Analysis of Barriers to World Class Manufacturing Using Graph Theory

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In the present work various barriers in the way to attain WCM has been identified through extreme literature review and discussion with the personal from industry. Some of the factors are qualitative and some are quantitative. Therefore, Graph theoretic approach (GTA) is used assess the impact of different barriers. GTA is selected because it is capable of taking in account the inheritance and inter-dependencies of barriers which may either be qualitative or quantitative. Interaction in-between barriers are represented with digraph representation. For easy processing with computer digraph is converted into matrix representation and expanded as permanent function.

1. Introduction

1.1 Genesis Of World Class Manufacturing (WCM) System

The quick changes in the business environment due to its unique characteristics, the growth of international competition among the manufacturing firms, contraction of markets and diffusion of the IT through organizations have put pressure on business to continuously review and adopt their traditional manufacturing strategy. All the firms are searching constantly new ways to achieve the competitive advantage through new manufacturing techniques. Certainly a combination of external and internal factors including population growth, weak infrastructure, foreign debt and inequality between the individuals, group and region has prevented the many developing countries from achieving world class status. The competitors who are active in the global markets always keen to have improved performance i.e. called world class performance. The world class manufacturing includes three strategies i.e. customer focus, quality and agility and six supporting competencies employee involvement, supply management, technology, product development, working environment and safety issues regarding the employees. Thus in order to compete at the global level Indian firms needs to obtain world class status. The word WCM is coined by Hayes and Wheelwright (1984). The term WCM is used because it is a group of techniques which helps the manufacturing firms to compete at global level. WCM became popular after Sconberger (1986) discussed it. It is one of the philosophies focusing mainly on production. Within a manufacturing context, quality refers to the perception of the degree to which the product or service meets the customer's expectations. For any manufacturing process to be capable it must be able to produce a quality product. As the customer requirements for quality increase the manufacturing capability must also evolve. The dimensions associated with the production and in particular quality, efficiency and flexibility ultimately define the unit cost of the finished product and are therefore a central focus of any organization's business plan and performance monitoring. Manufacturing activities in the current situation and during the recent decades have been faced with globalization. Therefore to meet the competition at the global level manufacturing firms have to use the WCM techniques.

In the present work various barriers in the way to attain world class manufacturing has been identified through extreme literature review and categorized. Some of the factors are qualitative and some are quantitative. Therefore, Graph theoretic approach (GTA) is used assess the impact of different barriers. GTA is selected because it is capable of taking in account the inheritance and inter-dependencies of barriers which may either be qualitative or quantitative. A methodology based on GTA has been proposed in the present work is capable of comparing and categorizing the barriers. The present study observed that tactical barriers are most intensive and therefore, requires very careful handling by managers.

1.2 Graph Theory for WCM

In graph theory an engineering system is usually represented as a diagram, with nodes, lines, and words or numbers which assign values to some or all nodes or lines. For instance, it is common to use a diagram to show a truss, or a mechanism, or a gear system, or electrical circuit, gas turbine system, combined cycle power plant system, coal based thermal power system or a mass-spring dashpot oscillator. The elements of the diagram are syntax symbols, and the diagram itself is considered to be a sentence which describes the system. Following mathematical tradition for applying graph theory and matrix method, the work should be done in two parts.

1. Check whether the problem is well defined and hence solvable. In the words of logic, check that the syntax of the engineering system being dealt with, in other words, its diagrammatic representation, is a Well-Formed Formula (WFF). Attention is immediately focused on the numerical mathematical formula to be applied to a problem, with no systematic attention paid to whether the system is correctly defined.
2. Before proceeding into the analysis effort, ensure that the solution will require as low a computational effort as possible. This is of less practical importance for small systems, but is very important for large systems with many components. A

large and complex system such as WCM is very difficult to study without converting it into small set of barriers. Barriers must be dependent upon each other. Then system is converted into a digraph. A digraph helps in visual inspection of dependency of one barrier on the other. Further it is possible that a barrier is also affected by some barriers. Then firstly effect of these barriers is studied on the barriers and then interdependency to these barriers is studied. This subject is usually dealt with by heuristic rules of thumb, known as expert domain knowledge. When using the graph theory representation of the engineering system, it can often be dealt with using mathematically proven algorithms of graph theory rather than man-made heuristic rules.

The graph theoretic mathematical model is a proven tool for representing explicitly system structure that is for consideration for its systems, sub-systems and components and their interconnections. It helps in the understanding of any system as a whole, its sub-systems and their interconnections. Graph theory has been extensively applied in numerous disciplines of science and technologies. Dev et al (2013) applied graph theoretical approach to evaluate the reliability of a combined cycle power plant while considering all of its sub-systems and effect of control systems and actuators were also taken in to consideration. Dev et al. (2013a) develop a mathematical model using graph theory and matrix method to evaluate the performance of a power plant. Graph theoretic approach assumes systems perspective and considers various factors nodes and interdependencies among them. It is a three stage unified systems approach.

- Modeling of barriers and sub-barriers in terms of nodes and edges gives a structural representation in the form of directed graph. This representation is suitable for visual analysis and gives a better understanding of interrelationships among system and subsystems.
- For further analysis, digraph representation is converted to matrix form, which makes it suitable for computer. In the matrix value of each element assigned is based on the importance of element itself and its impact on the other performance parameters. However the matrix representation is not unique as changing the labeling of nodes can change it.
- Matrix model is modified according to the suitability of graph theory and results in permanent function model, which is in the expression form. Simplified permanent function expression is represented in terms of a single numerical index which is the indication of system performance.

Graph Theoretic Approach is a very useful approach as it synthesizes the inter-relationship among different variables or subsystems and provides a synthetic score for the entire system. It also takes care of directional relationship and inter-dependence among variables. In the present study GTA has been used to assess the impact of different barriers. As all the barriers identified from the literature are in qualitative form therefore to convert these qualitative barriers into quantitative results Graph theoretic approach (GTA) is used. GTA is capable of taking in account the inheritance and interdependencies of barriers which may either be qualitative or quantitative. GTA is a systematic and logical approach that is applied in various disciplines (*e.g.*, Attri et al, 2012, 2013; Attri and Raj, 2010; Raj et al, 2010; etc).

GTA has three main elements:

1. The digraph representation.
2. The matrix representation.
3. The permanent function representation.

The diagraph is nothing but a directed graph. The directed graph use pointed or directional edges to connect various variables. The digraph is the visual representation of the elements (barriers) and their interdependence. The matrix converts the digraph into mathematical form. The permanent function is a mathematical model that helps to determine index which is helpful for comparison. The permanent function gives a single numerical value that represents the impact of barriers.

1.3 Objective of Present Study

The objective of the present study is to fill the gap in existing literature and given as below.

1. To identify and categorize barriers in the implementation of WCM.
2. To develop a mathematical model of these identified barriers using GTA.
3. To suggest a single numerical index representing the hindering strength of barriers.

2. Identification of Barriers to WCM

There are so many definitions of world class manufacturing but not a single one is consistent definition of WCM. The term "world class manufacturing" has been used first by Hayes and Wheelwright (1984). But WCM got fame after discussed by Sconberger (1986). Sconberger (1986) provided a list of 16 principles of WCM and categorized them into 8 categories: general, design, operations, human resources, quality and process improvement, information for operations and control, capacity, promotion and marketing. After Sconberger Many researchers have focused on this area. Banker and Khosla (1995) cited the lack of employee motivation and lack of coordination are two main barriers to the WCM. Flynn et al (1999) investigate the Hayes and Wheelwright's research and concluded that the use of the practices which Hayes and Wheelwright described was strongly related to competitive performance. This relationship was robust to differences in measurement of competitive performance, with the world class manufacturing practices significantly related to cost, quality–performance, product flexibility and volume flexibility. Saxena and Sahay (2000) emphasize that WCM is driven by never ending needs of customers and cited poor planning and lack of organizational communications as two barriers to the WCM. Poor planning is also cited as a barrier by ward et al (1996). Ahuja and Khamba (2002) cited lack of coordination, employee resistance and financial constraints as major obstacles to the world class manufacturing. Salaheldin (2007) observed poor planning and lack of knowledge as the main barriers to WCM in Egyptian manufacturing firms. However many other barriers such as lack of coordination, lack of organizational communications, lack of education and training, employee resistance, partial implementation of WCM techniques, lack of employee motivation, lack of management support and appropriate monitoring cited by Salaheldin (2007). Abdulla et al (2008) believes that management commitment, employee involvement, training and education, and reward and recognition are the main obstacles to the quality improvement in Malaysian firms. Lack of knowledge and cultural resistance are cited as barriers to WCM by Abdulla et al (2009). Employee resistance, lack of management support, lack of appropriate monitoring and lack of employee education and training and cultural resistance are cited as the barriers to WCM by Syan et al (2009). Lack of management support also cited as barrier by Bhat and Rajashekher (2009). Financial constraints, employee resistance, lack of management support and lack of employee education and training are observed as barriers to the implementation of WCM (Attri and Raj; 2010, 2012). Hicks et al (2010) cited employee resistance as a main obstacle to process improvement. Effectiveness of decision taken in an organization depends upon information collected (Aggarwal et al; 2010). Gharakhani (2011) observed employee education and training as a barrier to WCM. lack of clarification of relationships among widely spreading elements of manufacturing process by applying an integrated model of system dynamics (SD) by causal loop and stock & flow diagrams, and the lack of attention to non-linearity and time delays, all are the main reasons that some companies may be far away from developing a comprehensive, and advantageous model in a WCM system (Seyed et al; 2011). Goriwando et al (2012) found the partial implementation of the WCM techniques as barrier to WCM in Zimbabwean firms. Lack of management support is identified as barrier by Goyal et al (2013).

Table 2.1 *Barriers Identified in the Literature*

S. No.	Barriers	Sources
1	Employee resistance	Ahuja and Khamba (2008), Salaheldin(2007), Attri and Raj(2010) Hicks et al (2010) , Syan et al(2009), Attri et al(2012)
2	Financial constraints	Attri and Raj(2010), Ahuja and Khamba (2008), Salaheldin(2007), Attri et al(2012)
3	Lack of management support	Amar and Zain (2002), Bhat and Rajashekhar (2009) , Attri and Raj (2010), Goyal et al(2013), Pasic et al (2011), Syan et al(2009), Attri et al(2012),Abdulla et al(2008)
4	Lack of appropriate monitoring	Salaheldin(2007),aggarwal et al(2010) Bourne et al (2000), Syan et al(2009)
5	Lack of employee education and training	Amar and Zain (2002), Adebanjo and Kehoe (1998), Salaheldin(2007), Attri et al(2012) , Gharakhani(2011) and Syan et al(2009), Attri and Raj(2010), Abdulla et al(2008)
7	Overly optimistic expectations	Salaheldin(2007)
8	Lack of employee motivation	Salaheldin(2007), Attri et al(2012), Banker et al (1995), Syan et al(2009) Attri and Raj(2010)
9	Cultural resistance	Amar and Zain (2002)), Syan et al(2009) , Goyal et al(2013)
10	Major losses	Ahuja and Khamba (2008), Gupta et al (2006)
11	To Change of priorities	Gupta et al (2006)
12	Lack of persistence	Gupta et al (2006)
13	Failure to allow sufficient time for the evolution	Attri and Raj (2010), Attri et al (2012), Attri et al (2013)
14	Instability of senior managers.	Attri and Raj (2010)
15	Lack of planning	Amar and Zain (2002), Salaheldin(2007), Attri et al(2012), Ward et al (1996),Zimwara et al (2012), Saxena and Sahay (2000), Syan et al(2009), Attri and Raj(2010), Attri et al (2013)
16	Lack of organizational communications.	Salaheldin(2007), Saxena and Sahay (2000), Syan et al(2009), Attri et al(2012), Attri et al (2013)
17	Poor quality infrastructure facilities	Attri and Raj (2010), Attri et al (2013)
18	Lack of coordination among the processes	Ahuja and khamba(2008), Salaheldin(2007), Attri et al (2012), Banker et al (1995), Attri and Raj(2010), Attri et al (2013)
19	Inadequate tools and equipment	Attri and Raj (2010), Attri et al (2013)
20	Unscheduled and nonconformity to the specification of raw materials	Attri and Raj (2010)

21	Non clarity of organizational policies about WCM techniques	Attri and Raj (2010), Attri et al (2013)
22	Lack of continuous quality control.	Attri and Raj (2010)
23	Lack of attention to the needs of internal and external customers.	Attri and Raj (2010)
24	Lack of access of data and results	Attri and Raj (2010), Attri et al (2013)
25	Lack of feedback from customers.	Attri and Raj (2010)
26	Non participation and apathy of employees.	Attri and Raj (2010),
27	Lack of knowledge	Salaheldin(2007), Attri and Raj(2010) Abdulla (2009), Gharakhani(2011), Syan et al(2009), Attri et al(2012), Attri et al (2013)
28	Inadequate tools and equipment	Attri and Raj (2010), Attri et al (2013)
29	Employee resistance	Ahuja and Khamba (2008), Salaheldin(2007), Attri and Raj(2010) Hicks et al (2010) , Syan et al(2009), Attri et al(2012)

From the literature review following twenty nine barriers in the path of WCM is concluded. These barriers are very large in number. Therefore, they will be classified in to sub-categories so that they can be handled easily. These sub-catogaries should include the barriers of same nature. The barriers identified are listed below:

1. Poor planning
2. Lack of knowledge
3. Lack of coordination among the processes
4. Employee resistance
5. Financial constraints
6. Lack of management support and involvement.
7. Lack of appropriate monitoring
8. Lack of employee education and training.
9. Partial implementation of WCM techniques
10. Overly optimistic expectations
11. Lack of organizational communications
12. Lack of employee motivation
13. Cultural resistance
14. Major losses
15. Change of priorities
16. Lack of persistence
17. Failure to allow sufficient time for the evolution
18. Instability of senior manager
19. Non participation and apathy of employees
20. Poor quality infrastructure facilities
21. Inadequate tools and equipments
22. Unscheduled and non uniformity to the specification of raw material
23. Non clarity of the organizational objective
24. Lack of mechanisms for the formulation of strategies in managing the organization
25. Lack of continuous quality control
26. Lack of feedback from customers
27. Lack of attention to the needs of internal and external customers
28. Lack of access of data and results
29. Non clarity of organizational policies about WCM techniques.

3. Development of Graph Theoretic Model

The existing literature shows that numerous authors have barriers identified independently. The existing literature does not deliberate the interaction of one barrier to another barrier. These barriers not only affect WCM implementation but also affect each other. The evaluation of the overall effect of these interacting barriers is accountable for the confrontation of the WCM implementation. The quantification of these barriers was not described in the literature by graph theoretic approach (GTA). In another words impact of these WCM barriers have not computed. The intensity of these barriers indicates the deterring strength in the implementation of WCM.

The barriers identified in previous steps, are categorized into five categorizes. These are given below.

(i) Behavioural barriers (B1)

These barriers are related to those people who interact with the organization. These may be customers, employer, supplier and employees. The behaviour of the human resources has a great impact on implementation of WCM in the organization. They are the ones who raise the organization to newer heights in a competitive scenario. The behavioral barriers are as follows:

- Lack of top management commitment and involvement.
- Instability of senior managers.
- Employee resistance.
- Non participation and apathy of employees.
- Lack of organizational communications.
- Overly optimistic expectations.

(ii) Non Behavioural Barriers (B2)

These barriers are related to physical requirements of production system and utilization of tools, techniques and methodologies in an organization. Physical requirements may be the incoming material in the form of raw material or the semi-finished and finished goods from the supplier. This category includes the following barriers:

- Poor quality infrastructure facilities
- Inadequate tools and equipment
- Unscheduled and nonconformity to the specification of raw materials
- Partial implementation of WCM techniques
- Major losses

(iii) Human and Cultural Barriers (B3)

These barriers are related to the existing culture that affects the working of human resources. These barriers are coupled with values, behavior and perceptions of human resources which promote the work culture. WCM is the set of techniques such as TQM, TPM, JIT 5S etc. WCM is being considered as a function of hard and soft elements. The hard elements include strategy, technology and structural aspects whereas soft elements consider values, behavior and perceptions of human resources. Ability and willingness of human resources to work are equally important for an organization. Ability refers to qualities of employee, scrutinized at the time of recruitment; willingness is affected by the employee's own behavioral characteristics and work environment of an organization. This category of barriers includes the following:

- Cultural resistance
- Lack of employee education and training
- Lack of knowledge
- Lack of employee motivation

(iv) Tactical Barriers (B4)

These barriers are related to poor strategic planning of the company. Strategic planning is crucial as it provides a framework for proactive decision making to evaluate performance continuously and also to assess what could go wrong, determine significant risks and implement strategies to deal with those risks. Tactical barriers are as follows:

- Non clarity of organizational objectives
- Lack of planning
- Lack of mechanisms for the formulation of strategies in managing the organization
- Non clarity of organizational policies about WCM techniques
- To Change of priorities
- Lack of persistence
- Failure to allow sufficient time for the evolution
- Lack of coordination among the processes
- Financial constraints

(v) Performance Appraisal Barriers (B5)

Following barriers are included in under this category.

- Lack of continuous quality control.
- Lack of appropriate monitoring.
- Lack of feedback from customers.
- Lack of attention to the needs of internal and external customers.
- Lack of access of data and results.

Digraph Development

A diagraph is developed between above said five categorizes at system level. The description of the diagraph is given as. Human and cultural barriers (B3) affect the working of the personnel, therefore human and cultural barriers (B3) and behavioral barriers (B1) is connected by a directed edge. The behavioural barrier (B1) is shown affecting all the other barriers. It is the lack of commitment, involvement and relations of people in an organisation that affect all other barriers. Non behavioural barriers (B2) affect performance appraisal barriers (B5). It is the poor facilities, lack of equipment, tools and materials and non utilization of tools, techniques and methodologies that lead to performance appraisal barriers. This is shown by a directed node from B2 to B5. Non behavioural barriers (B2) do not affect human and cultural barriers (B3), behavioural barriers (B1) and tactical barriers (B4), so there is no directed edge from B2 to B3, B1 and B4. But Tactical barriers (B4) affect all others barriers and it is shown through a directed edge from B4 to B1, B2, B3 and B5. It is the non clarity of organisation policy, objectives, implementation plan and inflexibility that affect all other barriers. Performance appraisal barriers (B5) affect B3 and B1. It is the ineffective performance measurement techniques and inadequate attention to customers that affect behavioural barriers and human and cultural barriers. The diagraph is shown as below. Here in the diagraph a node directed in both sides is used in place of two separate nodes. Such node indicates that both the barriers affect each other between which it is drawn.

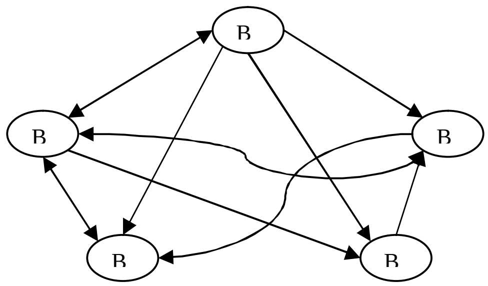

Figure 3.1 *Diagraph for Barriers at System Level*

The Matrix Representation

A digraph is a visual representation so it helps in analysis to a limited extent only. To establish the expression for WCM barriers, the digraph is represented in matrix form, which is also a convenient form of computer processing (Attri and Raj; 2010). Consider a digraph of n barriers leading to an *n*-th order symmetric (0, 1) matrix A = [bij]. The rows and columns in the matrix represent interactions among barriers, *i.e.*, bij represents the interaction of the *i*-th barrier with the *j*-th barrier:

bij = 1; if barrier i is connected to barrier j
= 0, otherwise.
bii = 0, as a barrier, is not interacting with itself.

This WCM barriers matrix is square and non symmetric. The generalized WCM barriers matrix representing the digraph of categories can be written as below:

$$\begin{matrix} & B_1 & B_2 & B_3 & .... & .... & B_N & & Barriers(B_i) \\ B = & \begin{Bmatrix} B_1 & b_{12} & b_{13} & .... & .... & b_{1N} \\ b_{21} & B_2 & b_{23} & .... & .... & b_{2N} \\ b_{31} & b_{32} & B_3 & .... & .... & b_{3N} \\ .... & .... & .... & .... & .... & .... \\ .... & .... & .... & .... & .... & .... \\ b_{N1} & b_{N2} & b_{N3} & .... & .... & B_N \end{Bmatrix} & & \begin{matrix} B_1 \\ B_2 \\ B_3 \\ .... \\ .... \\ B_N \end{matrix} \end{matrix}$$

Permanent Function

Permanent function of barrier interaction is called Variable Permanent System Barrier Function, abbreviated as VPF-ep and for matrix representation in the above section is written in sigma form in expression as shown below. Equation contains $N!$ terms organized in $N+1$ groups, where *N* is number of elements. The physical implication of various grouping is elucidated as under:

- The first grouping epitomizes the measures of *N* barriers.
- The second grouping is absent as there is no self-loop in the digraph.
- The third grouping encompasses 2-design barriers interaction loops and measures of (*N-2*) barriers.
- Each term of the fourth grouping exemplifies a set of 3- barriers interaction loop or its pair and measures of (*N-3*) barriers.
- The fifth grouping comprises two subgrouping. The terms of the first subgrouping are a set of two 2- barriers interaction loops and the measures of (*N-4*) barriers. Each term of the second subgrouping is a set of 4 - barriers interaction loop or its pair and the measures of (*N-4*) barriers.
- The sixth grouping encompasses two subgrouping. The terms of the first subgrouping is a set of 3- barriers interaction loop or its pair and 2- barriers interaction loop and the measures of (*N-5*) barriers. Each term of the second subgrouping is a set of 5- barriers interaction loop or its pair and the measures of (*N-5*) barriers.

Correspondingly other terms of the expression are demarcated.

$$
\begin{aligned}
per(B^*) = {} & \prod_{1}^{N} B_i + \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N b_{ij} b_{ji} B_k B_l \cdots\cdots B_N \\
& + \Big\{ \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{ij} b_{jk} b_{ki} \right) B_l B_m \cdots\cdots B_N \\
& + \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{ik} b_{kj} b_{ji} \right) B_l B_m \cdots\cdots B_N + \Big\} \\
& + \Big[\Big\{ \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{ij} b_{ji} \right) \left(b_{kl} b_{lk} \right) B_m B_n \cdots\cdots B_N \Big\} \\
& + \Big\{ \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{ij} b_{jk} b_{kl} b_{li} \right) B_m B_n \cdots\cdots B_N \\
& + \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{il} b_{lk} b_{kj} b_{ji} \right) B_m B_n \cdots\cdots B_N \Big\} \Big] \\
& + \Big[\Big\{ \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{ij} b_{ji} \right) \left(b_{kl} b_{lm} b_{mk} \right) B_n B_o \cdots\cdots B_N \\
& + \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{ij} b_{ji} \right) \left(b_{km} b_{ml} b_{lk} \right) B_n B_o \cdots\cdots B_N \Big\} \\
& + \Big\{ \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{ij} b_{jk} b_{kl} b_{lm} b_{mi} \right) B_n B_o \cdots\cdots B_N \\
& + \sum_i \sum_j \sum_k \sum_l \cdots\cdots \sum_N \left(b_{im} b_{ml} b_{lk} b_{kj} b_{ji} \right) B_n B_o \cdots\cdots B_N \Big\} \Big] + \cdots\cdots
\end{aligned}
$$

Quantification of inheritance and interdependencies of design parameters may be established with the help of industrial data or literature survey. The data available in literature is on a variable scale. This data source may vary from place to place. Therefore, it is required to standardize the data. For this purpose two standard tables available in the literature are adopted. These tables are on the scale of 1-9 and 1-5. If industrial data is not available then quantification of diagonal elements of matrix can be done on a scale of 1-9 as given in Table 3.1, based on the inheritance of each design parameters. Interdependency is decided on the scale of 1-5 as per Table 3.2.

Table 3.1 *Quantification of WCM Barriers*

S. No.	Qualitative measure of WCM barriers	Assigned value of barriers (inheritance)
1	Exceptionally low	1
2	Very Low	2
3	Low	3
4	Below average	4
5	Average	5
6	Above Average	6
7	High	7
8	Very High	8
9	Exceptionally High	9

Table 3.2 *Quantification of Interdependencies/ off Diagonal Elements*

S. No.	Qualitative measure of interdependencies	Assigned value of interdependencies
1	Very Strong	5
2	Strong	4
3	Medium	3
4	Weak	2
5	Very weak	1

4. Steps of the Methodology Developed

Following steps are involved in the proposed methodology.

1. Identify the various barriers affecting the implementation of WCM. Barrier may differ from organisation to organisation depending on the size of organisation, prevailing culture and environmental factors.
2. Group the identified barriers into categories.
3. Develop digraph between the major barrier categories (at system level) depending on their interdependencies. This is the digraph at the system level.
4. Develop digraph for the individual barrier category between the barriers in each category as done in step (3). This is the digraph at the sub-system level.

5. Develop sub-barrier matrix for each category of barrier. This will be of size M × M, with diagonal elements representing attributes and the off-diagonal elements representing interactions among them. Substitute the value of inheritance and interdependency in sub-barrier matrix of each barrier category. The value of inheritance (diagonal element) of WCM barrier is to be decided on the basis of scale 1–9 and value of interdependency is decided by the experts (academia and industries) on the basis of scale 1–5.
6. Compute the value of permanent function for each category of barrier.
7. Develop WCM barrier matrix at the system level.
8. Put the value of inheritance and interdependency in barrier matrix of system level. At the system level,
9. The permanent value of each sub-barrier matrix provides inheritance of barrier in WCM implementation and quantitative value of interactions among barriers is decided on the basis of scale (1–5) through proper interpretation by experts.
10. Find the value of permanent function for the system. This value of permanent function will provide the intensity of barrier. This is the value of BI_{WCM} which mathematically characterizes the inhibiting strength of various barriers in a particular organisation based on the presence of different barriers and their interdependence.
11. Record the results of study and document them for future analysis.

5. Limitations of Present Study

The present study finds various barriers to the implementation of WCM in Indian industries. It is well known that no work can be faultless. In this study identification of barriers is done through extreme literature review and verified by a questionnaire based survey. The information collected from questionnaire may be erratic. Therefore quality of work depends upon the information collected. The present study is limited to automotive industries.

Scope of future work

The gap in the existing work always creates an opportunity for further work. The present study is limited to automotive industries therefore it can be done for other industries like sheet metal industries. Further more in future new barriers may arise and present barriers may not behave as barriers. The result of the present study is qualitative in nature; therefore in future a mathematical model may be developed to get quantitative results.

Conclusion

The main aim of this study is to identify various barriers to the world class manufacturing in Indian firms. The objective is fulfilled by identifying various barriers through extreme literature review. These barriers are verified by conducting a questionnaire based survey in automotive industries. It is very important to remove these obstacles to implement WCM in the organizations. Therefore preventive and corrective steps can be taken on the basis of present study to overcome these barriers. This study may be taken as the important step towards the formulating strategies and tactics that remove the obstacles in the way of successful implementation of WCM in Indian manufacturing firms.

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