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A Synoptic Panorama of Psychology Based System Maintainability and Design

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Abstract The challenges of global market continue to inspire companies to consider all prominent attributes of system/product including maintainability to develop reliable, safe, maintainable and novel systems/products. Moreover, system/product maintainability involves human beings in almost all important maintainability affecting activities like design, maintenance, operation and support. Thus, maintainability of the product/system does depend on the performance and psychological orientations of human beings involved in these activities. The paper reviews the published literature and extends it further in the context of system maintainability. With the purpose of signifying the role of psychology of personnel on system's maintainability, the psychological perspectives on planning, organization and design for maintainability have been presented in this paper. This paper presents a framework to incorporate the prominent aspect of human psychology in the maintainability and design of systems. The paper highlights a new orientation in the total design of systems, in general, and mechanical systems, in particular. Limitation and future scope associated with this paper are mentioned in the last section.
Keywords *Maintainability; Psychology; Human Factors; Human Values; Product Design; Psychology Based System Maintainability (PBSM)*

1. Introduction

Maintainability was evolved from the results of the reliability programs conducted in the late 1940s and early 1950s, which indicated that 100% reliability of equipment was an unobtainable goal. Despite the fact that the reliability programs were effective in prolonging the life of equipment and systems, maintenance requirements, however, could not be eliminated. With the increased size and complexity of systems, the maintenance costs for the systems approached one-third of all the operating costs (Blanchard and Lowery, 1969). In addition, it was established that nearly one-third of all personnel were engaged in maintenance or support functions. Maintainability was believed to deal with these problems of maintenance and support. Since then, the field of maintainability has been evolving continuously and gone through many stages of progressive development. In recent times, there is an emphasis on using “systems approach” for the design and development of maintainable products/systems. For accomplishing product/system maintainability, the emphasis is given on early planning, effective organizational structure and focus at design stage.

The concept of ‘Maintainability’ discussed by notable authors (Blanchard et al., 1995; Blanchard, 2006; Blanchard, 2008) recognize the role of human beings and state that − higher maintainability of system is almost impossible unless product/system is operated and maintained in accordance with the prescribed procedures. Also, designers do play a central role in incorporating maintainability and other innovative/creative features of the product/system. Companies use design to compete in the international markets (Whyte et al., 2003). One can say that maintainability of the mechanical product/system does depend on the performance of human beings involved in the design, maintenance, operation and support activities. Hence, talk on increasing product/system maintainability is incomplete without taking into consideration human element of the process.

A number of researchers from the field of engineering design have made an attempt to understand and incorporate psychological aspects in the process of design (Pahl et al., 1999; Jin and Chusilp, 2006; Wilpert, 2007; Howard et al., 2008). The psychological factors (e.g., emotional attributes, attitudinal responses, and behavioural patterns relative to the performance of design, operation, maintenance and logistic support functions) should be addressed at design stage itself. In the context of design for maintainability of mechanical system/product, it is also observed that when maintainability requirements are being established, particularly with regard to the human element, often important psychological factors are ignored (Blanchard et al*.*, 1995). It is also apparent from the reviews of psychology related research papers (Rokeach, 1979; Elizur et al., 1991; Schwartz, 1992; Schwartz, 1994; Meglino and Ravlin, 1998; Roe and Ester, 1999; Rohan, 2000; Schwartz and Bardi, 2001; Schwartz et al., 2001; Schwartz, 2006; Pakizeh et al., 2007; Fritzsche and Oz, 2007; Hall and Davis, 2007; Davidov et al*.*, 2008) that the performance and decisions taken (in this case, at design stage) by personnel are significantly affected by the psychological orientation of individuals, especially by their espoused/adopted human values. Human values theory defines values as desirable, trans-situational goals, varying in importance, that serve as guiding principles in people's lives (Schwartz, 1992; Rokeach, 1973).

This paper extends the work of prominent researchers/authors (Blanchard et al., 1995; Tjiparuro and Thompson, 2003; Blanchard, 2006; Blanchard, 2008; Kumar et al*.*, 2011) from the field of maintainability and emphasizes on the consideration of psychological aspects. Inclusion of psychological aspects could be of great significance in the total design and development of psychology-based maintainable mechanical systems/products. The total design of maintainable system/product necessarily includes people and organization (Pugh, 1994; Blanchard, 2008). Therefore, this paper also presents the need of an effective organizational structure. However, the paper focuses more on psychology-based design of maintainable systems/products.

The paper is organised with, Section 2 discusses the methodology used for writing this research paper; Section 3 presents a kaleidoscopic view of psychology in system maintainability. Section 3 further elaborates Psychology Based System Maintainability (PBSM) concepts, planning for PBSM, organization for PBSM, design for PBSM and a framework for PBSM. The last section is on conclusion and future scope followed by references.

2. Methodology

This paper reviews the work of notable researchers/authors on Maintainability (Blanchard et al., 1995; Tjiparuro and Thompson, 2003; Blanchard, 2006; Blanchard, 2008; Kumar et al., 2011) and engineering design (Pahl et al., 1999; Jin and Chusilp, 2006; Wilpert, 2007; Howard et al., 2008) who have made an attempt to understand and incorporate psychological aspects in the process of design. The paper also reviews some prominent psychology of human values related research papers (Rokeach, 1979; Elizur et al., 1991; Schwartz, 1992; Schwartz, 1994; Meglino and Ravlin, 1998; Roe and Ester, 1999; Rohan, 2000; Schwartz and Bardi, 2001; Pakizeh et al., 2007; Fritzsche and Oz, 2007; Hall and Davis, 2007) and comes out with a theoretical framework for psychology-based system/product maintainability. This paper has made an attempt to bridge the gap between the technical and non-technical world in the context of psychology based maintainability of mechanical systems. Table 1 highlights few important studies related to this present work.

***Table 1:** Studies Related to Present Work*

S. No.	References	Objective/ Topic	Field of Research
1.	Pahl et al., 1999	Interdisciplinary Empirical Studies	Engineering Design
2.	Tjiparuro & Thompson, 2003	Review of Maintainability Design Principles	Mechanical Engineering
3.	Jin & Chusilp, 2006	Mental Iteration in Design	Engineering Design
4.	Wilpert, 2007	Psychology & Design Process	Engineering Design
5.	Howard et al., 2008	Cognitive Psychology in Design	Engineering Design
6.	Kumar et al., 2011	Review of Psychology in Design for Maintainability	Mechanical Engineering

3. A Kaleidoscopic View of Psychology in System Maintainability

With the purpose of signifying the role and inevitable impacts of psychology of personnel on system maintainability, the psychological perspectives on planning, organization and design for maintainability have been presented in this section. The nature of psychological requirements is kaleidoscopic in nature as they change rapidly with respect to considered activity, organization, place of work, etc. Following sub-sections are highlighting the application of human psychology in some prominent activities pertaining to system maintainability.

3.1. Psychology-Based System Maintainability (PBSM) Concepts

The Psychology-based System Maintainability (PBSM) constitutes an integrated and life cycle oriented holistic approach to maintainability. PBSM program follows the footprints of existing maintainability program requirements with the additional considerations of human values oriented psychology (Kumar et al., 2011) of concerned personnel. The objective of PBSM is to maximize maintainability by due considerations of psychological aspects of associated human beings. PBSM is based on the principle that maintainability improvement must involve everyone in the organization, from design, production, operation, maintenance and, support personnel to top management. PBSM presume that improvement of system maintainability is a team effort and requires contribution from everyone in the organization. High degrees of motivation promote good result. In particular, possible difficulties arising during problem-solving will be easier to overcome with higher motivation (Pahl et al., 1999). Personnel with coveted psychological traits (involved in design, maintenance, operation and support activities) will be motivated to work diligently thereby reducing chances of breakdowns and frequent maintenance actions and thus, helps in promoting overall system maintainability.

3.2. Planning for PBSM

The early planning is necessary for successful execution of any program (Blanchard et al., 1995; Blanchard, 2008). The psychology-based system maintainability (PBSM) activities should begin at program inception. As physical and psychological needs for a system are identified and feasibility studies are accomplished in selecting a technical design approach, requirements are being established to define a program structure that can be implemented to bring the system into being. The definition of PBSM requirements is an underlying part of the process.

Planning should start with the definition of PBSM program requirements. PBSM functions and tasks should be identified, an organizational structure should be defined, key policies and procedures should be described, and a detailed PBSM program plan can be prepared and implemented. The initial plan should consider all maintainability activities throughout the system life cycle, which involve human beings.

From the standpoint of implementation, PBSM ought to be an integral requirement in each phase of the system life cycle. PBSM can be initially specified in terms of requirements, during the conceptual design phase. These requirements should concern directly to the mission or the functions that the system is expected to perform.

After establishing the basic criteria for design in conceptual design, the design activity continues with the iterative process of analysis, optimization, and the ultimate development of prototype models of the system for the purposes of testing and evaluation. Maintainability characteristics should also be considered in the light of psychology when conducting design trade-off studies to ensure that PBSM is adequately reflected in the proposed design configuration.

During the production and system utilization phases, efforts should be made to ensure that the system configuration meets all initially specified requirements. It is imperative that recent factory and field data pertaining to human beings and system interface should be collected and analyzed, and recommendations for further improvement should be initiated as appropriate.

The above life-cycle based activities thus far very briefly outline the implementation of PBSM requirements, applicable in bringing into being any new system or product. This concept may be applied to any mechanical system, be it car, an airplane or any other manufacturing capability, or the equivalent. As soon as a new consumer need is identified, one should proceed through the basic process as discussed above. PBSM activities should be carried out in each phase of system's life-cycle and need to be tailored for the specific system being developed. Following sub-section further delve into PBSM program requirements.

3.2.1. *PBSM Program Requirements*

PBSM program requirements follow the conventional (Blanchard et al., 1995) line of action described for maintainability program requirements. Like maintainability, PBSM should also be addressed at conceptual design phase when system-level requirements are established. In addition to performance, reliability, supportability, environmental, and other factors; user requirements should be analyzed in the light of psychology. These PBSM requirements should be taken care while doing feasibility analysis, trade-off studies and description of system specification. For designing the system/product for PBSM, a formal program may be established to facilitate this objective. This program should address the major activities and should also include the PBSM program plan task.

3.2.2. *Development of PBSM Program Plan*

PBSM program plan should identify, integrate, and assist in the execution of all management tasks applicable to fulfilling PBSM program requirements. This plan includes a description of the psychology-based basic requirements for maintainability in system/product design, the specific tasks to be accomplished, the organization for PBSM, organizational responsibilities and interfaces, supplier requirements, task schedules and milestones, applicable policies and procedures, and projected resource requirements.

PBSM planning should begin during the conceptual design phase when the overall requirements for the system are first laid down on the basis of consumer need. These requirements should be elaborated, through advance system planning, and included in a top level program management plan. This, in turn, should lead to the development of a system engineering management plan. The PBSM program plan should be then developed with the objective of describing the management approach and the tasks to be implemented in the conduct of a formal maintainability program effort. Like conventional maintainability program plan, the PBSM program plan should also be monitored by the 'Maintainability Program Manager', and may be accomplished by the consumer/user or by a major contractor, depending on the program.

3.3. Organization for PBSM

The management aspects of maintainability commence with the maintainability planning requirements (Blanchard et al., 1995; Blanchard, 2008). Staffing of organization plays huge role in meeting objective of maintainability or PBSM. Tasks with due consideration of psychological requirements of involved human beings should be identified from both short and long-range projections, and combined into work packages.

The organization for PBSM put together resources in such a manner as to fulfil some specific need. Organizations call for a group of individuals of varying levels of expertise combined into a social structure of some type to accomplish one or more functions. Organizational structures should vary with the functions to be performed, and the results depend on the established goals and objectives, the resources available, the communications and working relationships of the individual participants, personal motivation, and most importantly, the compatibility between human values of personnel with the task assigned to them. The final objective, of course, is to achieve the most effectual utilization of human, material, and monetary resources through the establishment of decision-making and communications processes designed to accomplish specific objectives.

The fulfilment of PBSM targets is highly dependent on the proper mix of resources, the development of good communications and psychological compatibility of personnel with so many factors like, the task in hand, with the existing environment and with the overall objective of the organization. The uniqueness of tasks and the many different interfaces that exist require not only good communication skills, but an understanding of the system as an entity and the many design disciplines that contribute to its development. Maintainability is only one of these design disciplines; however, the successful implementation of PBSM program functions requires a thorough understanding of not only system-level requirements, but also a in-depth understanding of the psychology of human values of personnel involved therein.

3.4. Design for PBSM

The entire range of life-cycle activities of a system/product are interrelated with each other and significantly affect the activities of other phases Therefore, it is essential that one consider full life cycle with due considerations of psychological aspects for having a maintainable system with reduced life-cycle cost. While addressing the aspect of life-cycle cost, one often considers only the short-term costs (design, development, production, etc.) associated with the initial procurement of a system or product. However, the long term costs associated with system operation and support are often hidden; yet these costs often constitute even up to 75% of the total life-cycle cost for a given system (Blanchard et al., 1995). Additionally, one finds that a major portion of the projected life-cycle cost for a system roots from the consequences of decisions made during the early phases of advance planning and conceptual design. Those decisions pertaining to the utilization of new technologies, the selection of components and materials, the identification of equipment packaging schemes and diagnostic routines, the selection of a manufacturing process and maintenance support policies, etc., have a great impact on life-cycle cost. In other words, the maintenance and support costs for a system, which often constitute a large percentage of the total, can be highly impacted by early design decisions and, design decisions are affected by the espoused/followed/adopted psychological traits of the design personnel.

A major objective of design for PBSM is, of course, to ensure that maintainability characteristics are included in system or product at design stage itself. Particular qualitative and quantitative requirements should be identified through the needs analysis, the accomplishment of feasibility studies, and the development of system operational requirements and the maintenance concepts. These requirements should be addressed through the execution of program planning activities and the organizational tasks.

The day-to-day design participation process and the program tasks that are directed to facilitate the incorporation of maintainability in design are other significant tasks. As the design team advances toward the definition of a specific design configuration, one should consider several design factors, acquiring the proper balance between maintainability and the many other factors that need to be addressed to meet the user's (physical and psychological) needs. This consideration should be accomplished through the representation of a maintainability specialist as part of the design team.

3.4.1. *User Needs and Feasibility Studies*

The psychology-based system design should typically begin with the identification of a 'want' or 'desire' for some items arising out of a perceived deficiency. An individual and/or organization specify a deficiency in an existing capability, e.g., inadequate system performance. Consequently, the 'need' for a new system is defined along with the priority, the date when the new system is required for operational use and an estimate of the resources required for investing in the new capability. Where possible, the need should be defined in specific quantitative terms so that one can completely define the problem before proceeding with the design and development of the system. However, prevailing tough competition in the world market has made it imperative to incorporate cutting edge features pertaining to the psychological aspects of the need. Defining the statement of need in complete and unambiguous terms with due consideration of psychological need is extremely important if one is to ensure maximum customer satisfaction in the end. Often, there are ambiguities, descriptors omitted, and sometimes faulty statements in a customer-originated statement of need. Deliberate effort is necessary to verify these anomalies and correct them as part of the marketing strategy. A preliminary maintenance concept, stating the approach preferred by the customer along with their psychological requirements, should be a part of this statement of need. This, in turn, calls for close ongoing communications between the customer and the prime contractor/producer from the beginning. Given a complete statement of need, it is appropriate to carry out a feasibility analysis, the scope of which will vary depending on the type and complexity of the requirement. The feasibility analysis leads to the description of a preferred technical and non-technical approach for system design and development. Efforts should also be made for the identification of possible technology applications, the availability of such, the potential cost, the associated risks and most importantly, very specific guidelines about the required personnel with best suited psychological traits. At this stage in conceptual design, PBSM characteristics should be considered as part of the technology selection process, particularly since these early decisions have a large impact on the ultimate life-cycle cost of a system.

3.4.2. *Psychological Factors in System Development*

These days, most of the competitive systems/products are necessarily incorporating the cutting edge research outcomes from human factors science. Human factors science is a multidisciplinary field incorporating contributions from psychology, engineering, industrial design, anthropometry and from a number of other emerging fields. Human factors refer to the human element of the system and the interfaces between the human being, equipment, facilities, and associated software. The objective is to assure complete compatibility between functional design features of the system and human element in the operation, maintenance, and support of the system. Apart from anthropometric factors, human sensory factors and physiological factors, considerations in design should be given to human values based psychological factors (e.g., human needs, behaviour, wants, expectations, attitude, and motivation), and their inter-relationships. Psychological factors should be considered early in system development through functional analysis, detailed operator and maintenance task analysis, operational sequence diagramming, and related design support activities. Psychology-based operator and maintenance personnel requirements and training needs should be understood from the task analysis effort. Psychology-based human factors design criteria should be included in the determination of maintainability requirements, particularly with regard to those maintenance functions involving the human being.

3.4.3. *Maintainability – Design for Maintenance*

Since the Industrial Revolution, maintenance of plant equipment has been a challenging task. Each year billions of dollars are spent to maintain systems throughout the world. For example, USA industry spends over $300 billion on plant maintenance and operation annually (Dhillon, 2009). In spite of all the developments, the human errors in maintenance activity have been following an upward trend and their consequences are tremendous. Three Mile Island nuclear accident, crash of aircrafts throughout the world and, 70 to 90% of the partial or complete system failures (Rasmussen, 1985) are few hurting consequences of human errors. Keeping in view the huge stake at risk, it is imperative that all possible steps should be taken to avoid human errors in plant maintenance, including design for maintainability considerations.

Design team, while designing a maintainable system or product, should keep in view the ground realities of maintenance. So often, maintenance technicians work in an environment that is more hazardous than all but a few other jobs (Hobbs, 2004). The maintenance may be carried out at heights, in confined spaces, in blunting cold or sweltering heat amid acute time pressure and stress. It is important for the design personnel to understand physical as well as psychic requirements of the maintenance personnel and accordingly, maintainability features should be incorporated. Design for maintainability emphasizes the inclusion of maintainability features or characteristics, which can bring ease, accuracy, economy and safety in maintenance actions. However, recent researches (Kumar et al*.,* 2011) suggest that decisions taken by human beings are affected by their motivational domains (human values) and design personnel are no exception. Design personnel with desired psychological orientation can give-forth highly maintainable and successful systems or products with minimum design (or design-induced human) errors.

A theoretical framework for psychology-based system/product maintainability is developed and is shown in Figure 1. The figure shows that the various maintainability elements can be summarized succinctly into four fundamental areas of influence: personnel factors, logistic support, design factors and the operation context factor. The personnel factor is further associated with anthropometrical, physiological, human sensory and psychological factors. This paper further highlights psychological factors.

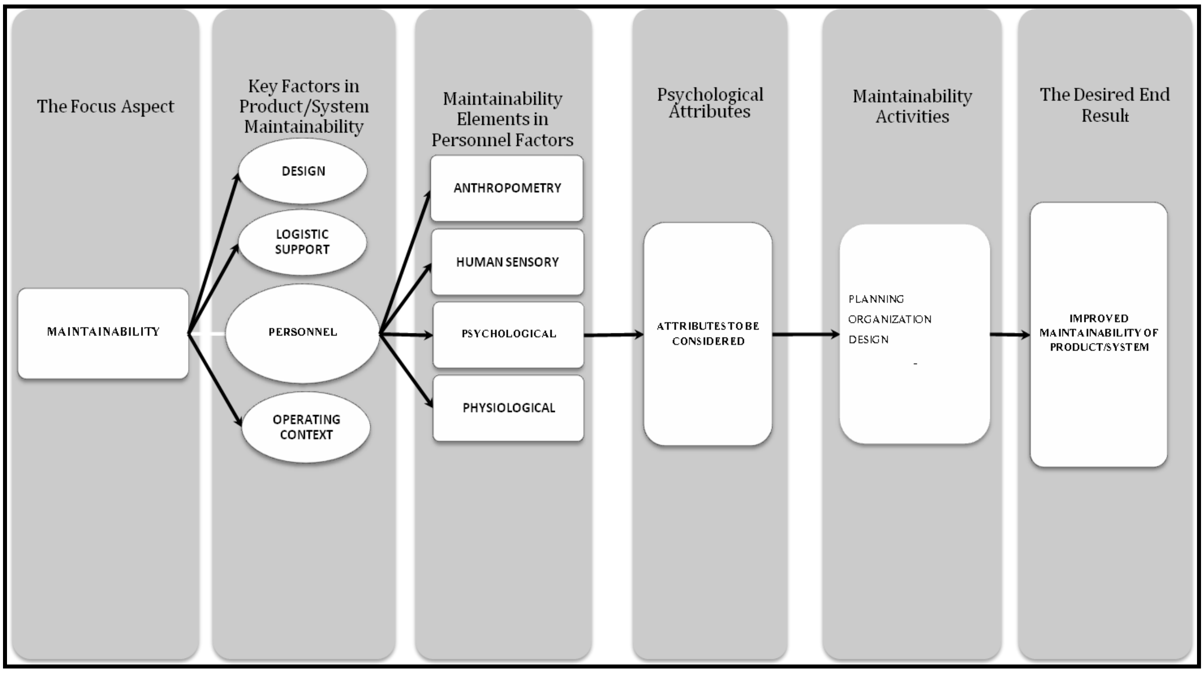

Figure 1: *A Framework for Psychology-Based System Maintainability*

4. Concluding Remarks and Future Scope

This paper has presented a theoretical framework for psychology-based system maintainability with special emphasis on aspects like planning, effective organizational structure for implementing the decisions made at planning stage and, design activities concerning to the maintainability of system/product. Psychology-based system maintainability has been introduced with a view to increase the overall maintainability of the system. This paper presents synoptic panorama of psychology in system maintainability and design; comprehensive research studies are needed further for empirical confirmation of the hypothesized connection between psychological aspects of personnel and different facets of system maintainability.

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