Model of analysis of design characteristics for maintainability – determining an index of maintainability in a product/system design

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Abstract: Nowadays, the products/systems project has demanded the inclusion of maintainability characteristics in order to facilitate support activities, and, so, to reduce the time of intervention used for repair, life cycle cost, and improvement of availability and operational regularity. This work develops a scale evaluation model of the maintainability indexes, using value functions acquired with the application of MCDA (Multiple Criteria Decision Analysis). Applying the developed scales, which come to be definite and belong to the model, the index values which will determine the index of maintainability at three levels – at the support activity level, at the component level, and at the product/system level – will be obtained. In order to obtain the last global index, which belongs to the product, the index of each component – presenting their support intervention frequency – will be correlated. The objective of this research, addressed to maintainability, is to facilitate the product/system specification adapted to support needs, to comparisons between different options for the same product, to the correlation of maintainability index with other parameters of interest on the evaluation of support activity development, among other points concerning the treatment of project characteristics for maintainability on the part of the planner, producer and consumer.
Key words: Index of maintainability – maintainability – support.

1. Introduction

Maintainability of structural system is represented by its intrinsic and extrinsic characteristics (here called indexes), which provided with property to facilitate its support. These characteristics must be created while planning the system in order to have an attractive life cycle cost, compared to other products (BLANCHARD, 1995).

The need to include maintainability characteristics which are specific to each support activity, such as lubrication, detection of failures, support for assembly/disassembly, etc, is in search of systems able to develop support activities, or having reduced and predictable mean time for repair (MTR).

Maintainability, together with reliability, determine the operational availability of a system, which, according to NAKAJIMA (1989), must be globally efficient, that is, the three-efficiency product: productive, in terms of effective production time/scheduled time; speed efficiency, in terms of effective hourly production/nominal hourly production; and efficiency of quality, in terms of approved products/produced products.

Maintainability characteristics have been studied in different ways. The MIL-HDBK-472 (1984) normalizes maintainability characteristics and develops scales for non-justified semantic evaluation. BAUER (1985) investigates possible solutions to be used in the project of guillotine used for cutting paper, with the purpose of reducing the risk of accident in production and support activities. WANI (1998) develops a model of evaluation of maintainability characteristics, using the MIL-HDBK-472 scales complemented by others specified by him. In his model, the author determines an index of maintainability through a matrix which combines the direct and indirect relation of characteristics in the facilitation of determined support activities, thus, obtaining an index which represents the maintainability of a point of the evaluated system, as for example, semantic articulation, attachment system, etc. CARTER (1999), relates the concept of Supportability through the needs of logistic support for support development with the lowest life cycle cost, related to maintainability and reliability.

These studies, among others, leave gaps in the study of maintainability, such as the specification of a project characteristics spectrum covering the main support conventional needs; organize characteristics according to specific attribute groups for support; evaluate characteristics in a qualitative way, with justified value scales; determine indexes of maintainability at several levels of the evaluated system, that is, per support activity, per component/set and in a global way for the whole system; etc. The aim of this study is to supply some of these needs.

Maintainability characteristics and value scales necessary for the evaluation are discussed next.

2. Maintainability characteristics and value scales

In order to facilitate maintainability characteristics, such as quantitative indexes of the project, it is necessary to have them clearly defined and assembled in areas of knowledge linked by identity in the functional contribution on the product/system to facilitate maintenance activities. This cluster definition and classification has been accomplished by ALVAREZ (2001). Figure 1 presents some examples of the classification accomplished.

The presentation of indexes through specific linking or cluster areas offers a useful classification for the study, analysis, and evaluation of maintainability characteristics.

After obtaining the classification and definition of indexes to be evaluated, the quantitative value scales of each index are built, vindicated by the Multiple Criteria Decision Analysis – MCDA (ENSSLIN, 2001). The scales obtained start to be definite and will become scale instruments of the model for evaluation of maintainability indexes.

ALVAREZ (2001), develops these scales in order to evaluate indexes which facilitate assembly/disassembly activities for support with five indexes (Ii) (see figure 1). Figure 2 shows these scales together with figure 3, which shows the pondering taxes of indexes, acquired through the same process (MCDA), necessary to develop the additional values assembly of each index in a single scale value, with global representation for the group of indexes.

GROUP	INDEXES	GROUP	INDEXES
Structural Facility	Duty cycle compatibility	Labor Facilitation	Ergonomic Factors
	Standardization and exchange		Preparation and Professional Ability Factors
	Rejection		Motivation Factors
	Modularity		Conditioning of Working Places
Assembly/ Disassembly Facility	Type of attachment/union		Safety Characteristics
	Characteristics of Adjustment and Calibration		Dangerousness
	Structural Simplicity		Aggressiveness
	Accessibility and Visibility	Lubrication Facility	Auto-lubricated Hinges
	Attainment and Handling		Waste-proof materials
Facility in Detecting and Localizing Failure	Test Spots for Diagnosis		Elevated duty cycle lubricants
	Monitoring		Automated systems of lubrication
	Auto-diagnosis		Assembled points for lubricant feeding
	Redundant Components		

Figure 1 – Classification of indexes in specific areas.

Index: "Type of attachment/ Union"	Value (V)
Attachment with passer-by elements or elastic constraint.	100
Attachment with a screw, union glove or an element of various turns.	83,3
Attachment with up to three screws or a similar element	58,3
Attachment with up to six screws or a similar element	33,3
Attachment with more than six screws or a similar element	0

Index: "Accessibility and visibility"	Value (V)
Totally accessible and visible	100
Totally accessible, but not visible	90,9
Totally visible, but not accessible	81,8
Limited Accessibility and Visibility, demanding effort for physical index of worker.	54,5
With no Accessibility or Visibility, demanding advanced disassembly	0

Index: "Attainment and handling"	Value (V)
Totally Attainable and Handy	100
Totally Attainable, but not Handy	83,3
Totally Handy, but not Attainable	58,3
Limited Attainment and Handling, demanding physical effort of the worker	33,3
No Attainment or Handling, demanding advanced disassembly	0

Index: "Adjustment and calibration"	Value (V)
Calibration is not necessary or auto-adjustable.	100
Adjustment with a screw or element and no calibration/ standard.	72,7
Adjustment with a screw or element and with calibration/ standard.	54,5
Adjustment with more than one screw or element and without calibration/ standard.	27,3
Adjustment with more than one screw or element and with calibration/ standard.	0

Index: "Structural/Functional simplicity"	Value (V)
Conventional mechanisms of unique specialty with no structural/functional dependence, a little labor's ability.	100
Structural and Functional dependence of components and preponderance of only one specialty, labor's medium ability	83,3
Great number of components with structural and functional dependence, preponderance of only one specialty, demanding normal ability and labour capacity	58,3
Structural and functional dependence mechanisms and several specialties, demanding high information Quantity, concentration and quality	33,3
Structural and functional dependence mechanisms of several specialties, demanding high information Quantity, concentration, memorization, high ability and quality. Use of new technology, several involved resources and high error probability.	0

Figure 2 – Value scales for maintainability indexes which facilitate disassembly/assembly.

Weight (Pi)	Maintainability index (Ii)	Weight value (substitution rate)
P1	I1: Attachment Type /Union	31,48
P2	I2: Structural and Functional Simplicity	25,93
P3	I3: Accessibility and Visibility	20,37
P4	I4: Attainment and Handling	14,81
P5	I5: Adjustment and Calibration	7,41
		$\sum Pi = 100$

Figure 3 – Substitution weights for addictive aggregation of indexes.

Scales presented with values from 0 to 100 will be definite evaluation instruments of the model, and their application occurs observing the analyzed component/set, observing at what scale level, among the possible five levels in the index scale, the constructive characteristic observed belongs to.

The methodology for maintainability evaluation in products/system in order to obtain the global index of maintainability is explained next.

3. Maintainability evaluation in products/systems

According to Alvarez's approach, the evaluation of maintainability characteristics of a system must be made using specific index sets (see figure 1). This work presents the evaluation of maintainability indexes belonging to disassembly/assembly cluster for support activities, whose scales are presented in figure 2.

In order to execute the index evaluation and obtain the indexes of maintainability, the sequence of the procedure shown in figure 4 must be followed.

The procedure indicated in figure 4 will provide the scale values (V) of each maintainability index (Ii) evaluated, and with their adding aggregation through substitution weights (figure 3), the maintainability value (SIm) of the support activities is obtained, being detected by the support tree (NBR 5462). With this sub-index (SIm), the local maintainability index (Im) is determined for each component/set; and, finally, the global maintainability index of the product/system is also determined, applying the logarithmic expression which correlates the local maintainability value (Im) of the components/set of the system with its support frequency (F). This is necessary to differ the components with high frequency value, whose local maintainability (Im) will be reduced logarithmically, depending on how high the value (F) is, so affecting the global index of maintainability value (Img).

In order to assist the identification of variables used in the calculation process, figure 5 shows nomenclature and meaning.

From the process to obtain the value of indexes and the local and global index of maintainability of the system, it is possible to make the following comments:

- when the system has more than one set/subset subjected to support activities, the value Img will represent the medium maintainability value over the whole product/system, pondered by the frequency of support interventions (F) of each evaluated item;
- the local index of maintainability (Im) of each component/set of the evaluated system is an intrinsic characteristic of the project, which depends on the maintainability characteristics projected;

Sequence	Procedure	Result
1	Develop the structural tree of the product	Identification of components in need of support
2	Calculate the Intervention frequency of support (F) in each identified component in the sequence (1)	Frequency obtaining of each component; F = Vuf p / Vuf c
3	Develop the support tree with the assembly/ disassembly sequence in each identified component	Graphic representation in blocks of the support activities to facilitate evaluation
4	Apply the value functions corresponding to maintainability indexes (Ii), in all blocks of the flowchart.	The obtaining of maintainability values (V) of each factor (Ii)
5	Calculate the maintainability sub-index (SIm) in each block of activities	The obtaining of maintainability sub-indexes in each block of activities $SIm = \sum_i^n V_{(Ii)} \cdot p_i$
6	Calculate the local maintainability index (Im) corresponding to each component/set.	The obtaining of local maintainability indexes in each component/set $Im = \sum_j^n \frac{SIm_j}{N_a}$
7	Calculate the global maintainability index (Img) of the product/system.	The obtaining of global maintainability index of the evaluated product/system $(Img) = \sum_u^n Im_u \times \left(\frac{\log_k (K+1-F_u)}{N_c} \right)$

Figure 4 – Methodology sequence for maintainability evaluation in products/system .

Nomenclature	Meaning
Ii	Maintainability index
V	Maintainability value of the index
P	Substitution weights for the adding aggregation of index
SIm	Maintainability value of the support activity of the component/set, aggregated to the spectrum of indexes (Ii) and substitution weights (Pi)
Im	Maintainability value or local index of maintainability, belonging to the evaluated component/set
Img	Maintainability value or global index of maintainability of the product/system
F	Support frequency of the system components
K	Logarithm basis, with value higher than the highest F value of the system (K=100 is recommended, if the system has lower frequencies than this value (K > F)
Na	Number of disassembly/assembly activities in the component/set support
Nc	Number of components/sets evaluated in the system

Figure 5 – Variables nomenclature and meaning used in the calculation process.

♦ the higher the intervention frequency (F), the higher the local maintainability value (Im) projected for this item might be, being the inverse also true, that is, the lower the frequency (F), the lower the local maintainability value accepted for it might be;

♦ the highest global maintainability value of the system is obtained when all components have unitary intervention frequencies (F =1), that is, when the life-ending of components/sets coincides with the life-ending of the system, because they have physical life compatibility among themselves. Thus, there is a support need only for the total recovery of the system, provided that it is technically and economically feasible, otherwise being rejected;

♦ the intervention frequency F = 1 (rejection) makes the acceptance of local maintainability values Im=0 possible;

♦ the maintainability value projected must be searched, balancing the two variables (Im and F), that is, searching for the best relation between them in order to obtain the best maintainability economic value (cost-benefit);

♦ the reliability value of the product components is directly related to the effective frequency of the support interventions (F), because the percentage of the accidental support – which exceeds the prevision made for F due to the physical life-ending of the components and product – will depend on them, not being considered non-predicted support occurrence,

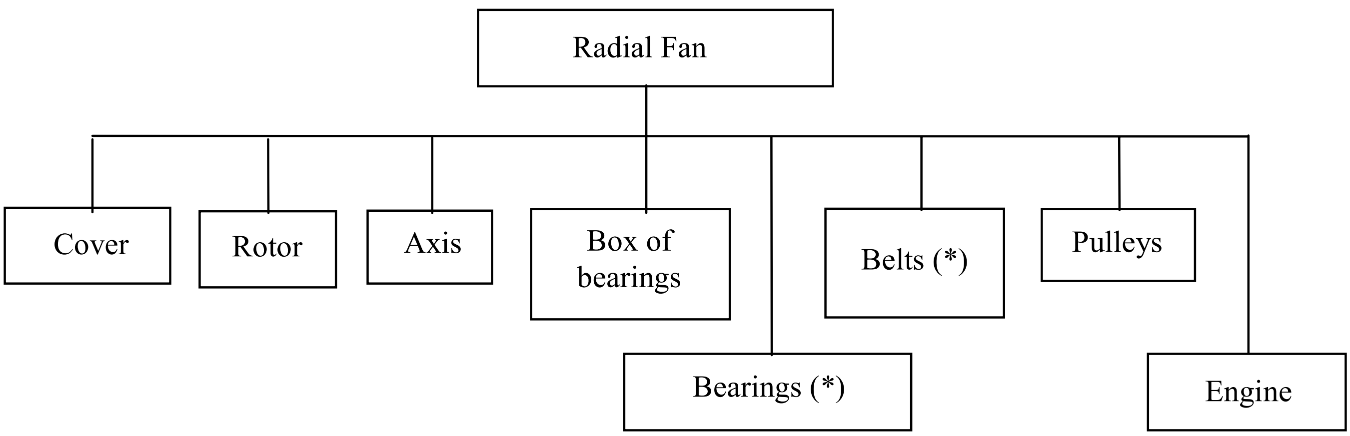

Figure 6 – Structural tree of the radial fan.

because modern support techniques have been developed aiming at the eradication from them.

In order to better interpret the performances of the evaluation of the process, an application example is described next.

4. Application of the model

The evaluation model will be applied to a straight blade radial fan with power of 25 HP and 5-year-physical duty cycle. Through the structural tree of the fan shown in figure 6, the components which need support can be identified, indicated by asterisk (*). These components are a set of two hinges bearings assembled on conic pads (named C1), transmission set with four V straps (named C2).

Figure 7 shows the support tree (NBR 5462) with the disassembly/assembly diagram of the product (fan), showing necessary disassembly/assembly activities to substitute the transmission belts and the bearings. The activities represented in blocks (a) and (b) have common tasks sub-blocks , such as "sub-block 1: Remove/ stretch belts" and "sub-block 2: Remove/ place protection".

Figure 8 shows the evaluation of maintainability indexes for support activities represented in blocks "a" and "b" together, for the fact that sub-blocks 1 and 2 are common to both activities (figure 7). The choice of the scale level can be explained by the type of construction presented by the evaluated component and commented in the figure.

Figure 9 shows the final maintainability values of the evaluated product, with indexes of maintainability obtained by the calculation procedure shown in figure 4.

Values of figure 9 are presented for each index by disassembly/assembly type of activity (sub-blocks from 1 to 5), and for each of the sub-blocks, the sub-index of maintainability (SIm). The indexes of local maintainability (Im) belonging to components/ sets which deal with the support activity (belt exchange and bearings) are presented at the end of blocks a and b. Finally, the figure shows the global index of maintainability (Img) which belongs to the evaluated product.

From the evaluation presented, the zero-value obtained by the adjustment and calibration index is highlighted, and this value might need a project improvement, if technically and economically justified through the performances as TMR, statistical maintainability value M(t), availability D(t), life cycle cost, improvement cost of the product characteristics, serial/ parallel dependence of the product in the flux of the process, among others.

The trace of low maintainability values shows the quality of the model to be used as a managerial tool in the search

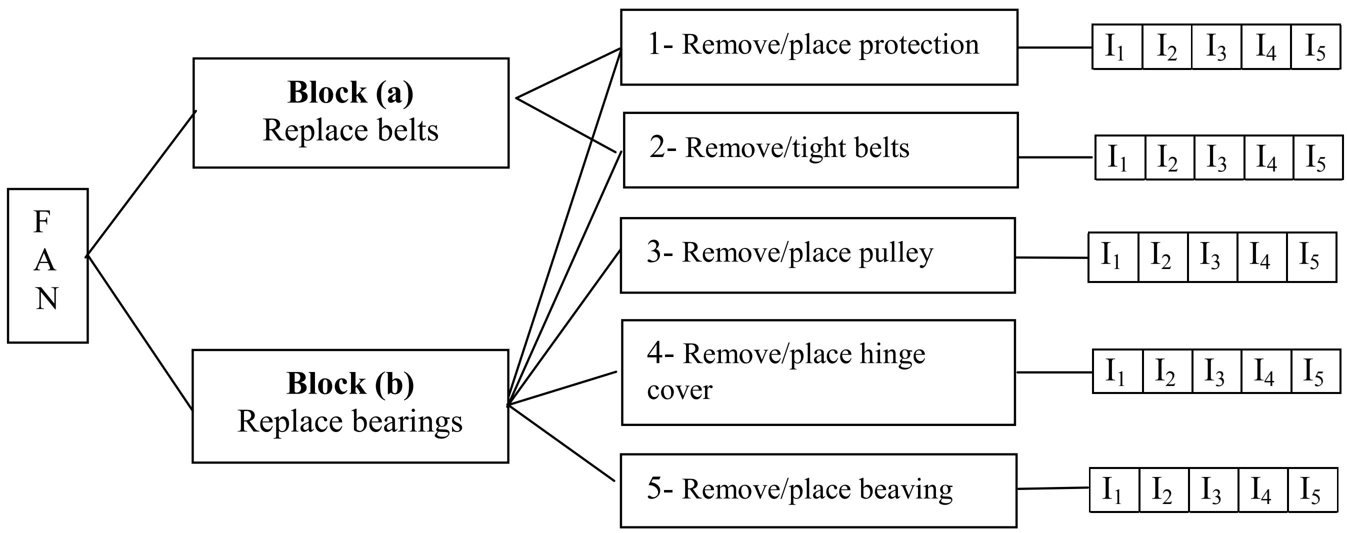

Figure 7 – Support tree with diagram of disassembly/assembly activities to "replace belts and beavings".

Evaluation of blocks (a) – replace Belts and block (b) – replace beavings

	Sub-Block1 Remove/ place belts protection		Sub-Block 2 Remove/ tight belts		Sub-Block 3 Remove/ place pulley		Sub-Block 4 Remove/ place hinge cover		Sub-Block 5 Remove/ place beaving	
Maintenability index	**Scale level**	**Value**	**Scale level**	**Value**	**Scale level**	**Value**	**Scale level**	**Value**	**Scale level**	**Value**
1– Type of attachment/ Union	Protection attachment with three screws	58,3	Electric engine attachment with four screws	33,3	Pulley attachment with one screw	83,3	Attachment with two screws	58,3	Attachment with a scouring pad	83,3
Structural/ Functional plainness	Conventional mechanism	100	Conventional mechanism	100	Conventional mechanism	100	Conventional mechanism	100	Conventional mechanism	100
3- Accessibility and Visibility	Totally accessible and visible	100	Totally accessible and visible	100	Totally accessible and visible	100	Totally accessible and visible	100	Totally accessible and visible	100
4- Attainment and Handling	Totally attainable and handy	100	Totally attainable and handyling	100	Totally attainable and handy	100	Totally attainable and handy	100	Totally attainable and handy	100
5- Adjustment and Calibration	No need of adjustment / calibration	100	Adjustment with two screw with calibration	0	No need of adjustment / calibration	100	No need of adjustment / calibration	100	Adjustment with one screw and gauge with blade	54,5

Observation: Sub-blocks 1 and 2 are common for support activities represented by blocks (a) and (b).

Figure 8 – Evaluation of the maintainability indexes corresponding to the support activities of blocks "a" and "b".

	Support activities of block (a)		Support activities of block (b)				
Maintainability index	**Sub-block 1**	**Sub-block 2**	**Sub-block 1**	**Sub-block 2**	**Sub-block 3**	**Sub-block 4**	**Sub-block 5**
Attachment type/ union (I_1)	58,3	33,3	58,3	33,3	83,3	58,3	83,3
Structural/functional simplicity (I_2)	100	100	100	100	100	100	100
Accessibility and visibility (I_3)	100	100	100	100	100	100	100
Attainment and handling (I_4)	100	100	100	100	100	100	100
Adjustment and calibration (I_5)	100	0	100	0	100	100	54,5
Maintainability sub-index (SIm)	86,87	69,11	86,87	69,11	94,74	86,87	91,37
Local index of maintainability (Im)	Im_1 = 77,99		Im_2 = 85,79				
Global index of maintainability (Img)	81,44						

Figure 9 – Maintainability final values of the evaluated product with its indexes of maintainability.

for strong and weak maintainability characteristics, allowing for decision-making guidance for the improvement of products in project phase or existent products, and specification, when buying new products.

A practical application of the model with the procedure of indexes evaluation and the form of index of maintainability calculation were presented here.

5. Conclusion

The model presented investigates the project characteristics which influence the performance of the product in support activities, developing a scale evaluation system of maintainability indexes, correlated with indexes which represent a comparable value of the support facility presented by the evaluated product/system. This comparison is valid only for product projects which have the same function, size and capacity, besides the same spectrum of indexes. Thus, the values obtained make numerical reference to the degree of development acquired in the project for the maintainability characteristics, according to scales from 0 to 100.

By the same token, the interpretation of the absolute index value, which evaluates the maintainability of the system in a local and formal way, might be given through the relative comparison of these values (higher/lower), and between identical products (function, size and capacity).

The trace method consists of this value comparison, which allows detection of strong and weak maintainability characteristics of the project, making projects and products incompatible with the expected performance needs in support activities. So, the evaluation obtained by the model might be used as a managerial support tool to identify systems with conditioning needs to facilitate support activities.

In order to better observe the importance of this research, up-dated demands must be taken into account to continuously develop the system of production and services, in search of better productivity and quality, mainly in the context of globalized economy (See TPM and KAIZEN philosophies as reference).

With such a need for strategic performance of companies, the importance and contribution of the model can be observed as a tool for the maintainability analysis and evaluation. The model assists the project, improvement and support system specification in search of productivity profits in production systems, and in the effectiveness of the labor use and support.

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