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TOTAL PRODUCTIVE MAINTENANCE IMPLEMENTATION PROCEDURES IN MANUFACTURING ORGANIZATIONS USING AXIOMATIC DESIGN PRINCIPLES

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ABSTRACT

Total Productive Maintenance (TPM) is one of the World Class Manufacturing tools that seeks to manage assets by involving everyone in the manufacturing organization. The financial and productivity benefits of implementing TPM are significant. Many approaches have been proposed regarding TPM implementation procedures, of which logically sequenced implementation procedure is an identified success factor; yet the majority of TPM implementation attempts fail to achieve their intended goals. Moreover, Axiomatic Design principles have been proven to provide fast and reliable implementation procedures for engineering and non-engineering applications. This paper aims to assess a reliable TPM implementation procedure by systematically arranging the TPM affiliated parameters using Axiomatic Design principles. The paper presents an open TPM implementation matrix for organizations to further develop in accordance to their needs.

Keywords: Total Productive Maintenance (TPM), Axiomatic Design, implementation procedures.

1 INTRODUCTION

TPM is one of the World Class Manufacturing tools that seeks to manage assets by involving everyone in manufacturing organization. Nakajima [1989] defined TPM as an organization wide programme that tries to create a conducive environment to maximize effectiveness of a production system by eliminating accidents, defects, and breakdowns. "TPM involves everyone in an organization, from top-level management to production mechanics, and production support groups to outside suppliers" [Ahuja and Khamba, 2008a].

The financial and productivity benefits of TPM for a manufacturing organization are significant. TPM has a strong impact on manufacturing performance in terms of low cost, high level of quality and strong delivery performance [McKone *et al.*, 2001]. A case study by Ahuja and Khamba [2007] in manufacturing organizations that have successfully implemented TPM reported a 14-45% improvement in overall equipment effectiveness (OEE), a 45-58% reduction in inventory, a 22-41% improvement in plant output, 50-75% reduction in customer rejections, a 90-98% reduction in accident, a 18-45% reduction in maintenance cost, a 65-80% reduction in defects and rework, a 65-78% reduction in breakdowns, an 8-27% reduction in energy costs, and a 32-65% increase in employee suggestions.

Considering the stated benefits, researchers and TPM practitioners have been proposing different TPM implementation approaches. A twelve-step implementation methodology has been developed by Nakajima [1988]; additions and improvements to this methodology have been suggested by Hartmann [1992], Pirsig [1996], Carannante *et al.* [1996], Bamber *et al.* [1999], Leflar [2001], and Ahuja and Khamba [2009]. One of the prevalent TPM implementation approaches is that of Japanese Institute of Plant maintenance (JIPM)—the eight pillar approach which includes autonomous maintenance, focused maintenance, planned maintenance, quality maintenance, education and training, office TPM, development management, and safety health and environment [Ireland and Dale, 2001; Rodrigues and Hatakeyama, 2006]. A similar approach purposed by Ahuja and Khamba [2009] suggests an Indigenous TPM methodology with top management commitment, cultural transformation, employee involvement and integration, KAIZEN, education and training, CMMS, 5S, and visual workplace as foundations to the JIPM's remaining pillars plus tool management and maintenance benchmarking pillars. The methodology also suggests deploying key performance indicators and lean manufacturing practices and sustaining TPM initiatives as requirements to standardize the TPM program.

The common goal of the above TPM implementation methodologies is to avoid all losses that impede a manufacturing organization's performance. Shirose [1996] proposed the inclusion of 16 losses which are categorized as seven major losses impeding equipment efficiency (breakdown, setup/ adjustment, speed, idling/minor stoppages, defects/rework, startup, and tool changeover losses], loss that impede machine loading time [planned shutdown loss], five major losses that impede human performance (logistic/ distribution, line organization, measurement/adjustment, management and motion losses) and three major losses that impede effective use of production resources (yield, consumables, and energy losses).

With so many TPM implementation options and clearly identified losses, however, less than 10% of the companies that attempted to implement TPM succeeded to achieve their goals [Mora, 2011]. Further, a common TPM implementation methodology for all organizations cannot be developed due to factors such as variable skills and age of the workforce, complexities and age of equipment, organizational cultures, and status of maintenance capability [Wireman, 2004]. Moreover, working out the right sequence of initiatives for deploying TPM practices successfully in a structured and most effective manner has been a challenge and an identified success factor for organizations world-wide, a key element of TPM programs [Ahuja and Khamba, 2008a].

With these needs in mind, this paper uses Axiomatic Design principles for developing a structured and logically sequenced TPM implementation process. Axiomatic Design principles have been expanded and applied to numerous engineering and non-engineering applications and proved to provide structured implementation procedures [Kulak *et al.*, 2010] and specifically the principles have been used in design of manufacturing systems systemically and logically [Cochran *et al.*, 2002]. In the following sections, the steps followed in the decomposition of the TPM implementation process are explained and the matrix generated out of the decomposition is discussed.

2 DECOMPOSITION OF TPM IMPLEMENTATION PROCEDURE

Top management expectations out of a successful TPM implementation can fairly be assumed to be the same in all organizations. According to Yamaguchi [2011], from a management point of view, a successful implementation of a TPM project should yield increased productivity, reduced costs and customer complaints, and eliminated accidents. Nakajima [1988] recommends allocation of time to prepare and kick-off the TPM program; and Ahuja and Khamba [2008a] cover many papers that suggest the need to practice the necessary activities to sustain the program. Hence,

FR0 - Implement TPM successfully
DP0 - Methods for successful TPM implementation

Further decomposing DP0- Methods for successful TPM implementation yields:

Table 1. FR/DP1 decomposition.

	FR	DP
1	Initiate a TPM program	Preparation stage and TPM kick-off
2	Reduce accidents to zero	Methods to reduce accidents to zero
3	Reduce costs	Methods to reduce costs
4	Reduce customer complaints	Increasing customer satisfaction
5	Increase productivity	Methods to increase productivity
6	Sustain the TPM program	Methods to sustain TPM activities

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \\ FR4 \\ FR5 \\ FR6 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 & 0 \\ X & X & 0 & 0 & 0 & 0 \\ X & X & X & 0 & 0 & 0 \\ X & 0 & 0 & X & 0 & 0 \\ X & X & X & X & X & 0 \\ X & 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \\ DP4 \\ DP5 \\ DP6 \end{Bmatrix} \quad (1)$$

The above relationship between the FRs and DPs will be used as a TPM implementation framework which aids the TPM implementation process in discrete parts manufacturing organizations. The 6 FR/DP pairs (modules) are necessary and sufficient modules for a successful TPM implementation process. These modules are named as preparation and kick off, accidents, costs, customer satisfaction, productivity and sustainability modules. Any parameter affiliated with the TPM implementation process is considered to fit in any of the 6 modules, based on its primary effect on the process. The decomposition of the modules is summarized in Figure 1. The matrix is filled by posing a question while jumping from row to row, “Does this particular DP directly contribute to the performance of the FR in question?” The relationships between FRs and DPs and some of the proposed solutions (DPs) are based on author’s industrial experience, knowledge on TPM implementation process and wide literature references. Some of the decisions that produce the lower level FRs associated with TPM implementation process, shown in Figure 1, are briefly explained below.

2.1 INITIATING A TPM PROGRAM (FR/DP1)

Planning to implement a TPM program has a positive effect on all FRs of the program. Preparing and kicking-off a TPM program can follow the first six steps suggested by Nakajima [1988]. It is worth noting that the planning activities are done in such a way to increase the effect of the DP on the remaining 5 FRs.

2.2 REDUCING ACCIDENTS TO ZERO (FR/DP2)

OSHA [2011] lists the common causes of accidents in organizations; to eliminate the causes FR21-26 are identified. Further decomposition of one of the causes of accidents, DP22-methods to reduce equipment breakdown, yields FR221-involve everyone and FR222-planned maintenance.

2.3 REDUCING COSTS (FR/DP3)

Costs associated with TPM can be reduced by reducing inefficient use of production resources, labor cost, delays in recognizing and communicating problems, and facilities cost [Gomez *et al.* 2000], which lead to FR/DP31, FR/DP33, FR/DP321, FR/DP322, and FR/DP34 respectively. Further decomposition of FR/DP31 and FR/DP 33 lead to the three major losses that impede efficient use of production resources (energy, yield and consumables losses), two of the seven major losses that impede overall equipment efficiency (speed and defect/rework losses), and the five major losses that impede worker efficiency (logistic, inspection, motion, management and line organization losses). To maintain the functional independence of the FRs, equipment break down loss which can also be grouped under this module, is considered under FR2 only. The particular selection of the FRs is done in such a way to separate the requirements that directly affect predictability of the operations from those that do not.

				DP1	DP2: Methods to reduce accidents to zero							DP3: Methods to reduce costs													DP4: Increasing customer satisfaction				DP5: Methods to increase productivity						DP6: Methods to sustain TPM activity									
				Preparation stage & TPM kick-off	21 Education & training program	22: 221 Autonomous maintenance	222 Preventive maintenance	23 5S	24 Safe working environment	25 Mistake proof operation	26 Following standard procedures	31: 311 Quality maintenance	312 Energy system maintenance	313 Product & tool design	314 Sustaining optimum speed	315 Consumables management	32: 321 Configuration for detection of disruptions	322 Specified communication paths & procedures	33: 331 Automated process	332 Inspection integrated with operator work pattern	333 Uninterrupted material supply	334 Efficient layout	335 Balanced work flow	34 Reduction of consumed floor space	41 R & D	42 Office TPM	43 Fast office throughput	44 Rescheduling capability	51 Synchronization with break time	52 Operator engaged in value adding activity	53 Quick changeover mechanism	54 Converting internal to external setup	55 FMEA	56 Design to avoid production interruption	61 Top management commitment	62 Cross functional teams	63 Maintenance benchmarking	64 Lean manufacturing philosophy	65 Reward & recognition mechanism	66 KAIZEN activity	67 Standardization of improvements	68 Development maintenance	69 Investment based on long term strategy	Module #
FR1			Initiate TPM program	X																																								M1
FR2 Reduce Accidents to zero		21	Educate & train		X																																							M21
	22	221	Involve everyone		X	X																																	Y					M221
		222	Planned maintenance		X	X	X																																					M222
		23	Eliminate parts that drop & causes of slip		X			X																																				M23
		24	Eliminate health hazards		X	X	X	X	X																																			M24
		25	Ensure errors don't translate to accidents		X					X																																		M25
		26	Eliminate random activities		X					X	X																																	M26
FR3 Reduce costs	31	311	Eliminate defect & rework		X	X	X			X	X	X		Y											Y																			M311
		312	Eliminate energy loss			X	X				X		X																															M312
		313	Eliminate yield loss			X	X			X	X	X	X	X																														M313
		314	Eliminate speed loss		X	X	X				X		X	X	X																													M314
		315	Eliminate consumables loss		X	X	X	X			X		X	X		X																												M315
	32	321	Rapidly recognize disruptions		X	X		X			X						X																											M321
		322	Communicate problems to the right people		X						X						X	X																										M322
	33	331	Eliminate logistic loss					X		X				X		X			X																									M331
		332	Eliminate inspection loss		X					X				X						X																								M332
		333	Eliminate management loss		X			X		X	X			X		X	X	X			X					Y	Y	Y																M333
		334	Eliminate motion related loss					X						X					X			X																						M334
		335	Eliminate line organization loss					X												X	X		X																					M335
		34	Eliminate facilities cost		X								X	X								X	X	X		Y																		M34
FR4 Reduce c. complaints		41	Increase product quality									Y		Y											X																			M41
		42	Increase dependability			Y	Y					Y					Y	Y			Y				X	X																		M42
		43	Increase speed of delivery																						X	X	X																	M43
		44	Increase flexibility																						X	X		X																M44
FR5 Increase productivity		51	Eliminate planned shutdown			X	X				X																	X	X	Y														M51
		52	Eliminate startup loss			X	X				X	X	X			X									X			X	X	X			Y									Y		M52
		53	Eliminate changeover loss													X			X						X			X			X													M53
		54	Eliminate set-up loss											X		X			X						X							X												M54
		55	Eliminate minor stoppage loss		X	X	X			X	X	X	X			X	X	X			X		X		X								X											M55
		56	Eliminate systematic operational delays		X						X							X			X	X												X										M56
FR6 Sustain TPM program		61	Create conducive environment																																X	Y		Y						M61
		62	Increase synergy between functions																																X	X								M62
		63	Monitor & control progress																																X	X	X							M63
		64	Improve working practices					Y	Y																										X	X		X						M64
		65	Improve moral & job satisfaction		Y			Y	Y	Y												Y	Y			Y									X	X	X	X	X					M65
		66	Improve continuously		Y	Y																													X	X	X	X	X	X				M66
		67	Standardize improvements																																X	X	X			X	X			M67
		68	Ensure equipment maintainability																																X		X			X		X		M68
		69	Minimize investment over system lifecycle																																X							X	X	M69

Figure 1. Full design matrix table.

2.4 REDUCING CUSTOMER COMPLAINTS (FR/DP4)

Customer complaints can be reduced by increasing product quality, increasing dependability, increasing the speed of delivery and increasing flexibility [Nigel *et al.*, 2007]. In addition, the price of a product influences customer satisfaction, which is mainly dependent on costs; this requirement is considered in FR3-reduce costs.

2.5 INCREASING PRODUCTIVITY (FR/DP5)

Productivity is expressed by the ratio of output to input; in this framework, however, operator input, or labour hours, is considered in FR3-reduce costs. To increase operations output, the remaining major losses that impede overall equipment efficiency that also delay or reduce the speed of predictable-operations (planned shutdown, change over, start-up, setup and minor stoppage losses) are considered. In addition, productivity can be increased by reducing systematic operational delays [Cochran *et al.*, 2002].

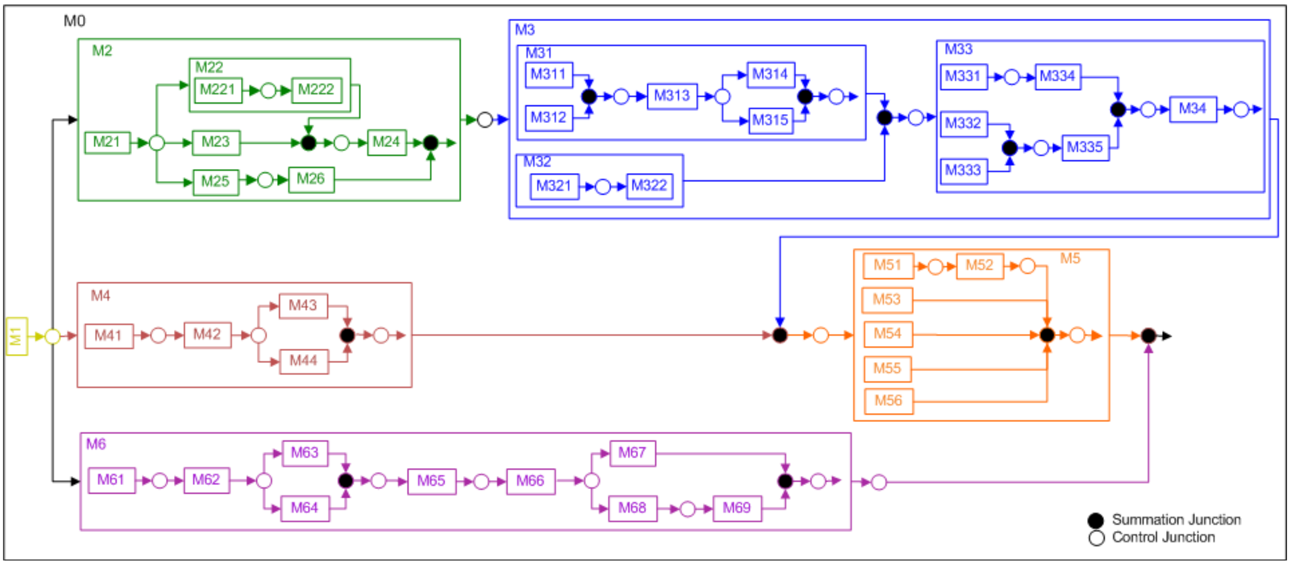

Figure 2. Flow diagram for TPM implementation.

2.6 SUSTAINING THE PROGRAM (FR/DP6)

Using the factors that influence TPM failure presented by Rodrigues and Hatakeyama [2006] and Chan *et al.* [2005], arguments to standardize improvements by Shukla and Cochran [2011], and the need to minimize investment over the production system lifecycle suggested by Cochran *et al.* [2002], a list of requirements is prepared.

3 RESULTS AND DISCUSSION

After decomposing the TPM implementation goals, a decoupled design matrix was derived. The derived design matrix, Figure 1, was put in the form of a flow diagram shown in Figure 2. The pillars and foundations of TPM that commonly appear in literature were highlighted for comparison with this framework. Weak design couplings and weak relationships between FRs and DPs that were identified after decomposition of the top level requirements were indicated by the letter "Y"; these relationships were neglected in the generation of the flow diagram because of their limited effect on TPM implementation process. All FR/DP pairs were assigned module numbers "Mx(xx)"; the module numbers were used to refer a module in relation to other modules and aid checking whether the left most DPs of a module have been attempted before initiating the right most DP.

At the highest level of this framework, the accident reduction parameters satisfy cost reduction and productivity increment requirements; moreover, customer satisfaction increment parameters satisfy productivity requirements while their requirements are independent of accident and cost parameters. Hence accident, cost reduction and customer satisfaction activities should be attempted before making any activity related to productivity increment. Further, the rest of the parameters cannot satisfy the requirements to sustain the TPM program, which suggests the need to start all the activities necessary to sustain the program early on.

Any attempt to alter the sequence of implementation would likely be ineffective to achieve the intended goals, or would require iterations and extra investment. Attempts to reduce costs before attempting to reduce accidents, for instance, will likely increase costs by adding expenses to cover incidences of accidents, besides human safety is a priority. Similarly, attempt to increase productivity or reduce costs not along activities that satisfy the customer would likely increase inventory of unsold products. Furthermore, if activities to sustain the program are attempted at the middle or the end of the duration, successful implementation of TPM cannot be guaranteed [Ahuja and Khamba, 2008a]. Aside from the accidents module, the results are in line with that of *manufacturing system design decomposition* approach developed by Cochran *et al.* [2002], whose implementation or improvement of manufacturing systems follows the sequence of quality improvement, problem solving, predictable output and delay reduction.

In this framework, the accident reduction module is attempted right after planning and kicking-off the program. Since an education and training program fulfills the highest number of requirements, it is a priority in the TPM implementation process. The result is similar to that of Steinbacher and Steinbacher [1993] and Ahuja and Khamba [2009] who argue that education and training is an element of all other pillars (functional requirements in this framework). Using the design matrix, the curriculum for an education and training program or any other DP can be designed in such a way to satisfy the indicated FRs in the costs and productivity modules. Thus, investment in education and training or in any other DP should continue until the monetary benefits gained from all the functional requirements that they depend on matches [Cochran *et al.*, 2011]. Furthermore, the 5S and activities to make operations mistake proof can be carried out in parallel with autonomous and preventive maintenance activities, which greatly increases the speed of implementation.

In the costs module, the activities follow the sequence shown in Figure 2. The benefits of this particular sequence are two fold: (1) reduce costs associated with the machines and worker inefficiency, and (2) in line with the argument from Cochran *et al.* [2002], provide predictable output through

DP311-315 and reduce operational delays through DP331-335. To sustain the operations' output predictability, operators have to quickly recognize problems and communicate to the right people preferably in real time, which is provided by DP321 and DP322.

The level of success of the TPM implementation program is highly dependent on the costs module; the DPs, efficient layout and balanced work flow, have a significant contribution to the success of the program. It is a cautious belief of the author that TPM implementation programs fail to achieve their intended goals mainly due to the low level of achievement of the two DPs on satisfying their respective requirements. A case on the importance of the two DPs is shown by Estrada et al. [2000] where a long assembly line which had a slow defect detection capability, high work in progress, low process predictability, no flexibility and low operator interest to solve problems other than on their part of a line, when the system was converted to cell layout all the problems were significantly improved. When a TPM program is attempted for systems which have not achieved a cell level layout will likely inherit the weaknesses of the lower level manufacturing system layouts, leading to limited success or failure of the program. Furthermore, the conventional approach of prioritizing and addressing operational losses has being using the effect of the losses on costs or overall equipment effectiveness (OEE). This approach is more operations focused thinking than systems thinking which limits the effectiveness of the maintenance efforts.

In the customer satisfaction module, office TPM is a major activity next to research and development activities. Customers do not benefit much by the activities to reduce accidents, costs and increase productivity in production floor, but by some activities in the offices. Hence due effort should be invested in R&D, office TPM, through put and rescheduling capability. Further, this module is weakly coupled with the costs module. Some of the efforts to increase equipment predictability contribute to a reduction of customer complaints by increasing the dependability of the organization while research and development efforts contribute to the elimination of defects/rework in production floor. Similarly, office TPM, fast through put and rescheduling capability efforts contribute to management losses. However, from the point of view of TPM implementation these relationships can safely be ignored.

In the productivity module, the selected FRs intend to eliminate the causes that impede overall equipment efficiency, which an operator has limited capability to influence the process or the machine. To gain maximum benefit out of the proposed sequence in this framework, the production system should sustain a predictable output before attempting this module. After devising a method to synchronize plant shut downs and equipment start up times with operator break times, and a method to engage operators in value adding activities during star ups, the rest of activities can be implemented simultaneously.

In the sustainability module, the sequence of implementation should follow the one shown in Figure 2 to reduce the investment necessary to achieve the requirements. For example, employee moral can be improved by committed top management, participation in the cross functional teams, regularly published results as part of a benchmarked maintenance activities, and proper application of lean manufacturing philosophy; hence, relatively small reward and recognition efforts would likely suffice to improve moral. Since this module contributes to the health of the overall program, an early maturity of this module is advisable. The control junction, in Figure 2, leading to this module has a responsibility to allocate resources to achieve the intended maturity levels. Moreover, in line with maintenance benchmarking, the practicing organization should develop qualitative or quantitative metrics specifically designed to check the level of achievement by each DP in meeting the requirements set in this framework. The metrics can be used to check whether to continue or stop making efforts and predict the likelihood of success of the succeeding activity. As part of this framework, a general metric fit for the stated TPM implementation requirements is set for further research.

Once the top level TPM implementation sequence is determined, on a need basis, organizations can further decompose the stated high level modules to low level modules. This further decomposition to lower hierarchies should be checked against the constraints in an organization; barriers which Ahuja and Khamba [2008b] classified as organizational, cultural, behavioral, technological, operational, financial and departmental can be used as constrains. Even though most of the proposed DPs are conventional for achieving their corresponding FRs, the matrix is open for improvement on the arrival new management principles or organization specific DPs, as far as decoupled nature of the matrix is maintained. The improvement efforts should give priority to the modules indicated by "Y". Such practice avoids what Wireman [2004] calls a "cook-book" approach.

Further, this procedure is developed with an organization-independent scenario in mind, unlike most of the existing methods, which are based on empirical results that were found to work on specific organizations. The non-AD approaches do not argue on the efficiency and effectiveness of the approach used outside the bounds of empirical comparisons. Using the decoupled nature of the approach developed in this paper, however, the efficiency and effectiveness of TPM implementation procedure can be argued.

4 CONCLUSION

The paper has used AD principles to systematically sequence TPM affiliated parameters to ease the implementation process in discrete parts manufacturing organizations. The developed AD matrix presents three benefits. First, it identifies TPM activities that can be attempted along other activities, thereby increasing the speed of implementation. Second, it identifies the right sequence of implementation that would likely reduce the effort to actually attempt to satisfy a particular goal. Last, it becomes easier to identify the functional requirements that could be affected by a TPM activity, hence easier to design and plan activities to satisfy particular requirements. The paper also leaves the TPM implementation matrix open for further decomposition and improvement by practicing organizations in accordance to their needs.

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