is always used in this modelling approach (Watson 1978, Sharma, Panda, Mahapatra, & Sahu, 2011 ; Sushil, 2005a, 2005b). It also helps in maintaining the conceptual consistency. The final reachability matrix will then consist of some entries from the pair-wise comparisons and some inferred entries. The transitivity concept is used to fill the gap, if any. Following the above rules, the initial reachability matrix was prepared. After incorporating the transitivity concept as described above, the final reachability matrix is obtained (Table 9).

✷ **Level Partitioning :** The final reachability matrix obtained in the Table 9 is now partitioned into different levels. After the first iteration, the factors classified to level 1 are discarded and the partitioning procedure is repeated on the remaining factors to determine the level 2. These iterations are continued until the level of each factor has been determined. The results for iterations 1 to 9 are summarized in the Table 10.

✷ **ISM Model :** The analysis above yields an ISM hierarchy in which FMS workforce commitment is at level 1 (the top level) followed by other levels. The resulting ISM model is illustrated in the Figure 2.

MICMAC Analysis

MICMAC analysis (Matrice d' Impacts croises multiplication appliqué an classment (cross-impact matrix multiplication applied to classification)) is abbreviated as MICMAC. The objective of the MICMAC analysis is to analyze the drive power and dependence power of factors. Based on the drive power and dependence power, the factors have been classified into four factors: autonomous factors, linkage factors, dependent, and independent factors (Figure 3). The Table 11 shows the dependence and driving power of key factors, which are derived from the final reachability matrix (Table 9) of ISM steps.

Table 10. Level Partitioning

Variables	RS	AS	IS	Level
1	1,8,9,10,11	1,2,3,4,5,6,7	1	4
2	1,2,3	2,3,4,5,6,7,8	2	5
3	1,2,3,9	2,3,4,5,6,7,8,9	3,9	5
4	1,2,3,4,8,9,10,11	4,5,6	4	6
5	1,2,3,4,5,8,9,10,11	5,6,7,8	5	7
6	1,2,3,4,5,6,7,8,9,10,11	6	5	9
7	1,2,3,5,7,8,9,10,11	6,7	7	8
8	2,3,5,8	1,4,5,6,7,8,9,10,11	8	7
9	3,8,9,10	1,3,4,5,6,7,9,10,11	9	3
10	8,9,10	1,4,5,6,7,8,9,10,11	8,9, 10	1
11	8,9,10,11	1,4,5,6,7,11	11	2

Figure 2. The ISM Model

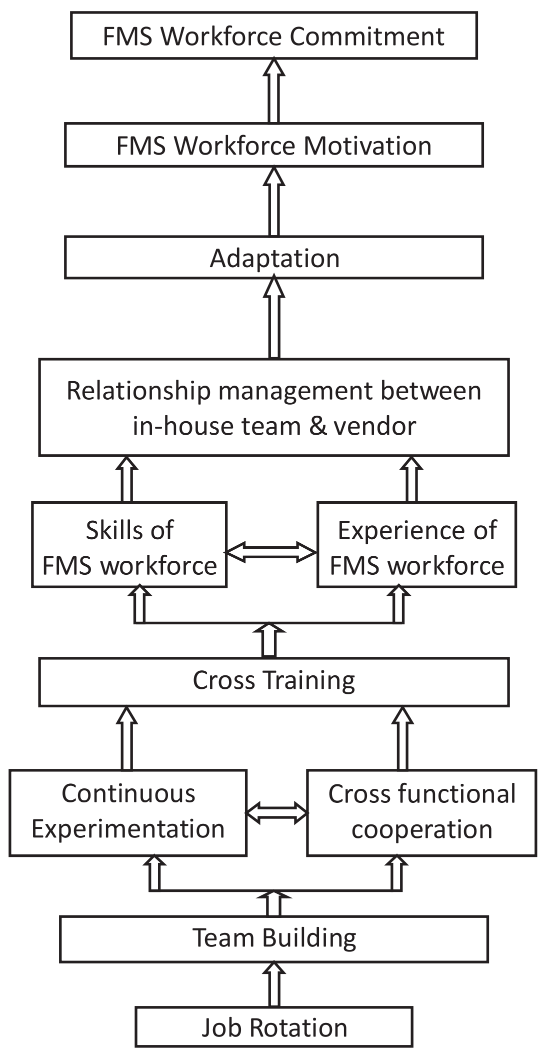
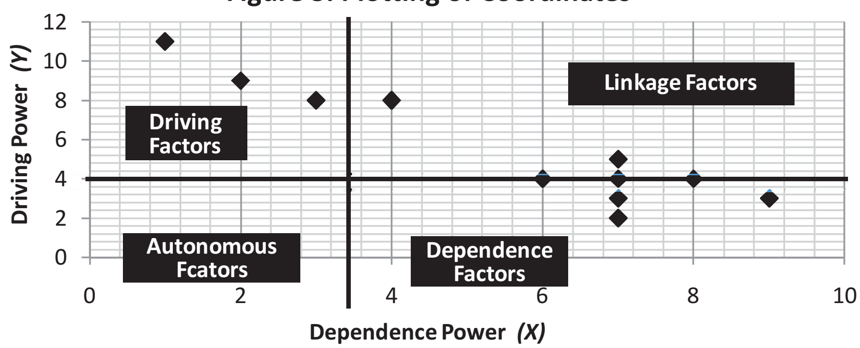


Table 11. Position Coordinates of Identified Factors

Variables	Dependence Power *(X)*	Driving Power *(Y)*
1	7	5
2	7	2
3	7	4
4	3	8
5	4	8
6	1	11
7	2	9
8	8	4
9	9	3
10	7	3
11	6	4

Figure 3. Plotting of Coordinates



Discussion on MICMAC Analysis

✷ **Cluster 1 - Autonomous Factors :** These factors have a weak drive power and weak dependence power. In this cluster, we do not have any factor.

✷ **Cluster 2 - Dependence Factors :** These factors have a weak drive power, but a strong dependence power. In this cluster, we have six factors, that is, 2 (skills), 3 (experience), 8 (continuous experimentation), 9 (adaptation), 10 (commitment), and 11 (motivation).

✷ **Cluster 3 - Linkage Factors :** These factors have a strong drive power as well as strong dependence power. In this cluster, we have two variables, that is, 1 (Relationship between in-house team and vendor) and 5 (Cross functional cooperation).

✷ **Cluster 4 - Driving Factors :** These factors have a strong drive power but weak dependence power. In this cluster, we have three variables, that is, 4 (Cross training), 6 (Job rotation), and 7 (Team building).

Implications and Conclusion

In the current uncertain business environment, a flexible manufacturing system is necessary to compete in global markets. Organizations must understand and evaluate the resources available to them for a flexible manufacturing system enabled production. It has been observed that most organizations go ahead in implementing FMS without estimating the capabilities and limitations. The present study proves that soft dimensions of FMS are important for the success of any FMS project. The findings show that cross training, team building, and job rotation are the major FMS drivers and can be considered as the key enablers. The ISM model portrays a practical view of the interrelationships between soft dimensions of FMS. These soft factors must be dealt with utmost care for the success of any organization. Linkage factors are very sensitive and unstable that any action on the factors will trigger an effect on other factors and also on the feedback regarding themselves. The present study provides a systematic approach in developing a structural FMS model pertaining to the Indian manufacturing sector. Furthermore, this study has provided a hierarchy of factors, which will help supply chain managers in decision making towards building a successful flexible manufacturing system. The present study provides insights into the soft dimensions of FMS. It further provides insights into which soft dimensions of FMS will have a major role in an organization. The study will enable managers to respond cost effectively and promptly to changing production requirements.

Limitations of the Study and Scope for Future Research

The present study has employed ISM and MICMAC analysis. Like the very methodology, ISM and MICMAC have its own limitations because these are purely based on expert opinions and need to be validated statistically. To eradicate the limitations of the present study, future studies can apply structural equation modeling technique to validate the findings of the present study.

References

Adler, P.S. (1988). Managing flexible automation. *California Management Review, 30* (3), 34-56.

Adler, P. S., Goldoftas, B., & Levine, D. I. (1999). Flexibility versus efficiency? A case study of model changeovers in the Toyota production system. *Organization Science, 10* (1), 43-68.

Attri, R., Dev, N., & Sharma, V. (2013). Interpretive structural modeling (ISM) approach: An overview. *Research Journal of Management Sciences, 2* (2), 3-8.

Avlonitis, G. J., & Parkinson, S. T. (1986). The adoption of flexible manufacturing systems in British and German companies. *Industrial Marketing Management, 15* (2), 97-108. DOI: 10.1016/0019-8501(86)90050-7

Belassi, W., & Fadlalla, A. (1998). Flexible manufacturing is gotten easier to change on demand. *Omega, 26*(6), 699-713.

Boer, H. (1994). Flexible manufacturing systems. In J. Story (Eds.), *New wave manufacturing strategies*. London : Paul Chapman Publishing Ltd.

Browne, J., Dubois, D., Rathmill, K., Sethi, S. P., & Stecke, K. E. (1984). Classification of flexible manufacturing systems. *The FMS Magazine, 2* (2), 114-117.

Buzacott, J. A., & Shanthikumar, J. G. (1993). *Stochastic models of manufacturing systems* (Vol. 4). Englewood Cliffs, NJ: Prentice Hall.

Dubey, R., & Ali, S.S. (2013). Identification of flexible manufacturing system dimensions and their interrelationship using total interpretive structural modeling and fuzzy MICMAC analysis. *Global Journal of Flexible Systems Management, 15* (2), 131-143. DOI : 10.1007/s40171-014-0058-9

El- Tamimi, A. M., Abidi, M. H., Mian, S. H., & Aalam, J. (2012). Analysis of performance measures of flexible manufacturing system. *Journal of King Saud University - Engineering Sciences, 24*(2), 115-129. DOI: 10.1016/j.jksues.2011.06.005

Graham, M. B. W., & Rosenthal, S. R. (1986). Flexible manufacturing systems require flexible people. *Human Systems Management, 6* (3), 211-222.

Gunasekaran, A. Patel, C., McGaughey, R. E. (2004). A framework for supply chain performance measurement. *International Journal of Production Economics, 87*, 333-347. DOI: 10.1016/j.ijpe.2003.08.003

Kim, M. H., & Kim, Y. D. (1994). Simulation-based real-time scheduling in a flexible manufacturing system. *Journal of Manufacturing Systems, 13* (2), 85-93.

Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritschow, G., Ulsoy, G., & Van Brussel, H. (1999). Reconfigurable manufacturing systems. *CIRP Annals-Manufacturing Technology, 48* (2), 527-540.

Kostal, P., & Velisek, K. (2010). Flexible manufacturing system. *World Academy of Science, Engineering and Technology, 77*, 825-829.

Lightfoot, H., Baines, T., & Smart, P. (2013). The servitization of manufacturing: A systematic literature review of interdependent trends. *International Journal of Operations & Production Management, 33*(11/12), 1408 - 1434. DOI : http://dx.doi.org/10.1108/IJOPM-07-2010-0196

Liu, V. B., Wires, D. L., Lamping, M. J., Fischer, A. M., & Miller, G. L. (2003).*U.S. Patent No. 6,574,520*. Washington, DC: U.S. Patent and Trademark Office.

Maffei, M. J., & Meredith, J. (1994). The organizational side of flexible manufacturing technology: Guidelines for managers. *International Journal of Production and Operations Management, 14* (8), 17-34.

Masuyama, A. (1995). Idea and practice of flexible manufacturing systems of Toyota. *Manufacturing Research and Technology, 23*, 305 - 316. DOI: 10.1016/S1572-4417(06)80015-X

Mizoguchi, K., Momoi, S., & Nakamura, Y. (1994). *U.S. Patent No. 5,310,396*. Washington, DC: U.S. Patent and Trademark Office.

Narain, R., Yadav, R. C., & Antony, J. (2004). Productivity gains from flexible manufacturing-experiences from India. *International Journal of Productivity and Performance Management, 53* (2), 109-128.

Parker, R. P., & Wirth, A. (1999). Manufacturing flexibility: Measures and relationships. *European Journal of Operational Research, 118* (3), 429-449.

Petri, C. (1962). Kommunikation mit Automaten *[Communication with automata]* (Ph.D Disseratation), University of Bonn, West Germany.

Petri, C., (1976). General net theory. In: *Procedings of the joint IBM/University of Newcastle upon Tyne seminar on computation system design*, Springer, Berlin, 131-169.

Pittaway, L., Robertson, M., Munir, K., Denyer, D., & Neely, A. (2004). Networking and innovation: A systematic review of the evidence. *International Journal of Management Reviews, 5 - 6*(3- 4), 137-168.

Sarin, S. C., & Chen, C. S. (1987). The machine loading and tool allocation problem in a flexible manufacturing system. *International Journal of Production Research, 25*(7), 1081-1094.

Sawik, T. (1990). Modelling and scheduling of a flexible manufacturing system. *European Journal of Operational Research, 45* (2), 177-190.

Shang, J., & Sueyoshi, T. (1995). A unified framework for the selection of a flexible manufacturing system. *European Journal of Operational Research, 85* (2), 297-315.

Shanker, K., & Tzen, Y. - J. J. (1985). A loading and dispatching problem in a random flexible manufacturing system. *International Journal of Production Research, 23* (3), 579-595.

Sharma, S.K., Panda, B.N., Mahapatra, S. S., & Sahu, S. (2011). Analysis of barriers for reverse logistics: An Indian perspective. *International Journal of Model Optimization, 1* (2), 101- 106.

Shivanand, H. K., Benal, M. M., & Koti, V. (2006). *Flexible manufacturing system*. New Delhi : New Age International.

Slack, N. (1983). Flexibility as a manufacturing objective. *International Journal of Operations & Production Management, 3* (3), 4-13.

Son, Y. K., & Park, C. S. (1987). Economic measure of productivity, quality and flexibility in advanced manufacturing systems. *Journal of Manufacturing Systems, 6* (3), 193-207. DOI: 10.1016/0278-6125(87)90018-5

Stecke, K. E. (1986). A hierarchical approach to solving machine grouping and loading problems of flexible manufacturing systems. *European Journal of Operational Research, 24*(3), 369-378.

Stecke, K. E., & Solberg, J. J. (1981). Loading and control policies for a flexible manufacturing system. *The International Journal of Production Research, 19*(5), 481-490.

Suri, R., & Whitney, C. K. (1984). Decision support requirements in flexible manufacturing. *Journal of Manufacturing Systems, 3*(1), 61-69.

Sushil. (2005a). Interpretive matrix: A tool to aid interpretation of management and social research. *Global Journal of Flexible Systems Management, 6*(2), 27-30.

Sushil. (2005b). A flexible strategy framework for managing community and change. *International Journal of Global Business and Competitiveness, 1*(1), 22-32.

Sushil. (2009). Interpretive ranking process. *Global Journal of Flexible Systems Management, 10* (4), 1-10.

Sushil. (2012). Interpreting the interpretive structural model. *Global Journal of Flexible Systems Management, 13*(2), 87-106.

Tetzlaff, U. A. (1990). *Optimal design of flexible manufacturing systems* (pp. 5-11). HD, Germany : Physica-Verlag.

Tranfield, D., Denyer, D., & Smart, P. (2013). Towards a methodology for developing evidence-Informed management knowledge by means of systematic review. *British Journal of Management, 14* (3), 207-222. DOI: 10.1111/1467-8551.00375

Van Aken, J. E. (2005). Management research as a design science: Articulating the research products of mode 2 knowledge production in management. *British Journal of Management, 16* (1), 19-36.

Warfield, J.N. (1974). *Structuring complex systems* (Battelle Monograph No. 4). Columbus, O.H: Battelle Memorial Institute.

Warfield, J.N. (1994). *A science of generic design: Managing complexity through systems design*. Iowa: Iowa State University Press.

Warfield, J.N. (1999). Twenty laws of complexity: Science applicability in organizations. *Systems research and Behavioral Science, 16* (1), 3-40.

Watson, R. H. (1978). Interpretive structural modelingA useful tool for technology assessment? *Technological Forecasting and Social Change, 11* (2), 165-185.

Wilhelm, W. E., & Shin, H. M. (1985). Effectiveness of alternate operations in a flexible manufacturing system. *International Journal of Production Research, 23* (1), 65-79.

Zhou, M. C., & Venkatesh, K. (1998). *Modeling, simulation, and control of flexible manufacturing systems: A petri net approach*. Singapore : World Scientific.