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INVESTIGATION FOR DEVELOPMENT OF NEW TOOL IN DFX SHELL THROUGH LITERATURE SURVEY: DESIGN FOR TPM

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ABSTRACT

In Indian manufacturing environment today total productive maintenance (TPM) is popular philosophy; already has been adopted by many original equipment manufacturers (OEMs) particularly in automobile sector. For vendors of these OEMs either it is recommended or made mandatory to adopt the TPM concepts. With all these activities going in industries major portion of the entire manufacturing sector has become familiar with the TPM concepts. Many of the activities carried in these industries are observed parallel and repetitive type. This includes small modifications in equipment done on the shop floor as part of TPM implementation. Strangely even in some newly purchased equipment also modifications are observed on the shop floor. It clearly indicates that at design stage only customer requirement for adaptation of equipment in TPM culture; has to be considered by equipment manufacturer. On the other side these requirements has to be identified before procurement of equipment by the equipment buyers. With these background observed the need for development of new tool Design for TPM.

Keywords: TPM, Total productive maintenance, equipment design, DFX, maintenance, CBR

I. INTRODUCTION

The maintenance activity (which is parallel with production) ensures that production equipment and support items are in decent condition, working and safe to operate. The maintenance process consists of servicing, inspection and repairs. Servicing is lubrication of equipment, cleaning the equipment, and carrying out adjustments as per need. Inspection

consists of measurement of actual wear with instruments and comparing it with maximum permissible wear, temperature monitoring, vibration and acoustical analysis and visual inspections. Repairing is done if the wear exceeds the maximum acceptable limits [1]. According to Jostes and Helms [2] maintenance expenses are 15 to 40 per cent of total production cost. In European Union countries expenditure on maintenance is estimated about 5% of total turnover [3]. Maintenance costs are about 15 to 60 per cent of cost of goods manufactured [4]. These costs involved in maintenance function clearly indicate importance of maintenance in manufacturing business process. Obvious attempts were observed for the improvement of this maintenance function to make it more cost effective and inclusive. TPM may be viewed as evolution resulted by these efforts over the years. TPM has made its' significant impact in Indian manufacturing environment particularly in automotive sector. Many of the original equipment manufacturers and their vendors have introduced TPM initiatives. In kaizen conventions, quality circle or TPM circle conventions and with interactions with industry people observed some common aspects in modification of equipment. Hence there exists need for further investigation so that these improvements may be considered at design stage.

II. TOTAL PRODUCTIVE MAINTENANCE

The term “total productive maintenance” consists of 1) Total effectiveness 2) Total maintenance system 3) total involvement of all the employees. Total effectiveness implies TPM's quest of economic efficiency or profitability. Total maintenance system comprises maintenance prevention (MP) and maintainability improvement (MI) and preventive maintenance (PM). Total involvement of all the employees also consists of autonomous maintenance by operators through small group activities [5]. TPM is born to increase profitability by eliminating equipment failures, reduced set-up, keeping up the speed of machinery, eliminating minor stoppages and improving the quality of the end product. The ultimate goal of TPM is to improve overall equipment effectiveness in quantifiable way and normally without much capital expenditure [6]. According to Ben-Daya [7] equipment management and empowerment of employees are two basic features which define and characterize TPM. Ahuja and Khamba [8] describes TPM as foundation of world class manufacturing due to its initiatives for lean activities and strive for elimination of accidents, defects and breakdowns. McKone *et al.* [9] focused on TPM and manufacturing performance (MP) and observed TPM as integral part of world class manufacturing strategy along with JIT, TQM and EI (employee involvement). TPM insists on the application of Total Quality Management (TQM) concepts in the maintenance function [10]. In TPM attempts are made to reduce or eliminate six major losses namely related to availability breakdown and set up losses related to performance efficiency are reduced speed and minor stoppages or idling and related to quality are start-up and defect losses with the focus to improve overall equipment effectiveness (OEE) [5] [11]. This is done by promoting focused groups and kaizen [12] [13]. Now a days TPM has expanded this concept by considerations for 16 types of losses [14] [15]. A typical 8- pillars (goals or principles) approach is observed for TPM in the industries. [14] [16] [17]. TPM targets should be achieved by continuous improvements through kaizen [18]. In broad TPM is basically maintenance, management, culture and improvement.

III. TPM AND DESIGN IMPROVEMENTS ON THE SHOP FLOOR

As TPM initiative kaizen related production tasks include reduction in set up losses, reduction in cycle time, flexibility in operations and maintenance tasks include reduction of cleaning times by devising more efficient cleaning methods, simplification of lubrication tasks by developing improved lubricating procedures [12]. No matter how much the engineers attempt after design the incremental improvement is quite small. The decisions made during design process have greatest effect on the cost of a product with least investment. As observed in number of studies key elements of reasons for product failures are product definition and management. About 80% of product's life cycle cost is locked at design stage. Well organised design reviews and communication between designers and engineers responsible for production and maintenance are inherent part of successful organisations. It is not possible for one design engineer to be familiar to all aspects of technology and complexities of product brought out; the developments in mechatronics, computers, materials and processing technology just by experience and teamwork [19]. Some strategic efforts are needed in early management of equipment aspect of TPM because of unfortunate poor horizontal communication and coordination between equipment planning, operations, and maintenance departments prevents the use of technical data for improvement in design. Maintenance engineers are reluctant to share data relating to maintainability and reliability that could be important at the design and fabrication stages; and design engineers are not able to standardize the technical data or use the data at design stage [5]. A particular type of equipment is used in different organizations for similar kind of operation during TPM implementation if needed is likely to undergo similar design modifications. In fact during kaizen or quality circle or TPM circle conventions arranged at regional or national levels we could observe some similar aspects in case studies of different companies.

IV. TPM AND DESIGN PROCESS

In TPM operators and technicians participate in equipment performance improvement and technicians and engineers participate in design of equipment for improved performance [20]. The purpose of TPM initiatives in a manufacturing company is to obtain the physical improvement of personnel and equipment, and hence also that of organisation [21]. Design is a complex and costly task that includes both internal company functions (from marketing to manufacturing) and external resources (from consultants to suppliers)[22]. Design is a problem solving process which contains decision making. Design guidelines are knowledge source which aids decision making of design and are based on literature, experiences of designer and established methods in companies. It is difficult to access experiences of designers and established methods in organisations due to psychological, social and circumstantial reasons [23]. Engineering design had usually focused on the consideration of product functionality. Design, process planning, manufacturing activities were completed in a sequential manner with no feedback to the designer [24]. Decision making is a critical stage in product development. When alternative design is considered, the best alternative is selected based on its estimated life cycle cost (LCC) and its benefits [25]. Any decision process includes three fundamental phases 1) setting the goal or objectives 2) identification of constraints 3) identification of options[26]. The main existing approach in the domain of decision support was through formal methodologies, methods and tools that meet the needs of the designer engaged in various industrial sectors. However, this research work did not find substantial application in industry, and it has not developed part of "best practice" [27]. In industries it is common practice to

design products based on a previous versions. Engineers and managers are more concerned with the results of design by following particular design process more rigorously[26]. One of the keys to a successful TPM program is to apply the knowledge acquired from existing equipment and special projects, into new projects. 'Getting kicked in the head by a milk cow a second time ain't any learning experience.' [28]

Excellent production technology and continuous improvement capability are two key factors to produce new and attractive products quickly and efficiently and the shop-floor people are integral to this process. This is a main reason TPM implementation is popular Japanese. Equipment will have some design weakness and equipment will deteriorate with the time, even if it is designed exceptionally well. Many times equipment needs modification and change to deal with increasing change of market demand. Moreover, the equipment may require modification by introducing newly developed techniques so that competitiveness in existing equipment is retained[29]. Due to cost and technological problems it is impossible to design out maintenance; so best option is that products can be for designed for effective and efficient maintenance support. Even though products are designed for maintenance free for entire life cycle there are chances of accidental and unexpected failures. During operation phase, manufacturers can obtain information about the product's technical status as well as conformance and deviations from the estimated performance targets. The collected data can be successfully used for the development of new generation of products. Not only that it can be used for changing design to eliminate or diminish any critical weaknesses in design that result in higher demands on service and maintenance [30]. For engineer-to-order (ETO) companies have to design most of their products from scratch, it is important that customers' requirements are included during the formulation of product specifications. A structured approach to design and manufacture is required to reduce development time and cost. This can be achieved by reducing iteration between design and manufacture. It is necessary to bring all customer requirements forward during the design stage [31]. Proprietary equipment development along with autonomous and planned maintenance, technology emphasis is basic practice of TPM [32]. So first thing is that at design stage only views or suggestions of shop floor peoples are to be considered but more than that with advancements in computer field there is a possibility of considerations for common aspects of past experiences of shop floor people in different organizations.

V. TPM AND RAMS

With proper consideration of reliability, availability, maintainability and supportability (RAMS) in the design, manufacturing, and installation phase, the number of failure could be reduced [33]. Very little progress has been made with respect to the improvement of equipment effectiveness through redesign. Rare attempts are observed for the incorporation of reliability, maintainability, human factors, supportability, and quality characteristics in the design of factory equipment. In the implementation of TPM emphasis is observed on the "after-the-fact" organizational activities associated with factory maintenance and support, such as development of a good preventive maintenance programme. However a very little consideration is made in the area of maintenance prevention (MP) and maintainability improvement (MI). Greatest potential for the improvement of equipment design effectiveness through reliability and maintainability exists with focus on MP and MI activities [34]. The research and development or engineering functions within the organization facilitates early equipment management activities. Early equipment management in TPM is responsible for the trade-offs between equipment attributes such as reliability, maintainability, operability, and safety. The

consideration of the life-cycle costing for equipment purchases is part of early equipment management activities. Focused improvement team strives to eliminate the major equipment losses including breakdown losses, setup losses, minor stoppage losses, speed losses, defects losses, and start-up losses [13]. At early concept stage in system design maintenance aspects should be taken into consideration. But most of the times maintainability considerations are postponed; till it becomes too late to make any significant design changes. Detailed maintenance strategies should be worked out before the system is put into operation but very often this is done in elementary manner and on an ad hoc basis [35]. TPM objectives are to develop a maintenance-free design and to involve the participation of all employees to improve maintenance productivity [36]. While designing preventive maintenance, maintenance prevention and maintenance improvement plans while implementing TPM participation from designers, technicians and operators is needed [18]. Lazimet *al.* [37] shared experience of a case study of TPM in one section of an automotive company that all the parts of machine were accessible so that daily autonomous maintenance activities were quite easy. It was easy for operators to monitor parameters such as oil levels, air pressure as there was no hidden area and more than that ease of locations.

Maintainability can be enhanced by implementing maintainability guidelines such as accessibility, diagnostics devices, captive hardware and quick attach/detach, modularity, visual management techniques, management of the spare parts, colour coding [38]. Maintainability is defined at design and development stage [39]. The availability can be enhanced by increasing MTBF (mean time between failures) and reduction of MTTR (mean time to repair). The period required for repair work can be reduced through design for maintenance [30]. Simplicity, accessibility, standardization, modularization, identification, testability and ergonomics are the factors to be accounted at design stage for improving the maintainability. Improved maintainability makes maintenance convenient, fast and economical [40]. Considerations of maintenance at design phase make significant savings in operation stage. In design customer requirements are to be reflected. The maintenance needs may be analysed at design stage [30]. At design the final features of forthcoming systems and products are decided. A designer should be provided with simple and logical measure qualitatively or quantitatively to assess and predict the maintainability. The decisions concerning the compatibility of a proposed design with indicated maintenance requirements or the selection of better alternatives can be done by early assessment of maintainability. Design review can help for assurance of voice of customer and customer satisfaction, reduction of cost and delays, improvement in overall integrity of design and standardization [41]. According to Wani and Gandhi [42] tribology has remarkable potential to improve maintainability of mechanical system. Indicators suggested for maintainability and safety can assist designers for design solution validation with respect to an admissible performance as described by design specifications. During design process these indicators may be used to check solution improvements [43]. Maintainability is the designs attribute of system which aids the performance of several maintenance activities such as inspection, repair, replacement and diagnosis. It is important to identify all the aspects of maintainability right from the design stage qualitatively and quantitatively [44]. The basic objective of Design for Maintainability (DFMt) is to assure that the product can be maintained throughout life-cycle at reasonable expense with ease. Qualitative requirements are in the form of maintainability design guidelines such as (1) accessibility, (2) ability to detect and isolate failure, (3) weight limitations, (4) dimensional limits, (5) design requirements in hazardous environments such as unmanned handling [24].

According to Shervin and Jonsson [45] for subsequent evolutionary designs feedback to designers of detailed reliability data and running conditions of machinery is essential. The

initial control process can be extended to all new equipment purchase and incorporation of manufacturing process information into procurement specifications. Traditional concept is to design system with high reliability. System reliability can be improved by extending failure time of components and by preventive maintenance as well. Based on reliability theory predictions of failures can aid to plan preventive maintenance. It is difficult to predict failures due to increasing sophistication and complex nature of machines [46]. For idle time or set up time related loss maintenance is not responsible. For speed and quality related losses maintenance may be a one of the factor. Though OEE gives broader perspective of losses may be considered as key maintenance performance indicator. Among the other key elements are the equipment failure frequency (measured by MTBF and the number of unplanned maintenance interventions) and the repair time, which determine the unplanned downtime of the equipment. The maintenance planning rate is defined by the number of planned maintenance activities and the PM time. The measurement of these performance indicators can aid improvement in equipment availability and reliability[47]. Reliability of equipment can be improved by adopting a simple and robust design, conducting design review sessions, going through failure mode and effect analysis. The equipment maintainability can be measured by the Mean Time To Repair (MTTR), which is the average time it takes to repair a failure [46]. Reasons for failure and means of prevention experienced by machine designer and that of shop floor operators or technicians may be different [48]. Reliability is defined qualitatively as absence of functional failure during use and quantitatively as the probability that an item will give failure-free performance. Reliability parameters that are used in common practice are [49] 1) Mean time between failures (MTBF); used for repairable products 2) Mean time to failure (MTTF); used for one shot items 3) Mean time to repair (MTTR) gives an indication of the maintainability 4) Failure rate or failure intensity; these are the inverse of MTTF and MTBF. 5) Availability; the proportion of total production time that will be available for use. Reliability consists of four factors: (1) probability, (2) specified function, (3) designated environment, and (4) length of time[24]. TPM focuses attention upon the reasons for energy losses, and failures of equipment due to design weaknesses which were previously assumed to be tolerated [50]. If process fails it is replaced to return to original condition. There are two problems with this renewal-assumption. Due deteriorations over the long haul replacing the components may not return system to its “New” condition. And more importantly after replacement it is assumed that nothing is learned which contradicts philosophy of continuous improvement[13]. Considerations of maintainability and reliability at design will have direct positive impact on availability and hence OEE which may be referred as TPM metric. Hence all the parameter discussed in literature for improving reliability and maintainability are important in relation with TPM as well.

VI. CUSTOMER FOCUS IN TPM

While applying TPM concept of early equipment management the product and process manufacturing experience may be gathered and documented and with this data development of new equipment can be done [51]. Design rework and unnecessary iterations between design and manufacture can be minimised by considerations of customers’ requirement into design process by establishing requirements of machine at the beginning of design process. Design and manufacturing engineers can plan their work to include customers, suppliers, contractors and manufacturing concern during the design stage with the help of suggested framework. Engineers and managers need tools to effectively capture the stakeholder outlooks, different customers involved, and their values; in today’ global scenario[19]. YojiAkao in Japan was

first to introduce QFD concept in 1966. QFD starts at what exactly customer wants not the organizations' assumption of what the consumer wants. . By defining the product at the beginning of the process and then determining how this product definition can be met most effectively by the company ensures proper product design [52]. It is important to recognise customer's functional needs and also the inspirational, emotional and cultural needs. A successful product design justifies all these consumer's needs[53]. QFD is a structured approach that translates customer needs into design specifications [19].QFD is used at early part of design stage and it starts with identifying customers of the organisation [31]. QFD is used to capture the voice of the customer through horizontal and vertical communications termed the House of Quality (HoQ) [49]. Many of the industrial applications of QFD focus on mapping of product functional requirements VOC (Voice of Customers) into product structure and product components[26]. Pramod *et al.* suggested adoption of QFD in TPM projects for synergic benefits [54]. Ahuja and Khamba [14] recognised QFD as one of the initiatives which may be applied with TPM [14] Garg and Deshmukh [55] mentioned about emerging role of QFD for performance measurement system for the maintenance. C. Sugumaran [56] after exhaustive literature study claimed that due to common aim for meeting customer needs there will be synergy if QFD is applied with TPM. In view of equipment manufacturers if QFD is applied for the while designing new equipment for companies following TPM philosophy many requirements related to TPM will be explored at design stage.

VII. HUMAN FACTORS IN DESIGN CONSIDERATIONS AND TPM

The role of human factors in a product may be defined in three ways. 1. Man, as occupant of space 2. Man, as reader of display 3. Man, as one who takes action [53]. Ergonomic information should be available with designers in a relatively narrow scope to maintain a degree of context at the same time sufficiently wide to be appropriate to sufficient range of design [57]. Human-equipment interaction in maintenance work is to be considered at design stage and following considerations may be made. (1) Visual access - The ability of the technicians to see his actions, to see actions of other teammates, to communicate by gestures and to see possible hazards (2) Physical access - The ability of the technician to position the body, or part(s) of it within the surroundings to perform task (3) Physical mobility - The ability of the technician to move the body or part(s) of it within the working environment to complete the task. (4) Strength - The ability of the technician to apply adequate muscular forces for the tasks (5) Muscular and physiological endurance – The ability of the operator to continue with a definite level of performance for a definite period. (6) Cognitive and decision making demands - The ability of an operator to perceive and process information (mentally) from the maintenance location (7) Education and training - The ability of the operator to accomplish the tasks successfully with written and other instructions provided (8) Safety - The ability of operators to use equipment and perform jobs without exceeding their mental or physical limits [58]. Pushbuttons, knobs, cranks, thumbwheels, switches, levers, pedals, pens etc. are typical operator controls which involve discrete or continuous finger, hand, or foot control inputs. Relevant anthropometric dimensions, operator force estimations, human control accuracy and error and skilled and unskilled operator movement patterns should be known. Some of the fundamental requirements in control design are specification of desired task and control inputs, accuracy and error requirements, selection of best operator control(s), anthropometric constraints, work load determination, control(s) layout, performance verification [59]. Human activities and limitations can be very important to system reliability. The design engineer must consider factors man-machine interface, evaluation of the person in the system, and human

reliability[24]. One pillar or principle of TPM Safety, Health and Environment should be kept in mind in the early steps of design. Design of equipment should be as per high safety standards [18]. Human factor considerations at design stage will aid operators as well as maintenance technicians and will improve operability, maintainability and safety as well and will have positive impact on TPM implementation.

VIII. SMED TOOL FOR TPM

In 1985 Dr.Shiego Shingo developed single minute exchange of dies (SMED) methodology. SMED is used useful in TPM and can aid KAIZENs due to its lean approach and reduction of setup time. SMED application in set up can reduce setup time up to 90 per cent with reasonable investments[60].The SMED originally developed by the Japanese Industrial Engineer Shigeo Shingo for reducing the time to exchange dies, is a straight forward approach to obtain reduction up to 90% in set-up time. Even for brand new equipment the design can be improved substantially. The typical set-up reduction approach is 1) Separate on-line and off-line activities 2) Transfer on-line activities to off-line 3) Minimise on-line and off-line activities. Some typical guidelines for SMED are use of light materials, use of less material, reduction of mechanism, use of quick release couplings, reduction of number of components, fasteners, standardisation of fasteners, shut heights for press tools, ease for cleaning, and provision of power aids, use of Poka Yoke[61]. Lazimet *al.* [37] mentioned about the application of SMED in Malaysian automotive parts manufacturing company to reduce set up losses as part of TPM initiatives.Activities such as adjustments of jigs and fixtures are to be done by applying SMED [62].Almeanazel [63] also stated the need of SMED as part of TPM initiative in his case study in steel in steel company. Chand and Shirvani [64] also stated the need of SMED while going for TPM in automotive component company in UK.While discussing state of implementation of TPM small and medium industries (SMIs) Shamsuddin *et al.* [65] indicated requirement on more focus on SMED to reduce set up losses.Ahuja and Khamba [14] suggested wide range of techniques and methods including SMED for implementing and sustaining TPM. SMED considerations at design will reduce set up losses and hence will improve availability and hence OEE the TPM metric.

IX. COMBINATION OF TPM WITH DESIGN METHODOLOGIES

The TRIZ methodology leads the user in a converged process toward inventive solutions for a specific problem in refusing compromises as a possible outcome. This approach is contrast with other creative techniques, such as brainstorming, which are based on the interaction between ideas for generating new proposals [26]. Darrell Mann and John Cooney [66] presented a case study on application of TRIZ to machine maintenance and claimed that maintenance function can be improved by use of TRIZ method.Taguchi Method is an approach to robust design developed by Genichi Taguchi in 1950s [26].Miyake [67] claimed some correlation between corrective maintenance (CM), maintenance prevention (MP), quality maintenance (QM) and life cycle engineering concepts of TPM with QFD, Taguchi method and design of experiments in total quality control (TQC) and further suggested possibility to explore the synergic benefits with effective strategy.

The designer should know the effects of his selections. He must aware of exponential nature of cost changes throughout the development cycle. Furthermore designer should be aware of his decision impacts on parameters like time to market, cost, quality, reliability, maintainability, recyclability and human factors[68].Trade-offs is an integral part of

engineering design. Concurrent engineering aims to provide a broad view of the physical and proposed natures of the products being developed; it also increases the number of conflicting goals. This obviously increases the number and complexity of the trade-offs that are needed [69].

X. CONCURRENT ENGINEERING

Increasing trend is observed towards using design tools based on concurrent engineering (CE) and integrated product development. (IPD) This is to ensure transferability of the information between the different members of a project, to improve the development process and to ensure customers or legal requirements, warranty and service[68]. Better quality, low price, good performance and less delivery time are customer needs in today's competitive market. Concurrent engineering integrates concurrent design and processes to meet these requirements. In CE, designers need to consider all elements of product life cycle in the early stage of design [70] Concurrent engineering (CE) makes considerations of life cycle factors including product functionality, manufacturing, assembly, testing, maintenance, reliability, cost and quality in the early design stage. Apart from concurrency of activities important aspect of CE is collaborative effort from all the involved teams to improve profitability and competitiveness [71] The key features of CE includes concurrent and parallel scheduling activities and tasks, integration of product, process and commercial information and integration of lifecycle issues in the design, integration of the supply chain through effective collaboration, communication and coordination [72]. TPM system should be internally strong to integrate different departments for improvement of the organization's performances; the most important part is equipment improvement [73]. TPM focus is that operators, maintainers, engineers, equipment designers and planners must work as a team if they really want to maximize the overall effectiveness of their equipment, by actively pursuing creative solutions for eliminating waste due to equipment problems [6]. Focus of TPM is actual improvement in production function and design of equipment needed for the same. An aggressive strategy like TPM requires more dedications in training, resources and integration to get better equipment and plant performance [74]. In CE customer requirements may be translated to design parameters using QFD [72]. Correlation in TPM and CE can be observed in some aspects such as cross-functional teams, early equipment planning for life cycle considerations.

XI. DFX TOOL FOR TPM

Design generalization is possible by concentrating on certain characteristics common to different types of products. By focusing on different concrete design goals within design, we obtain design for X. (DFX) DFX focuses on decision making process through identification of design goals[26]. DFX tools allow one to facilitate the decision making. DFX tools aid stakeholders to know the impact of their design choices and aid to improve the efficiency of development process [68]. DFX allows rationalisation of products, related process and systems and also product development. Concurrent improvement in quality, cost, cycle time can be done applying DFX. Development of DFX tool starts by customer-driven motives followed by cycle of continuous improvement [75]. The DFX shell can be expanded onto the Internet/ Intranets using the web technology [76]. In practice there is availability of number of DFX tools such as DFM, DFA, and Design for environment etc. Simultaneous application multiple "X" considerations may cause conflicts. The DFX system needs to include a cross-functional integration covering various functions and viewpoints, including functions such as RandD,

manufacturing, procurement, marketing, logistics, and the viewpoints of quality and cost [77]. The functionality of a product is the basic driver for the design process. Design for X emphasizes the aspect that functionality is not the only driver[78].As concurrent engineering requires a holistic view of the product, DFX tools should be integrated and not applied alone [69].Researchers should explore the use of other AI techniques, fuzzy logic, neural networks, genetic algorithms, and case-based reasoning in DFX. These techniques can play a significant role in DFX research and development [24].Product design evaluation is at all phases of product development from concept to design. Design evaluation being time consuming and lengthy; structured decision making tools are must. As design alternatives are too many and simultaneous impacts on decisions are too vast it is difficult to consider at once by human decision makers. There are numerous design aspects and are referred as design for X (DFX) where X represents a broad variety of design considerations which influence the design selection and are referred as design selection attributes [53].DFX can collect best internal practices and can disseminate information. Design for excellence (DFX) is approach to methodically adopt the early involvement and functional integration [79].Preferences should not be imposed by the design tools chosen. The overall preferences, captured as the intentional nature of the product, should drive the choice of DFX techniques [69].

‘Design-for-Assembly (DFA)’ is a design philosophy for improving product designs. DFA aids to simpler or less costly assembly operations. DFA also aids to improve serviceability, reliability, and quality of the end product [80].In DFA by decreasing the parts count (integrating several parts into one) and modifying the design to make it easier to handle and put together (reducing the assembly time) cost reduction is achieved. DFA leads improvement in quality and improvement in maintainability. In practice total cost saving in range of 30-40% is achieved. Following are some broad guidelines for DFA, design for a stable base, simplify insertion, and minimize parts count and levels of assembly, stability of intermediate assemblies, standardization [81].Primary focus of ease-of-disassembly is in designing for recycling but it also aids for servicing and maintenance and generating environment friendly decisions [82]. Disassembly of products is done to aid maintenance, to increase serviceability or may be for end-of-life (EOL) objectives such as reuse, remanufacture or recycle. The major portions of disassembly associated gains (80–90%) are achieved at the product design stage [83]. Design for maintainability (DFMt) tools is available to help designers to improve maintainability or maintenance ease and reduce maintenance cost[69].Environmental aspects and lifecycle constraints are the new considerations which need more information in the in areas such as utilisation, maintenance, recyclability, waste management[43].Growing concern about damage to the environment has led to a variety of research to develop more environmentally friendly products leading to a variety of design for environment (DFE) tools[69].Virtual maintenance system environment will lead to the design of maintenance friendly and robust products [84]. Simple logic easy to assemble will aid ease to maintain will work in many cases. Hence tools like design for assembly, design for maintainability, even also design for environment, design for safety will aid design of equipment to suit some TPM requirements. But dedicated tool design for TPM under DFX shell will have real focus on TPM aspects. Attempts can be made instead of generalization of TPM requirements to focus on commonalities in shop-floor TPM initiatives.

XII. ARTIFICIAL INTELLIGENCE TO AID DESIGN FOR TPM

Artificial intelligence techniques are much more used recently to strengthen the robustness of maintenance management. Four AI techniques typically observed are 1) Expert systems 2) Neural networks 3) Fuzzy logic 4) Model-based systems [85].

In design of new products decisions are complex, uncertain, qualitative, subjective and not structured. Hence it is difficult to set experiences as patterns but easier to view as distinct cases. Hence case based reasoning (CBR) approach is more popular than knowledge based systems. (KBS)[27]. In broad sense a decision making involves collection and evaluation of information, recognition of need for decision, finding various alternatives and choosing best suitable solution [86]. The CBR is used in decision support system is to improve CE process. CBR also aids for DFX type of studies [87].

In case-based reasoning (CBR) new solutions are obtained by retrieving the most relevant similar cases from memory and modifying them to fit new situations; thus reasoning is based on memory [88]. Case based reasoning is a problem-solving approach that relies on past similar cases. The CBR principle is based on the human task of “mentally searching for similar situations which happened in the past and reusing the experience gained” The CBR process as shown in figure can be represented as follows

- 1 Retrieve: the system searches and retrieves the case most similar to the problem case
- 2 Reuse: the user evaluates it in order to decide if the solution retrieved is applicable
- 3 Revise: if it cannot be reused, the solution is revised manually or by the CBR system
- 4 Retain: the confirmed solution is retained with the problem in the database [89].

Concept in CBR is similar to human experts to remember and adapt solutions for the problem from previous solutions stored as cases in case base. If similar case not found the solution developed will be stored as new case [90]. A case is data of previous experience and case base is database of all previously stored cases. Case can be in any form however features of case should be in some format [91]. In CBR while designing database proper indexing and organization of the attributes is necessary for effective reasoning [86]. CBR can aid to select the cases in shop-floor modifications during TPM implementation and develop the proposed Design for maintenance under the shell of DFX.

XIII. CONCLUSION

In this literature focused investigation we have identified need of total productive maintenance (TPM) considerations at design stage. Literature survey and overview of some design aspects, decision making process, design tools, possibilities of combination of TPM concepts with some design methodology, concurrent engineering approach was made. We observe possibility of development of relatively focused tool Design for TPM under design for X (DFX) shell. Further literature investigation suggested that case based reasoning (CBR) can be applied for design of TPM tool under DFX shell.

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