# Evaluation of intensities of Barriers in implementing Total Productive Maintenance (TPM) using Digraph and Matrix approach

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**Abstract:-** *The purpose of this paper is to evaluate the intensities of various barriers in implementing Total Productive Maintenance in an organisation and drive managerial insights. In this paper a graph theoretic approach has been used to find the intensity of the barriers through an index which is calculated through a permanent function attained from the digraph of TPM barriers. Four major barriers have been found from literature- Cultural barriers, Behavioural barriers, Technical barriers and Strategic barriers. The GTA method also permits modelling of interactions among various sub-barriers under each major barrier. It has been found that Technical barriers have the highest intensity in the case study and strategic barriers have lowest intensity. The intensities of each enabler is represented as a single numeric value.As the intensity of each enabler is known, managers can effectively utilize them during TPM implementation.*

## 1 INTRODUCTION

Modern dynamic market is forcing manufacturing organisations to adapt to novel techniques to increase their productivity. In this challenging ambience, reliability becomes an important factor in gaining competitive edge. Thus, effective and efficient maintenance is required by manufacturing organisations that want to be successful. Total Productive Maintenance (TPM) has emerged as one such approach that improves the performance of maintenance activities (Ahuja and Kumar, 2009).

In 1971, Seiichi Nakajima, regarded as the father of TPM, defined it as a program to maximize equipment effectiveness by establishing a maintenance system that covers entire life of equipment, requires participation from all employee and spans all equipment related fields.

TPM consists of three words: (1) Total-emphasisinginvolvement of everybody from top management to workers (2) Productive- signifies performing the maintenance work while production goes on (3) Maintenance- means keeping equipment in good condition by repairing, cleaning and greasing (Ahuja and Khamba ,2007). TPM originated in 1970s in the Japanese car industry. It developedas an indispensible part of the Toyota Production System at Nippondenso which was a major supplier of the Toyota Car Company (Ahuja and Kumar, 2009).

Implementing TPM has resulted into increased productivity by increasing equipment utilization, reducing breakdowns and motivating employees. Thus, companies were able to produce products of high quality at lower rates and that too at safer work environment (Ahuja and Khamba 2008b).

Though TPM provides a lot of benefits, implementation of TPM is a difficult task. According to Mora (2002) in recent years of all companies that have attempted to implement TPM programs, less than 10 % succeeded in implementing TPM.

## 2 Identification and categorisation of barriers in TPM implementation

On the basis of literature analysis and interactions with the managers (maintenance and production), a large number of barriers inhibiting the TPM implementation in industries were identified. As the number of these barriers is large, it becomes very difficult to perform their quantification by GTA. These barriers are grouped into different categories so that their intensity can be computed without much difficulty. If these large numbers of barriers are not categorised, then, this computation process will become highly complex and difficult. This conception of categorisation of factors has been done by some researchers (Wani and Gandhi 1999; Grover, Agrawal, and Khan 2004, 2006; Raj and Attri 2010; Raj, Shankar, and Suhaib 2010a, 2010b) in their work. For graph theoretic analysis, identified barriers are grouped into four categories (Figure 1) in the present study.
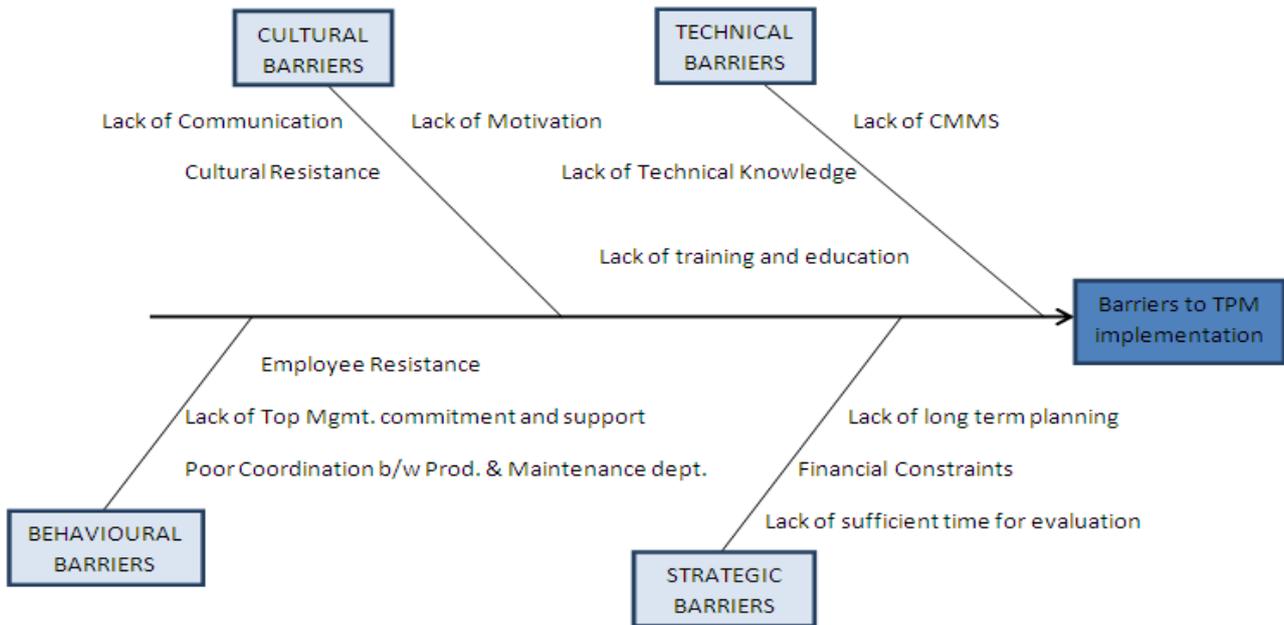
## 2.1 Cultural Barriers

The working of human resource is greatly affected by the prevailing culture in any organisation. Values and behaviour of workers are linked to these barriers which affects the work culture of the organisation (Attri, Grover, Dev 2014).

In UK Manufacturing organisations, Bamber, Sharp and Hides (1999) found motivation of both workers and management to be a deciding factor in successfully implementing TPM. Ahuja and Khamba (2008a, b) have also identified lack of motivation as a key obstacle in successfully implementing TPM in Indian manufacturing organizations. Lack of communication is also a key barrier in TPM implementation as specified by Ahuja and Khamba (2008b) and Becker (1993) as lack of communication often leads to less employee participation and also lowers their motivation.

According to Lawrence (1999) most TPM programs fail because of the inability of organisations to change their culture. Radical transformation of culture when required is one of the most necessary steps in ensuring successful TPM implementation (Attri, Grover, Dev, Kumar 2012a). Resisting this change by employees due to various reasons, also blocks successful TPM implementation as reported by Ahuja and Khamba (2008a, b) and Becker (1993).

Table: 1

| | | |
|---|---|---|
| $B^1_1$ | Lack of Motivation | Bamber, Sharp and Hides(1999) |
| | | Ahuja and Khamba (2008 a,b) |
| | | Attri, Grover, Dev, Kumar (2012 a) |
| $B^1_2$ | Lack of Communication | Becker (1993) |
| | | Ahuja and Khamba (2008 b) |
| | | Attri, Grover, Dev, Kumar (2012 a) |
| $B^1_3$ | Cultural Resistance | Ahuja and Khamba (2008 a,b) |
| | | Lawrence (1999) |
| | | Becker (1993) |

## 2.2 Behavioural Barriers

These barriers are related to the behaviour of employees because the behaviour of employees also plays an important role in successful TPM implementation(Attri, Grover and Dev 2014).

Lack of top management support has been attributed as one of the key reasons for unsuccessful TPM implementation by Co, Eddy and Hu(1998) and Chan et al. (2005). According to Attri, Grover, Dev, Kumar (2012a), top management when fail to understand the true goals of TPM are often not able to support others. The management's goal should always be to increase equipment utilization and not to reduce workers (Bamber, Sharp and Hides 1999).

According to Ahuja and Khamba (2008a,b) lack of coordination among maintenance and production personnel greatly affects successful TPM implementation. Relation between departments has huge influence on the performance of the organisation and thereby impacts successful TPM implementation (Attri, Grover, Dev, Kumar 2012a).

Table: 2

| $B^2_1$ | Lack of Top Management commitment and support | Co, Eddy and Hu (1998) |
|---|---|---|
| | | Bamber, Sharp and Hides(1999) |
| | | Chan et al (2005) |
| $B^2_2$ | Employee Resistance | Lawrence (1999) |
| | | Cooke (2000) |
| | | Ahuja and Khamba (2008 b) |
| $B^2_3$ | Poor Coordination between Production and Maintenance dept. | Ahuja and Khamba (2008 a,b) |
| | | Attri, Grover, Dev, Kumar (2012 a) |

## 2.3 Technical Barriers

Lack of knowledge about TPM principles and implementation practices acts as a major obstacle in successfully implementing TPM according to Baglee and Knowles (2010). Lack of knowledge of TPM or its benefits causes people to misinterpret what TPM actually is and also creates vague expectations.

Chan et al. (2005) have found lack of training and education to be one of the major reasons for TPM activities to fail because it not only leads to decreased equipment utilization but also makes shift to new and better technologies less viable. Efforts have to be made to change the mind-sets of workers and help them embrace new technologies (Bamber, Sharp and Hides 1999).

Absence of Computer Maintenance Management System (CMMS) has been found byAhuja and Khamba (2008c) as one of the major obstacles in successfully implementing TPM. CMMS makes data gathering and sharing amongst departments easy and convenient.

Table: 3

| $B^3_1$ | Lack of Technical Knowledge | Ahuja and Khamba (2008 b) |
|---|---|---|
| | | Attri, Grover, Dev, Kumar (2012 a) |
| $B^3_2$ | Lack of Training and Education | Becker (1993) |
| | | Chan et al (2005) |
| | | Ahuja and Khamba (2008 b) |
| $B^3_3$ | Absence of CMMS | Ahuja and Khamba (2008 c) |
| | | Attri, Grover, Dev, Kumar (2012 a) |

## 2.4 Strategic Barriers

Strategic planning of step by step process of TPM implementation is of paramount importance as it provides an outline for the decision-making required, taking into account potential risk factors and a robust feedback system to assess real time developments during the implementation phase itself (Raj and Attri 2010).

There is also need for long-term planning for not only the entire implementation phase but also after TPM has been implemented because TPM is not a method of attaining short-term fixes, but is a long-term guarantee to endeavour zero losses (Bamber, Sharp and Hides 1999).

Planning of finances is also an imperative issue in Indian manufacturing organisations as reported by Ahuja and Khamba (2008a).

Bakerjan (1994) has considerednot allowingadequate time for evaluation to be one of the major hindrancesin successful TPM implementation.For a reactive program to change into a proactive one, it takes three to five years.

Table: 4

| $B^4_1$ | Lack of Long term planning | Ahuja and Khamba (2008 c) |
|---|---|---|
| | | Attri, Grover and Dev (2014) |
| $B^4_2$ | Financial Constraints | Ahuja and Khamba (2008 a,c) |
| | | Attri, Grover, Dev, Kumar (2012 a) |
| | | Attri, Grover and Dev (2014) |
| $B^4_3$ | Lack of sufficient time for evaluation | Bamber, Sharp and Hides(1999) |
| | | Beckerjan (1994) |

**3 MEASURING THE BARRIERS OF TPM USING GRAPH THEORY**

3.1 Justification and explanation for adopting graph theory

The rationale for choosing Graph Theory Approach over other methods will be discussed in this section. Limestone and Turoff (1975) presented the Delphi method which is a structured method for forecasting in several fields. In Delphi technique several experts are asked a series of questions in form of a questionnaire and based on their common ground, consensus is created. The main problems faced while using Delphi technique is lack of reliability and consistency in experts' opinions and to gauge their degree of expertise (Makridakis and Wheelwright, 1987).

Structural equation models or SEMs is another method in which the relationships among variables are represented mathematically. In SEM, theory,and not collected data, is the main driver for development of model making it an "a priori" technique (Kline, 1998). The precision of the SEM model however depends largely on the sample size, so a large sample size is required for obtaining high precision (Anbanandam, Banwet and Shankar, 2011).

The purpose of this paper is to quantify the barriers in implementing TPM. This can be found by quantifying the inheritance if variables and interaction among them. This is not possible if we use SEM or Delphi technique.

However by using Graph Theory, not only analysis of the interactions among the variables can be done, but also they can be easily transformed into mathematical equations (Anbanandam, Banwet and Shankar 2011). Visual analysis and computer processing can also be performed if we use Graph Theory (Deo, 1974).

Some other approaches like case studies or empirical studies also don't work because they are industry specific or fail to establish interdependencies among the variables. Also, modification of variables one specified is not possible if we use these methods(Kaur, Kanda and Deshmukh, 2006).

On the other hand, Graph Theoretic Approach is flexible enough to include new factors over the time and can be easily applied to wider range of industries (Grover, Agrawal and Khan, 2004).

3.2 Digraph representation

Digraphs are directed graphs that have nodes anddirectional edges which are used to represent the variables and their interdependencies. A TPM Barrier digraph represents the barriers ($B_i$'s) through its nodes and dependence of barriers ($b_{ij}$'s) through its edges. $B_i$ indicates the inheritance of factors and $b_{ij}$ indicates degree of dependence of $j^{th}$ factor on $i^{th}$ factor. The directed edge from node i to node j represents$b_{ij}$ in this digraph and hence makes it possible to show the interactions among factors. In particular four barriers identified form the digraph. The four barriers – cultural barrier ($B_1$), behavioural barrier ($B_2$), technical barrier ($B_3$) and strategic barrier ($B_4$) interactions amongst them are shown in Figure 2.
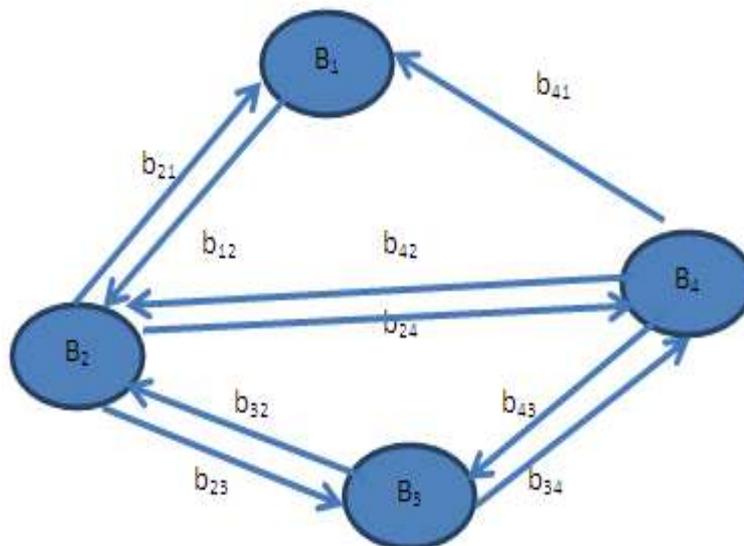


figure: 2

A brief reasoning of interactions (i.e. edges shown in the digraph) is given below.

As strategic barriers affect behavioural, cultural and technical barriers, edges aredirected from node 4 to all other nodes. However, behavioural and technical barriers may also affect strategic barriers to some extent. Thus, a directed edge from node 2 and node 3 to node 4.The extent to which one factor is dependent on other will not vary from one organization to another as it is global in nature.Behavioural barriers (B2) is dependent on cultural, technical and strategic barriers. Thus, edges are directed from node 1, 3and 4 to node 2. However, there is no edgedirected from node 1 to node 3 or from node

3 to node 1 as cultural and technical barriers are unrelated. Similarly as strategic barriers don't affect cultural barriers there is no edge directed from node 4 to node 1. Similarly other factors can be visualized from the digraph (Figure 2).

After the development of digraph between the barrier categories, digraphs for the individual barrier categories between the barriers in each category are developed. These are the digraphs at the sub-system level. Digraphs for each barrier categories are developed (Figures 6–10). In the digraphs, nodes represent the sub-barriers and edges represent their mutual interaction. Superscript denotes the sub-system and subscript indicates the barriers affecting the sub-system. It represents the relationships between the factors ($B^i$) and their interdependencies ($b_{ij}$) in the forms of nodes and edges. $b_{ij}$ indicates the degree of dependency of the $j^{th}$ attribute on the $i^{th}$ attribute. However, $b_{ij}$ is represented as a directed edge from node i to node j in the digraph.
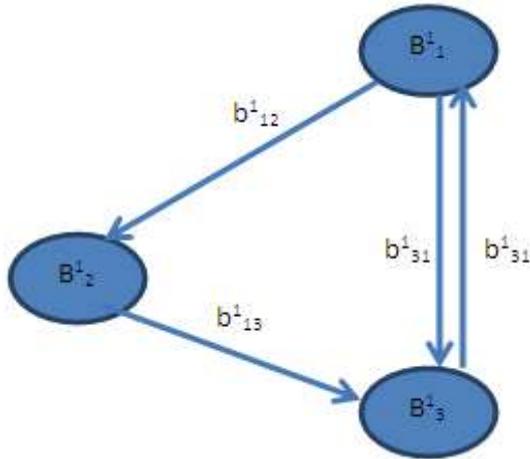


Figure: 3

Cultural resistance ($B^1_3$) is dependent on lack of communication andlack of communication. Thus, edges are directed from node 1 and 2 to node 3. However, there is no directed edge from node 2 to node 1 as lack of communication doesn't affect lack of motivation. Similarly other factors can be visualized from the digraph (Figure 3).
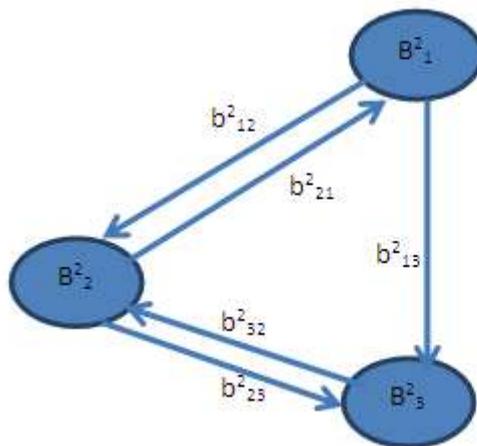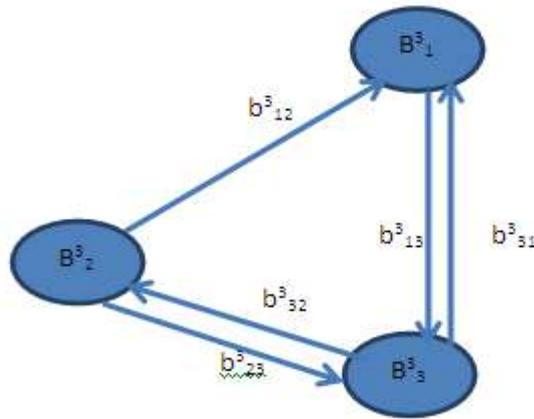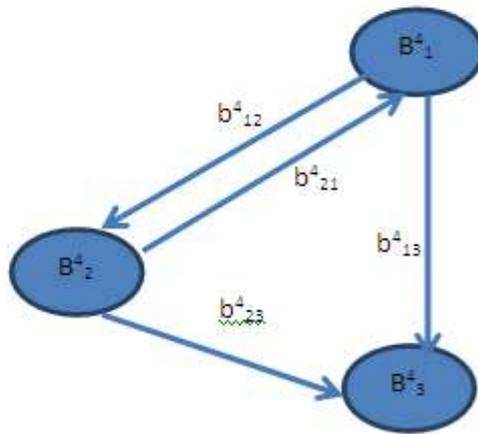


figure:4

figure:5



figure:6

3.3 Matrix representation

The digraphs presented above shows the relative importance of the barriers graphically. For a large number of sub-barriers, large number of nodes and edges are required, making the digraphs complex and visual examination difficult. Hence, matrices are introduced in order to make visual examination easy as matrices presents one-to-one barrier representation.

TPM barrier matrix is an N × N matrix, which considers all the barriers ($B_i$'s) and their relative interdependencies ($b_{ij}$'s). As a general case, if interaction among all the N categories of barriers is considered, the matrix is written as:

$$\text{TPM}_{N*N} = \begin{bmatrix} B_1 & b_{12} & \cdots & b_{1n} \\ b_{21} & B_2 & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \cdots \\ b_{n1} & b_{n2} & \cdots & B_N \end{bmatrix}$$

Matrix: 1

Thus, the variable permanent TPM matrix (VPM-B) corresponding to the four-critical barriers of TPM digraph (figure 2) is given by

$$\text{VPM-B} = \begin{bmatrix} B^1 & b_{12} & b_{13} & b_{14} \\ b_{21} & B^2 & b_{23} & b_{24} \\ b_{31} & b_{32} & B^3 & b_{34} \\ b_{41} & b_{42} & b_{43} & B^4 \end{bmatrix}$$

Matrix: 2

The diagonal elements $B_1$, $B_2$, $B_3$ and $B_4$represent the contribution of the four critical barriers in implementing TPM and the off-diagonal elements represent interdependencies of each barrier in the matrix.

3.4 Permanent representation

Both digraph and matrix representations are not unique because changing the labels on their nodes alters them. So, in order to develop a representation scheme that is not altered by changing the node labels, we introduce permanent function of the variable permanent matrix.

The permanent equation of matrix (1) or permanent of B is multinomial and is called variable permanent function (VPF-B). It is also represented as per (B) or per B. It can be solved using the general form of permanent equation (Sethi and Agrawal, 1993):

$$\text{Per(VPM-B)} = \prod_{i=1}^{4} B_i$$
$$+ \sum_i \sum_j \sum_k \sum_l (b_{ji}\, b_{ij})B_k B_l$$
$$+ \sum_i \sum_j \sum_k \sum_l (b_{ij}\, b_{jk}\, b_{ki} + b_{ik}\, b_{kj}\, b_{ji})B_l$$
$$+ \sum_i \sum_j \sum_k \sum_l (b_{ij}\, b_{ji})\,(b_{kl}\, b_{lk})$$
$$+ \sum_i \sum_j \sum_k \sum_l (b_{ij}\, b_{jk}\, b_{kl}\, b_{li} + b_{il}\, b_{lk}\, b_{kj}\, b_{ji})$$

The value obtained from the above equation represents DOR or Degree of Relationship – as it has captured both the degree of relationships between among critical barriers, and the contribution of each of these barriers by incorporating the degree of importance and the degree of relationship between the sub-barriers identified under each category. However, to solve this equation, the values for the entities in the matrix are needed which can be obtained from the literature.

3.5 Quantification of $B^I$'s and $b_{ij}$'s of the matrix for the given problem

Quantification of $B^i$'s at sub-system level. Each factor $B^i$ in matrix (1) can be considered as a sub-system with as many sub-factors affecting them. For clarity, the following notation is used: each sub-factor has been represented as $B^I_i$, where the subscript "i" represents the sub-factors that are grouped under a particular main factor, while the superscript "I" represents the critical factors.

Figures 3-6 show the digraphs representing the relationship and interdependencies among various sub-barriers within each of the main barrier for evaluating the intensities of barriers. Using those diagraphs Permanent Matrices are derived using steps mentioned in the previous section. These matrices are named VPM-$B_1$, VPM-$B_2$, VPM-$B_3$ and VPM-$B_4$ respectively. The value of $B_i^{1}$'s within the sub-system matrix represents the inheritances, while $b_{ij}^{1}$'s represent the interdependencies.

$$\text{VPM-B}_1 = \begin{bmatrix} B_1^1 & b_{12}^1 & b_{13}^1 \\ b_{21}^1 & B_2^1 & b_{23}^1 \\ b_{31}^1 & b_{32}^1 & B_3^1 \end{bmatrix}$$

Matrix: 3

Similar to matrix (2), VPMs for others main factors can be developed. From these matrices, the permanent function can be estimated using the general form of permanent equation after obtaining the values for $B_i^{1}$'s and $B_{ij}^{1}$'s.

$$\text{VPM-B}_2 = \begin{bmatrix} B_1^2 & b_{12}^2 & b_{13}^2 \\ b_{21}^2 & B_2^2 & b_{23}^2 \\ b_{31}^2 & b_{32}^2 & B_3^2 \end{bmatrix} \qquad \text{VPM-B}_3 = \begin{bmatrix} B_1^3 & b_{12}^3 & b_{13}^3 \\ b_{21}^3 & B_2^3 & b_{23}^3 \\ b_{31}^3 & b_{32}^3 & B_3^3 \end{bmatrix} \qquad \text{VPM-B}_4 = \begin{bmatrix} B_1^4 & b_{12}^4 & b_{13}^4 \\ b_{21}^4 & B_2^4 & b_{23}^4 \\ b_{31}^4 & b_{32}^4 & B_3^4 \end{bmatrix}$$

Matrices: 4-6

As mentioned earlier, the $B_i^I$ values within permanent matrices of sub-systems represent the rating of the organisation against each of the barriers, can be evaluated using a suitable scale. Table 5 suggests a scale to capture the degree of importance within the organisation ($B_i^{1}$'s) under the sub-systems. This scale is adapted from the Saaty's (1980) relative scale of importance used in the AHP. The value of $b_{ij}^I$'s represents the degree of relationships between two sub-barriers, which is assessed using another scale as shown in Table 6. Table 2]6 represents the scale to obtain the values of interdependencies ($b_{ij}$'s) between barrier($B_i$'s).

Table 5

| Scale | Degree of Importance |
|---|---|
| 1 | Extremely Low |
| 2 | Very Low |
| 3 | Low |
| 4 | Marginally Low |
| 5 | Average |
| 6 | Marginally High |
| 7 | High |
| 8 | Very High |
| 9 | Extremely High |

Table 6

| Qualitative Measure of Interdependency | Assigned Value of Factor |
|---|---|
| Very Strong | 5 |
| Strong | 4 |
| Medium | 3 |
| Weak | 2 |
| Very Weak | 1 |

In order to assess the relationship between different sub-factors, weight values can be collected from the team members through discussions or direct observation. For instance, under the "Technical Barriers" category, the "Absence of CMMS" represented as $(B^3_3)$ is related to other sub-factors such as "Lack of Training and Education" $(B^3_2)$ and "Lack of Technical Knowledge" $(B^3_1)$ in both ways. However, lack of training and education will have more impact on absence of CMMS; hence, a value of "4" is provided for $b^3_{23}$ while a value of "1" is only assigned for $b^3_{32}$, as the influence of absence of CMMS on lack of training and education is relatively weaker. In a similar manner, the values for remaining $b^I_{ij}$'s are obtained. In case, if there is no relationship (i.e. there is no directed arrow from one node to another in the digraph) then a value of "0" is assigned. For example, as cultural resistance doesn't affect lack of communication a value of "0" is assigned to $b^1_{32}$.

$$\text{VPM-B}_1 = \begin{bmatrix} 7 & 3 & 3 \\ 0 & 7 & 3 \\ 1 & 0 & 6 \end{bmatrix} \quad \text{VPM-B}_2 = \begin{bmatrix} 9 & 3 & 2 \\ 4 & 6 & 4 \\ 0 & 4 & 5 \end{bmatrix} \quad \text{VPM-B}_3 = \begin{bmatrix} 8 & 0 & 2 \\ 4 & 8 & 4 \\ 2 & 1 & 7 \end{bmatrix} \quad \text{VPM-B}_4 = \begin{bmatrix} 7 & 3 & 4 \\ 1 & 7 & 1 \\ 0 & 0 & 6 \end{bmatrix}$$

Matrices: 7-10

3.6 Evaluation of Permanent Value for each matrix

The permanent function value for each barrier category is computed .From the derived variable permanent matrices VPM-B$_1$, VPM-B$_2$, VPM-B$_3$ and VPM-B$_4$ the permanent of the matrices can be calculated, which are represented as Per (VPM-B$_1$), Per (VPM-B$_2$) and so on.

$$\text{Per( VPM-B}_4) = B^4{}_1 B^4{}_2 B^4{}_3 + (b^4{}_{21} b^4{}_{12} B^4{}_3 + b^4{}_{31} b^4{}_{13} B^4{}_2 + b^4{}_{23} b^4{}_{32} B^4{}_1) + (b^4{}_{12} b^4{}_{23} b^4{}_{31} + b^4{}_{13} b^4{}_{32} b^4{}_{21})$$

$$\text{i.e. Per( VPM-B}_4) = 7*7*6 + (1*3*6 + 4*0*7 + 1*0*7 ) + ( 3*1*0 + 4*0*1 )$$

$$= 294 + 18 + 0 = 312$$

In the same way Per(VPM-B$_1$), Per(VPM-B$_3$) and Per(VPM-B$_3$) can be found.

$$\text{Per(VPM-B}_1) = 324$$
$$\text{Per(VPM-B}_2) = 506$$
$$\text{Per(VPM-B}_3) = 520$$
$$\text{Per(VPM-B}_4) = 312$$

TPM barrier matrix at the system level is developed by taking the values of diagonal elements from sub-system level i.e. permanent function value for each barrier category as shown:

$$\text{VPM-B} = \begin{bmatrix} 324 & 4 & 0 & 0 \\ 4 & 506 & 3 & 4 \\ 0 & 2 & 520 & 3 \\ 3 & 3 & 3 & 312 \end{bmatrix}$$

Matrix: 11

The value of the permanent function is computed by using equation of permanent function and is found to be equal to 2.66E+10. This value indicates the value of intensity of barriers of TPM in the organisation under consideration. Besides this, it also portrays the inhibiting power of barriers mathematically in the path of implementation of TPM.

## 4 RANGE OF INTENSITY OF BARRIERS

The hypothetical highest and lowest values of eachPer(VPM-B$_i$) constitute the range of intensity of barrier B$_i$. For finding the highest value of Per(VPM-B$_i$), the inheritance value of each barrier is taken to be 9, and similarly, for finding its lowest possible value, the inheritance values are taken to be 1. As an example, for Behavioural barriers (B$_2$), VPM-B$_2$ $_{max}$and VPM-B$_2$ $_{min}$are shown below. The permanent value is minimum when the inheritance values of each sub-barrier are 1, and maximum when 9.

$$\text{VPM-B}_{2\ max} = \begin{bmatrix} 9 & 3 & 2 \\ 4 & 9 & 4 \\ 0 & 4 & 9 \end{bmatrix} \qquad \text{VPM-B}_{2\ min} = \begin{bmatrix} 1 & 3 & 2 \\ 4 & 1 & 4 \\ 0 & 4 & 1 \end{bmatrix}$$

Matrices: 12-13

Similarly, for each barrier category, minimum and maximum values of permanent function are calculated and are shown in the following table:

Table 7

| Permanent Function | Minimum Value | Maximum Value | Current Value |
|---|---|---|---|
| VPM-B$_1$ | 13 | 765 | 324 |
| VPM-B$_2$ | 61 | 1013 | 506 |
| VPM-B$_3$ | 17 | 809 | 520 |
| VPM-B$_4$ | 4 | 756 | 312 |
| VPM-B | 63705 | 3.57E+11 | 2.66E+10 |

## 5 CONCLUSIONS

Four major barriers in TPM implementation have been selected from literature and Graph Theoretic Approach has been applied to find their intensities. For each of those four barriers, their maximum possible and minimum possible values of intensities are also calculated. Using these three values, we can easily gauge the current functional capability of each barrier. Operation and maintenance managers can use this data to successfully implement TPM.

Current functional capacity for a barrier can be calculated as:

(Current value – Minimum value) / (Maximum value – Minimum value) * 100%

Thus, functional capabilities of each barriers are:

$B_1$ (Cultural barriers) :41.35%

$B_2$ (Behavioural barriers) :45.58%

$B_3$ (Technical barriers) :63.51%

$B_4$ (Strategic barriers) :40.95%

Although, the intensity of each barrier is represented as a numeric value, they can not be compared with each other.However, because the functional capabilities of barriers are evenly scaled they can be compared with each other to get managerial insights.

High value of functional capability of a barrier suggests that operation managers need to focus on reducing the impact of that barrier before and during implementing TPM. This knowledge of functional capability of several major barriers makes it possible for operation or maintenance managers to take timely and sound decisions.

In this case, the Technical Barriers have the highest intensity suggesting that managers need to pay special attention to training and education of employees as well as implement CMMS before implementing TPM.

Graph Theoretic Approach which has been used here is flexible i.e. new Barriers if found can be added anytime. Also, the interdependencies can be altered if required. As demonstrated, it is clear that visual examination is also very easy and useful if GTA is used.

## 6 FUTURE SCOPES

In the current paper four major barriers are stated and discussed. But due to dynamic nature of the organisation, new barriers may surface, or, some old ones may turn obsolete. Due to flexible nature of GTA these new barriers can be incorporated in the future.

On the basis of barrier intensities, two or more organisations can be compared. Similar organisations will have identical digraphs and this is only possible if they have similar TPM barrier matrices.

This method has huge future scope in analysing TPM implementation and removing the roadblocks for successful implementation. Healthy competition will be promoted if organisations are compared on this basis.

## References

1. Ahuja, I. P. S., &Khamba, J. S. (2007). An evaluation of TPM implementation initiatives in an Indian manufacturing enterprise. *Journal of Quality in Maintenance Engineering*, *13*(4), 338-352.

2. Ahuja, I. P. S., &Khamba, J. S. (2008a). "An evaluation of TPM initiatives in Indian industry for enhanced manufacturing performance", International Journal of Quality & Reliability Management, Vol. 25 Issue: 2, pp.147-172

3. Ahuja, I. P. S., &Khamba, J. S. (2008b). Total productive maintenance: literature review and directions. *International Journal of Quality & Reliability Management*, *25*(7), 709-756.

4. Ahuja, I. P. S., &Khamba, J. S. (2008c). Strategies and success factors for overcoming challenges in TPM implementation in Indian manufacturing industry. *Journal of Quality in Maintenance Engineering*, *14*(2), 123-147.

5. Ahuja, I. P. S., & Kumar, P. (2009). A case study of total productive maintenance implementation at precision tube mills. *Journal of Quality in Maintenance Engineering*, *15*(3), 241-258.

6. Anbanandam, R., Banwet, D. K., & Shankar, R. (2011). Evaluation of supply chain collaboration: a case of apparel retail industry in India. *International Journal of productivity and Performance management*, *60*(2), 82-98.

7. Attri, R., Grover, S., &Dev, N. (2014). A graph theoretic approach to evaluate the intensity of barriers in the implementation of total productive maintenance (TPM). *International Journal of Production Research*, *52*(10), 3032-3051.

8. Attri, R., Grover, S., Dev, N., & Kumar, D. (2013). Analysis of barriers of total productive maintenance (TPM). *International Journal of Systems Assurance Engineering and Management*, 1-13.

9. Attri, R., S. Grover, N. Dev, and D. Kumar. 2012. "An ISM Approach for Modelling the Enablers in the Implementation of Total Productive Maintenance (TPM)." International Journal System Assurance Engineering and Management 4 (4): 313–326.

10. Attri, R., S. Grover, N. Dev, and D. Kumar. 2012a. "Analysis of Barriers of Total Productive Maintenance (TPM)." International Journal System Assurance Engineering and Management 4 (4): 365–377.

11. Baglee, D., & Knowles, M. (2010). Maintenance strategy development within SMEs: the development of an integrated approach. *Control and Cybernetics*, *39*(1), 275-303.

12. Bamber, C. J., Sharp, J. M., & Hides, M. T. (1999). Factors affecting successful implementation of total productive maintenance: a UK manufacturing case study perspective. *Journal of Quality in Maintenance engineering*, *5*(3), 162-181.

13. Becker, S. W. (1993). TQM does work: ten reasons why misguided attempts fail. *Management Review*, *82*(5), 30.

14. Chan, F. T. S., Lau, H. C. W., Ip, R. W. L., Chan, H. K., & Kong, S. (2005). Implementation of total productive maintenance: A case study. *International Journal of Production Economics*, *95*(1), 71-94.

15. Co, H. C., Eddy Patuwo, B., & Hu, M. Y. (1998). The human factor in advanced manufacturing technology adoption: An empirical analysis. *International Journal of Operations & Production Management*, *18*(1), 87-106.

16. Grover*, S., Agrawal, V. P., & Khan, I. A. (2004). A digraph approach to TQM evaluation of an industry. *International Journal of Production Research*, *42*(19), 4031-4053.

17. Grover, S., Agrawal, V. P., & Khan, I. A. (2006). Role of human factors in TQM: a graph theoretic approach. *Benchmarking: An International Journal*, *13*(4), 447-468.

18. Gurumurthy, A., Mazumdar, P., &Muthusubramanian, S. (2013). Graph theoretic approach for analysing the readiness of an organisation for adapting lean thinking: A case study. *International Journal of Organizational Analysis*, *21*(3), 396-427.

19. Kaur, A., Kanda, A., &Deshmukh, S. G. (2006). A graph theoretic approach for supply chain coordination. *international journal of logistics Systems and Management*, *2*(4), 321-341.

20. Kline,R. B. (1998). Principles and practice of structural equation modeling.NewYork:Guilford.

21. Lawrence, J. J. (1999). Use mathematical modeling to give your TPM implementation effort an extra boost. *Journal of Quality in Maintenance Engineering*, *5*(1), 62-69.

22. Linstone, H. A., &Turoff, M. (Eds.). (1975). *The Delphi method: Techniques and applications* (Vol. 29). Reading, MA: Addison-Wesley.

23. Makridakis, S., & Wheelwright, S.C. (1987). *The Handbook of Forecasting: A Manager's Guide, Second ed.,* Wiley, New York.

24. McKone, K. E., Schroeder, R. G., &Cua, K. O. (1999). Total productive maintenance: a contextual view. *Journal of operations management*, *17*(2), 123-144.

25. Mora, E. 2002. The Right Ingredients for a Successful TPM or Lean Implementation. www.tpmonline.com.

26. Park, K. S., & Han, S. W. (2001). TPM—Total Productive Maintenance: impact on competitiveness and a Framework for Successful Implementation. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *11*(4), 321-338.

27. Raj, T., &Attri, R. (2010). Quantifying barriers to implementing total quality management (TQM). *European Journal of Industrial Engineering*, *4*(3), 308-335.

28. Raj, T., Shankar, R., &Suhaib, M. (2010). GTA-based framework for evaluating the feasibility of transition to FMS. *Journal of Manufacturing Technology Management*, *21*(2), 160-187.

29. Raj, T., Shankar, R., Suhaib, M., & Khan, R. A. (2010). A graph-theoretic approach to evaluate the intensity of barriers in the implementation of FMSs. *International Journal of Services and Operations Management*, *7*(1), 24-52.

30. Sethi, V. K., &Agrawal, V. P. (1993). Hierarchical classification of kinematic chains: a multigraph approach. *Mechanism and machine theory*, *28*(4), 601-614.

31. Wani, M. F., & Gandhi, O. P. (1999). Development of maintainability index for mechanical systems. *Reliability Engineering & System Safety*, *65*(3), 259-270.