International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 21 (2019) pp. 4047-4054

Evaluation of the Intensities of Enablers in the Implementation of Total Productive Maintenance (TPM) using Graph Theoretic Approach

Soumava Mandal[1], Rajeev Saha[2]

[1]*Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India.*

[2]*Department of Mechanical Engineering, YMCA University of Technology, Faridabad, India.*

Abstract

Modern manufacturing due to its highly competitive environment, demands organisations not only to have efficient manufacturing processes but also efficient maintenance procedures to be successful. Thus to achieve competitive advantage, companies worldwide have started implementing Total Productive Maintenance (TPM) to improve equipment efficiency and thus enhancing productiveness of production facilities. However, recent studies show that a number of organisations have failed to implement such strategies successfully. But, there are also several factors that facilitate TPM implementation significantly. In this paper twelve such enablers are identified from literature and then grouped into four categories: Cultural enablers, Behavioural enablers, Technical enablers and Strategic enablers. This paper aims to find the mutual relationship among these enablers and then create a model that provides a single numeric value corresponding to each enabler revealing their intensity, which can be of great help to the implementing managers. The relationships among enablers are shown using digraphs and matrices, and the intensity is computed though a permanent function obtained from corresponding digraphs.

Keywords: TPM Enablers; Graph Theoretic Approach; Maintenance; TPM

I. INTRODUCTION

The modern global marketplace is putting massive pressures on manufacturing organizations to acclimatize to proactive and innovative strategies for increasing the efficiency of their production system (Ahuja and Khamba, 2008a). In contemporary challenging atmosphere, reliable production systems are considered vital factors for competitiveness. Therefore, effective maintenance becomes a strategic issue for most manufacturing organizations for creating world-class-manufacturers (Brah and Chong, 2004).This recent focus on efficient and effective maintenance requirements have been asserting manufacturing managers to accentuate upon increasing equipment utilization, resource utilization thereby increasing maintenance productivity and quality of maintenance services to meet global standards imperative for surviving competition (Garg and Deshmukh, 2006).Traditionally maintenance was viewed as an operational expense which had to be minimized and not as an investment which would increase process reliability. But now it has been established that to achieve excellence in performance it is imperative to invest significantly in maintenance (Ahuja and Kumar, 2009). TPM is a putative strategy for increasing the performance of maintenance activities, which is paramount for succeeding in highly competitive markets (Nakajima, 1988).

Seiichi Nakajima, who is regarded as father of TPM, has defined TPM as a novel approach of maintenance which aims to eliminate breakdowns and promote autonomous maintenance by involving total workforce through everyday activities (Conway and Perry, 1999; Bhadury, 2000).

The procedure of TPM implementation in an organisation involves transformation of their shop floor by integrating cultures, processes and technologies. TPM has a completely new attitude towards maintenance as it not just a maintenance policy but a culture and a philosophy which has a holistic emphasis on organisations- their processes, the equipment and also human beings (Ahuja and Khamba, 2008a). Most researches on TPM implementation have been conducted on isolated cases where the authors are typically employees of the case company (Park and Han 2001). This paper aims to enlist the factors that contribute to successful TPM implementation. Having identified the patterns of success in the implementation of TPM, an important question is: How do these factors affect each other? Hence, in this paper, 12 enablers have been identified through literature and expert opinions, and analysed using the Graph Theoretical approach, which not only shows the inter-relationships amongst the enablers, but also their driving power and dependencies.

II. BENEFITS OF TPM

The crux of TPM is that production operators work on preventive maintenance (PM) and assist mechanics with repairs when equipment breaks down, and, together, they carry out improvements in equipment and processes (Jostes & Helms, 1994).

The most concrete benefit is planned and controlled maintenance expenses (Adair-Healy, 1989). Another very substantial benefit is that the maintenance force is greatly reduced. By assigning all the Preventive Maintenance activities to the production operators, the number maintenance personnel previously employed drastically reduces. This leads to not only a reduction in indirect labour, but also removes unnecessary scheduling of the PM work related to production and logistics (Van-Lane, 1991).

Thirdly, with an increase in employee involvement, there is notable improvement in employee relations. Also, due of improvements in product quality, customer satisfaction also increases. TPM helps achieve customer expectations of a consistent, reliable product (Park and Han 2001).

Fourth, problem solving rate of operators increases as they become more familiar with the tools and techniques used in the problem-solving process (Park and Han 2001).

Lastly, because of increased equipment reliability, there is less deviation from the work flow schedule and that increases production efficiency (Steinbacher & Steinbacher, 1993).

III. IDENTIFICATION OF TPM ENABLERS

Many effective criteria for successful and systematic TPM implementation ate presented in TPM literature. For realising the true potential of TPM it is very important to integrate TPM goals and plans with the organisation's strategic and business plans because TPM is not just limited to production but involves transformation of the whole organisation by integrating culture, processes and technologies.

The first task is establishing a strategic direction to be followed for TPM implementation. The functioning of production and maintenance managers need a paradigm shift for successful transition into TPM from traditional maintenance program. As TPM is a philosophy and not just a set of instructions, this shift requires a considerable change in attitude of the production and maintenance managers. (Ahuja and Khamba, 2008b).

For implementing TPM successfully in an organization, Swanson (1997) has recommended four key components: worker training, preventive maintenance, operator involvement and teams.

As this study considers a large number of enablers, the process of quantifying their intensities by GTA will require highly complex and difficult computations. Hence, these enablers are grouped into different categories so that their intensity can be computed without much difficulty. This concept of categorisation of factors has been used by many researchers (Wani and Gandhi 1999; Grover, Agrawal, and Khan 2004, 2006; Raj and Attri 2010; Raj, Shankar, and Suhaib 2010a, 2010b) in their works. For graph theoretic analysis, enablers are grouped into four categories in the present study.

III.I. Cultural Enablers

In any organization, the working of human resources is significantly affected by the culture prevailing in the organization. Cultural Enablers are those factors which are related to the organizational culture.

Workforce and management motivation were found to be a key factor affecting successful TPM implementation by Bamber, Chris, Sharp and Hides (1999) in UK manufacturing organizations. Motivation changes employee behaviour from negative to positive regarding work and hence it is required that all employees participating in TPM activities are motivated to do so (Attri, Grover, Dev and Kumar 2012).

Any exchange of information or understanding among different persons is communication. The exchange should preferably take place within the recipients' understanding and in the recipients' language (Eti, Ogaji and Probert 2004). Communication is very important in securing support for Total Productive Maintenance implementation (Park and Han 2001). Communication also helps the employees know about some of the philosophical and technical aspects of TPM (Attri, Grover, Dev and Kumar 2012).

As TPM implementation often involves total transformation of the shop floor it is quite important to bring about a change is the prevailing culture of the organisation to ensure overall employee participation. Top management has the most crucial job of clearly communicating with all employees about TPM project, make them understand its importance and motivate them to participate in it (Ahuja and Khamba 2008a).Preparation for TPM implementation includes creation of a favourable environment. According to Park and Han (2001), achieving a paradigm shift in the assumptions and beliefs of employees that support conducive implementation culture is both difficult and lengthy since change is aroused by unfavourable circumstances such as a crisis or low productivity and is mostly management driven.

Table 1: Cultural Enablers

E^1_1	Motivation	Bamber, Chris, Sharp and Hides (1999)
		Attri, Grover, Dev and Kumar (2012)
E^1_2	Communication	Park and Han (2001)
		Eti, Ogaji and Probert (2004)
		Attri, Grover, Dev and Kumar (2012)
E^1_3	Cultural Change	Park and Han (2001)
		Ahuja and Khamba (2008)

III.II. Behavioural Enablers

These enablers are concerned with the behaviour of management and workers of the organisation.

Along with training and motivation of workers, top management support, commitment and thorough understanding of TPM is vital in successful implementation of TPM. (Park and Han 2001). Bamber, Chris, Sharp and Hides (1999) have found management commitment as the most important factor which affects successful implementation of TPM.

Top management support ensures that TPM goals are incorporated in business strategy and such policies are continued across company divisions (Park and Han 2001). Top management should have strong commitment and evolve mechanisms to bring all employees in board by explaining them the scope of TPM by effective communication and coordination (Ahuja and Khamba 2008a).

Successful TPM implementation assumes the ready cooperation of all people within the organization (Attri, Grover, Dev and Kumar 2012). TPM emphasizes that for maximizing efficiency, operators, planners, designers and maintenance technicians must work as a team (Park and Han 2001). TPM should be treated as a team activity not as a single man activity since it requires overall cooperation of all employees especially maintenance and production personnel (Attri, Grover, Dev and Kumar 2012).

Table 2: Behavioural Enablers

E^2_1	Top management commitment and support	Bamber, Chris, Sharp and Hides (1999)
		Park and Han (2001)
		Ahuja and Khamba (2008)
E^2_2	Coordination	Park and Han (2001)
		Attri, Grover, Dev and Kumar (2012)
E^2_3	Cooperation	Park and Han (2001)
		Attri, Grover, Dev and Kumar (2012)

III.III. Technical Enablers

These enablers reflect the knowledge of the TPM concepts and principles to the employee.

Chan et al. (2005) have found training to be the most important TPM enabler in an electronics manufacturing company. Training and development of the employees must be ensured by the top management. This can be done by improving their skills, giving them knowledge and changing their attitudes so as to increase their productivity and achieve higher standards of quality. According to Ahuja and Khamba (2008a) this results in elimination of product defects, accidents and equipment failure and creation of a sense of pride among all employees. During employee training, equal focus must be given to enhancing skills and adding knowledge (Eti, Ogaji and Probert 2004).

According to Marques, Adolfo and Gupta (2004) Computer Maintenance Management System allows proper monitoring and control of personnel, equipment and schedules. Installation of CMMS is considered significant when the number of items to be monitored is high or the complexity of the plant is high.

Employee training should especially focus on necessary multi-skills and appropriate knowledge (Eti, Ogaji and Probert 2004). Thiagarajan, Thu and Zairi (1997) have recommended training and education as the most important factor after commitment has been secured.

Table 3: Technical Enablers

E^3_1	Training and Education	Ahuja and Khamba (2008 a)
		Chan et al (2005)
		Eti, Ogaji and Probert (2004)
E^3_2	CMMS	Adolfo and Gupta (2004)
		Fakhraddin Maroofi (2013)
E^3_3	Knowledge about TPM	Eti, Ogaji and Probert (2004)
		Thiagarajan and Zairi (1997)

III.IV. Strategic Enablers

To successfully implement TPM it is important to align TPM goals and objectives with the business plans of the organization. This is because TPM is not just limited to production, but affects the entire organization (Attri, Grover, Dev and Kumar 2012). The first step in implementing TPM is to establish a strategic plan for TPM. (Ahuja and Khamba 2008b).

Total employee involvement is an important pre-requite for successful TPM implementation and it can be ensured by augmenting the competencies of all employees towards the jobs, instilling the feeling of equipment ownership, providing adequate employee counselling and deploying safe working environment in the organizations (Ahuja and Khamba 2008a). Maximization of equipment utilization in TPM is achieved through total employee involvement and by using Autonomous Maintenance in form of small group activities which improves equipment maintainability, reliability and productivity (Chen 1997). Moreover, TPM requires not only active participation from all shop floor operators in successful conduct of continuous improvements activities but also cross functional teamwork and work suggestion schemes (Nakajima 1989).

People should be empowered so that they have the confidence and commitment to take responsibility of their actions. This encourages employee participation in TPM related activities (Davis and Willmott 1999). Employee empowerment is desired for creation of long-standing commitments amongst all personnel. Management must involve all employees in setting targets and planning a way to realize them (Eti, Ogaji and Probert 2004; Agyris 1998). The employees including operators should be empowered and encouraged to participate in TPM activities.

Table 4: Strategic Enablers

E^4_1	Integrating Goals and Plans	Ahuja and Khamba (2 008 b)
		Attri, Grover, Dev and Kumar (2012)
E^4_2	Total employee involvement	Chen (1997)
		Ahuja and Khamba (2008 a)
E^4_3	Empowerment and Encouragement	Patterson, Fredendall, Kennedy and McGee (1996)
		Eti, Ogaji and Probert (2004)

IV. GRAPH THEORETIC APPROACH

Phase 1: Development of digraphs

Step 1. The problem for which GTA is applied is determined. In this case, the problem is to evaluate the intensities of various enablers of TPM implementation.

Step 2. The factors affecting the problem under study are identified and are represented as E_is. In this case we have to identify the Enablers affecting TPM performance. As discussed earlier. We have identified four such enablers- Cultural Enablers (E_1), Behavioural Enablers (E_2), Technical Enablers (E_3) and Strategic Enablers (E_4).

Step 3. Relationships among critical enablers are developed using a digraph considering their interdependencies. This digraph serves the purpose of graphically capturing the inheritances and interdependencies among the critical enablers. The digraph represents the relationships between the enablers (E_i) and their interdependencies (e_{ij}) using nodes and edges where e_{ij} indicates the degree of dependency of the j^{th} enabler on the i^{th} enabler. However, e_{ij} is represented as an edge directed from node i to node j in the digraph.

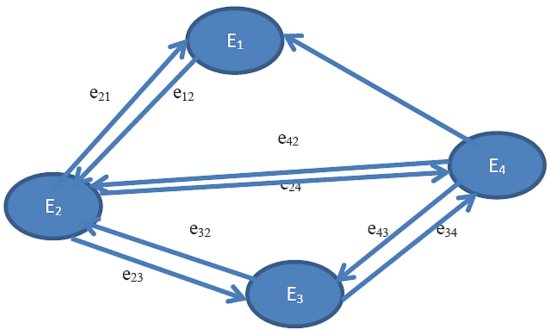

Figure: 1

Step 4. Relationships among the sub enablers are developed using a digraph for each critical enabler. The purpose of these digraphs is to graphically represent the inheritances and interdependencies among the sub-enablers under each critical enabler category. The sub enablers are represented as E^I_i where I represent the critical enabler category and i represents the sub enabler as explained in tables 1-4. e^I_{ij} represents the degree of dependency of the j^{th} enabler on the i^{th} enabler in I^{th} critical enabler category.

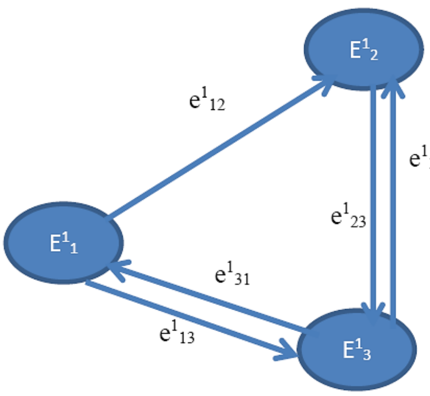

Figure: 2

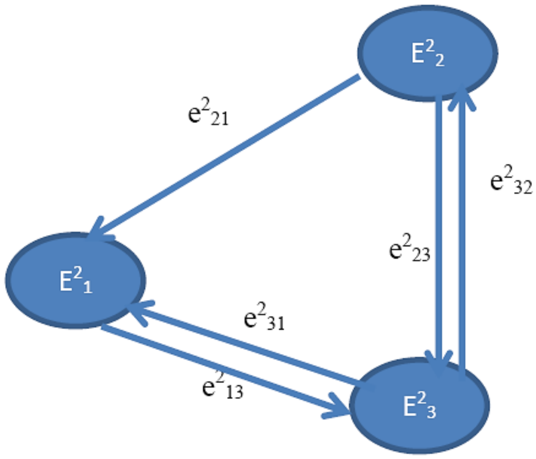

Figure: 3

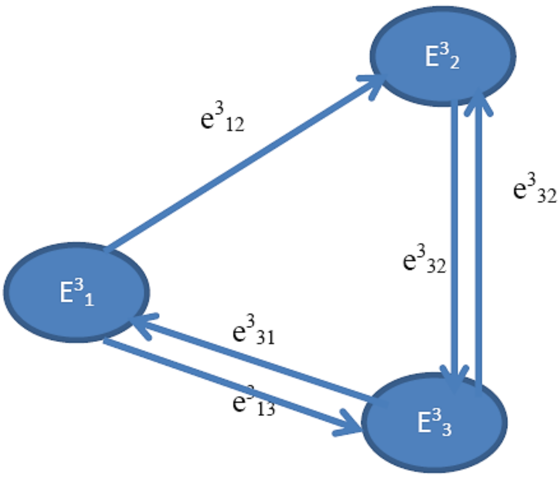

Figure: 4

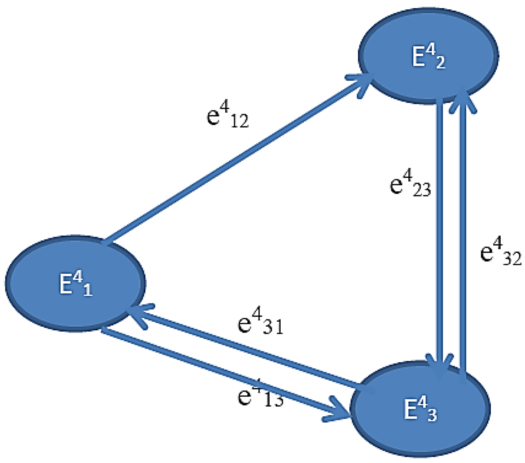

Figure: 5

Phase 2: Development of Permanent Matrices

Step 5. The permanent matrix at the level of critical enablers is represented as matrix VPM-E. The actual permanent matrix showing the degree of relationships of the case organisation is derived from digraph (Figure 1) and is shown below:

$$\text{VPM-E} = \begin{bmatrix} E_1 & e_{12} & 0 & 0 \\ e_{21} & E_2 & e_{23} & e_{24} \\ 0 & e_{32} & E_3 & e_{34} \\ e_{41} & e_{42} & e_{43} & {E_4}^4 \end{bmatrix} \qquad \text{matrix:1}$$

The nodes in the digraph which are represented as E_1 to E_4 occupy the diagonal position in the matrix VPM-E, while the off-diagonal elements are filled according to the relationship that exists between the critical enablers, which are represented using arrows in Figure 1. If an arrow is not present between the main factors, then the corresponding value in the matrix VPM-E is taken to be "0". This permanent matrix serves the purpose of capturing the degree of interdependencies (represented by e_{ij}'s) among the critical enablers, which directly impact the degree of inheritances represented by E_I's in mathematical form.

Step 6. The permanent equation of matrix (1) or permanent of VPM-E is multinomial and is called variable permanent function. It is also represented as per(VPM-E). It can be solved using the general form of permanent equation (Sethi and Agrawal, 1993):

$$\begin{aligned} \text{Per(VPM-E)} = & \prod_{i=1}^{4} E_i \\ & + \textstyle\sum_i \sum_j \sum_k \sum_l (e_{ji} e_{ij}) E_k E_l \\ & + \textstyle\sum_i \sum_j \sum_k \sum_l (e_{ij} e_{jk} e_{ki} + e_{ik} e_{kj} e_{ji}) E_l \\ & + \textstyle\sum_i \sum_j \sum_k \sum_l (e_{ij} e_{ji})\,(e_{kl} e_{lk}) \\ & + \textstyle\sum_i \sum_j \sum_k \sum_l (e_{ij} e_{jk} e_{kl} e_{li} + e_{il} e_{lk} e_{kj} e_{ji}) \end{aligned}$$

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

Phase 3: Quantification of E_i's and e_{ij}'s of the matrix for the given problem

Step 7. Quantification of E_i's at sub-system level. Each factor E_i in matrix (1) is considered a sub-system with as many sub-enablers affecting them. For clarity, the following notation is used: each sub-enabler has been represented as E^I_i, where the subscript "i" represents sub-enablers that are grouped under a particular critical enabler, while the superscript "I" represents critical enabler. For estimating the values of E_i's and the interdependency values e_{ij}'s in the VPM-E matrix (1), the following steps are followed:

The digraph for each sub- enabler are drawn in figures 2-5 in the previous phase, which represents the relationship and interdependencies among various sub-enablers within each of the main enabler for finding the intensities of enablers.

Using the steps in phase 2, the permanent matrices for sub-enablers represented as VPM-E_1, VPM-E_2, VPM-E_3 and VPM-E_4 are derived. The value of E_i^I's within the sub-system matrix represents inheritances, while e_{ij}^I's represent interdependencies.

$$\text{VPM-E}_1 = \begin{bmatrix} E_1^1 & e_{12}^1 & e_{13}^1 \\ e_{21}^1 & E_2^1 & e_{23}^1 \\ e_{31}^1 & e_{32}^1 & E_3^1 \end{bmatrix}$$

$$\text{VPM-B}_2 = \begin{bmatrix} E_1^2 & e_{12}^2 & e_{13}^2 \\ e_{21}^2 & E_2^2 & e_{23}^2 \\ e_{31}^2 & e_{32}^2 & E_3^2 \end{bmatrix}$$

$$\text{VPM-B}_3 = \begin{bmatrix} E_1^3 & e_{12}^3 & e_{13}^3 \\ e_{21}^3 & E_2^3 & e_{23}^3 \\ e_{31}^3 & e_{32}^3 & E_3^3 \end{bmatrix}$$

$$\text{VPM-B}_4 = \begin{bmatrix} E_1^4 & e_{12}^4 & e_{13}^4 \\ e_{21}^4 & E_2^4 & e_{23}^4 \\ e_{31}^4 & e_{32}^4 & E_3^4 \end{bmatrix} \qquad \text{matrices: 2-5}$$

From these matrices, the permanent function can be estimated using the general form of permanent equation after obtaining the values for E_i^I's and e_{ij}^I's.

As mentioned earlier, the E_i^I values within permanent matrices of sub-enablers represent the rating of the organisation against each of the enablers, which can be evaluated using an appropriate scale. Table 5 presents a scale to capture the degree of importance within the organisation (E_i^I's) under the sub-systems. This scale is adapted from Saaty's (1980) relative scale of importance.

Step 8. The value of e^I_{ij}'s represents the degree of relationships between two sub-enablers, which is measured using another scale as shown in Table 6. Table 6 represents the scale using which the values of interdependencies (e_{ij}'s) between enablers (E_j's) can be obtained.

Table 5: Scale Capturing Degrees of Importance

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: Scale Capturing Measure of Interdependencies

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

In assessing the relationship between different sub-enablers, weight values are collected from team members through discussions or direct observation. For instance, under the "Cultural Enablers" category, the "Communication" represented as (E^2_2) is related to other sub-factors such as "Cultural Change" (E^2_3), "Motivation" (E^2_1) in both ways. However, motivation will have more impact on communication; hence, the value of "3" is provided for e^1_{12}, while the value of "2" is only assigned for e^1_{32}, as the influence of cultural change on communication is relatively weak. In a similar manner, the values for remaining e^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 "Empowerment and Encouragement" doesn't affect "Integrating Goals and Plans" a value of "0" is assigned for e^4_{31}. The variable permanent matrices VPM-E_1, VPM-E_2, VPM-E_3 and VPM-E_4 are shown below:

$$\text{VPM-}E_1 = \begin{bmatrix} 7 & 3 & 3 \\ 0 & 7 & 3 \\ 2 & 2 & 6 \end{bmatrix} \qquad \text{VPM-}E_2 = \begin{bmatrix} 9 & 1 & 2 \\ 0 & 5 & 1 \\ 1 & 2 & 6 \end{bmatrix}$$

$$\text{VPM-}E_3 = \begin{bmatrix} 5 & 4 & 4 \\ 0 & 7 & 2 \\ 0 & 2 & 6 \end{bmatrix} \qquad \text{VPM-}E_4 = \begin{bmatrix} 6 & 1 & 2 \\ 0 & 8 & 3 \\ 0 & 1 & 7 \end{bmatrix}$$

Matrices: 7-10

Step 9. From the derived variable permanent matrices VPM-E_1, VPM-E_2, VPM-E_3 and VPM-E_4 the permanent of the matrices can be calculated, which are represented as Per(VPM-E_1), Per(VPM-E_2), Per(VPM-E_3) and Per(VPM-E_4). A sample permanent value for VPM-E_4 representing the degree of relationship of the "Strategic Enablers" is shown below:

$$\text{Per(VPM-}E_4) = E^4_1 E^4_2 E^4_3 + (e^4_{21}e^4_{12}E^4_3 + e^4_{31}e^4_{13}E^4_2 + e^4_{23}e^4_{32}E^4_1) + (e^4_{12}e^4_{23}e^4_{31} + e^4_{13}e^4_{32}e^4_{21})$$

$$\text{i.e. Per(VPM-}E_4) = 6*8*7 + (1*0*7 + 2*0*8 + 1*3*6) + (1*3*0 + 2*1*0)$$

$$= 336 + 18 + 0 = 354$$

Phase 4: Evaluating the value of VPM-E matrix

Step 10. For evaluation of the value of permanent matrix E at system level (i.e. matrix (1)) it is necessary to have the off-diagonal and diagonal values. The values of diagonal elements for matrix (1) are obtained from the "permanent" values estimated for each sub-system.

$$\text{Per (VPM-}E_1) = 396$$

$$\text{Per (VPM-}E_2) = 299$$

$$\text{Per (VPM-}E_3) = 230$$

$$\text{Per (VPM-}E_4) = 354$$

In the diagonal of the matrix, the permanent values such as 396, 299, etc. are used. The values of off-diagonal elements (e_{ij}'s) for matrix (1) can be obtained from Table 6 based on the degree of interdependencies (relationships) among the elements (E_i's). The complete VPM-E matrix is shown below:

$$\text{VPM-E} = \begin{bmatrix} 396 & 4 & 0 & 0 \\ 4 & 299 & 3 & 4 \\ 0 & 2 & 230 & 3 \\ 3 & 3 & 3 & 354 \end{bmatrix} \qquad \text{Matrix: 11}$$

Step 11. Again, the value of permanent function for the system level matrix is calculated using the general form of permanent equation and is found to be equal to $9.6*10^9$. This value indicates the value of Intensity of Enablers of TPM in the organization under consideration. Besides this, it also portrays the inhibiting power of enablers mathematically in the path of implementation of TPM.

V. RANGE OF INTENSITY OF ENABLERS

To find the range of the intensity of enablers, the hypothetical lowest and highest values of Per(VPM-E) are calculated. To estimate the highest hypothetical value of Per(VPM-E), the value of inheritance of each enabler is taken to be 9 and to find the lowest hypothetical value, the value of inheritance is taken to be 1. For example, for the category Technical Enablers, the value of permanent is maximum when inheritance of all its sub-enablers is 9 and minimum when inheritance of all sub-enablers is 1.

$$\text{VPM-}E_{3\,max} = \begin{bmatrix} 9 & 4 & 4 \\ 0 & 9 & 2 \\ 0 & 2 & 9 \end{bmatrix}$$

$$\text{VPM-}E_{3\,min} = \begin{bmatrix} 1 & 4 & 4 \\ 0 & 1 & 2 \\ 0 & 2 & 1 \end{bmatrix} \qquad \text{Matrices: 12-13}$$

In a similar way for each enabler category the maximum and minimum values are calculated. Using these values the maximum and minimum values at system level can be computed. Table 7 below shows all such values.

Table 7

Permanent Function	Minimum Value	Maximum Value	Current Value
VPM-E_1	31	855	396
VPM-E_2	6	766	299
VPM-E_3	5	765	230
VPM-E_4	4	756	354
VPM-E	9055	3.78795E+11	9643936647

VI. CONCLUSION

In this paper, four main enablers of TPM implementation, along with their sub-enablers, have been identified from literature and an attempt has been made to find the relationship among them. For each of the four main enablers, the maximum and minimum intensities have been calculated using graph theory. The values have then been utilized in finding the functional capability of each main enabler.

The functional capability is a scaled index represented as a percentage of total capability. It helps managers, both operational and maintenance, gauge the current extent to which the enablers have been utilized for TPM implementation. For a specific enabler, its functional capability can be calculated using the following formula:

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

For various main enablers, their functional capabilities have been independently calculated and are found to be:

E_1 (Cultural enablers): 44.29%

E_2 (Behavioural enablers): 38.55%

E_3 (Technical enablers): 29.60%

E_4 (Strategic enablers): 46.54%

As the functional capabilities are scaled (1-100); they can be compared amongst themselves and can help in decision making. The higher value of functional capability suggests that the enabler plays a large role in that organization. Managers must focus on improving the factors affecting enablers that have low functional capability.

In this example, Strategic enablers have the highest functional capability while technical enablers have the lowest functional capability. Therefore, managers must work to improve training, educating and imparting necessary skills to employees. Computerized Maintenance Management System (CMMS) implementation should also be ensured before implementing Total Productive Maintenance (TPM).

VII. FUTURE SCOPE

In the present work, four major categories of enablers are identified from literature for the quantification of enablers in the implementation of TPM. In the future, data may be collected from companies using questionnaires to better understand positions of different industries. Also the data can be verified using various means.

Further, as the world is ever changing, it is expected that new enablers will emerge and some of these will become obsolete. To handle this kind of situation, computer software can be developed which will quicken the quantification process.

REFERENCES

[1] Adair-Healy, C. B. (1989). Teams and Just-in-time: Why and How. In *Proceedings of the 32nd International Conference of the American Production and Inventory Control Society, Orlando* (pp. 576-577).

[2] Agyris C (1998) Empowerment: the emperor's new clothes. Harvard Bus Rev 76(3):98–105

[3] 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*, *25*(2), 147-172.

[4] 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.

[5] Amik Garg, S.G. Deshmukh, (2006) "Maintenance management: literature review and directions", Journal of Quality in Maintenance Engineering, Vol. 12 Issue: 3, pp.205-238, https://doi.org/10.1108/13552510610685075

[6] Attri, R., Grover, S., Dev, N., & Kumar, D. (2013). An ISM approach for modelling the enablers in the implementation of Total Productive Maintenance (TPM). *International Journal of System Assurance Engineering and Management*, *4*(4), 313-326.

[7] 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.

[8] Bhadury, B. (2000). Management of productivity through TPM. *Productivity*, *41*(2), 240-51.

[9] 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.

[10] Chen F (1997) Issue in the continuous improvement process for preventive maintenance: observations from Honda, Nippondenso and Toyota. Prod Inventory Manag J 38(4):13–16

[11] Conway, T., & Perry, E. (1999). Incorporating statistical process control into the team-based TPM environment. In *Semiconductor Manufacturing Conference Proceedings, 1999 IEEE International Symposium on* (pp. 281-284). IEEE.

[12] Davis R, Willmott P (1999) Total productive maintenance. Alden Press, Oxford

[13] Eti, M. C., Ogaji, S. O. T., & Probert, S. D. (2004). Implementing total productive maintenance in Nigerian manufacturing industries. *Applied energy*, *79*(4), 385-401.

[14] 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.

[15] 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.

[16] 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.

[17] Marquez, A. C., & Gupta, J. N. (2004). Modern Maintenance Management for Enhancing Organizational Efficiency. In *Intelligent Enterprises of the 21st Century* (pp. 321-332). IGI Global.

[18] Nakajima, S. (1988). Introduction to TPM: Total Productive Maintenance.(Translation). *Productivity Press, Inc.*, *1988,*, 129.

[19] 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.

[20] Patterson JW, Fredendall LD, Kennedy WJ, McGee A (1996) Adapting total productive maintenance to Asten, Inc. Prod Inventory Manag J 37(4):32–36

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

[22] 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.

[23] 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.

[24] Robert S. Jostes, Marilyn M. Helms, (1994) "Total Productive Maintenance and Its Link to Total Quality Management", Work Study, Vol. 43 Issue: 7, pp.18-20, https://doi.org/10.1108/EUM0000000004012

[25] S.A. Brah, W.K. Chong (2004) "Relationship between total productive maintenance and performance", International Journal of Production Research, Vol. 42 Issue: 12, pp. 2383-2401

[26] Saaty, T. L. (1980). *Analytic hierarchy process*. John Wiley & Sons, Ltd.

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

[28] Steinbacher, H. R., & Steinbacher, N. L. (1993). *TPM for America: What it is and why you need it*. Productivity Press.

[29] Swanson, L. (1997). An empirical study of the relationship between production technology and maintenance management. *International Journal of Production Economics*, *53*(2), 191-207.

[30] Thiagarajan, T., & Zairi, M. (1997). A review of total quality management in practice: understanding the fundamentals through examples of best practice applications-Part I. *The TQM magazine*, *9*(4), 270-286.

[31] Van-Lane, B. (1991). Jacks of all trades. PEM: Plant Engineering and Maintenance, 14, 53–55.

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