Theoretical model of materiel quality characteristics metrics

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Abstract

Facing the continuous enrichment of intension of quality characteristic, a theoretical model of quality characteristics metrics regarding complicated materiel was established in this paper so as to perform systematic metrics of the quality characteristic of complicated materiel. On the basis of definition of metrics, metrics was described, so as to clarify the intension of metrics; conceptual model of materiel quality characteristic metrics including three hierarchies of comprehensive characteristic, single characteristic and metrics element was established; on the basis of conceptual model of metrics, overall and complete quality characteristic metrics system was established from three dimensions including system dimension, characteristics dimension and process dimension; 4 steps of materiel quality characteristic metrics were further specified, so as to clarify the entire process of its metrics. Finally, typical quality characteristic metrics parameter system of the materiel was given by taking aircraft as an example. The model structure is clear and simple, and overall understanding and sorting of all contents of materiel quality characteristic were performed so as to provide energetic support for realization of metrics of quality characteristic of complicated materiel.

Keywords: metrics; quality engineering; reliability engineering; metrics parameter

1 Introduction

Quality is an important criterion for evaluation of good or bad product, while superior or inferior materiel quality directly results in strong or weak combating capability. Therefore, metrics of materiel quality characteristic is an important issue for all phases of development, usage and maintenance of materiel, only with accurate metrics and judge of materiel quality characteristic, can objective data be provided for development and purchase of materiel.

Starting from the birth of quality engineering, the intension of quality concept has been getting richer through the promotion of systematic engineering development, for example, development from the exclusive use characteristics at the very beginning to general purpose and full characteristic, from focus on quality capability in production process to focus on quality capability in full process, and from survey of system quality to survey of materiel/materiel system quality [1-7]. Quality characteristic is gradually developing towards overall, comprehensive and parallel design. Therefore, it is even more necessary to perform systematic and accurate metrics of complicated quality characteristic of materiel, so as to perform design and evaluation of materiel in a better way.

Initially originating from natural science field, metrics is a quantization evaluation method of known things, then it is used in social science and engineering science fields. In engineering field, software metrics theory has developed maturely at present [8-10], including software metrics model based on RUP [11], software metrics based on component [12] and field-oriented assembly quality metrics [13]. But systematic metrics method regarding hardware system especially large materiel quality characteristic is unavailable. On the basis of definition of materiel quality characteristic metrics, theoretical model of materiel quality characteristics metrics regarding numerous aspects such as conceptual model, metrics system model and metrics process model of materiel quality characteristic metrics was established in this paper, so as to realize quantitative metrics of materiel quality, which plays an important role for improvement and enhancement of materiel quality.

2 Quality and quality characteristic

2.1 QUALITY

Quality has been defined in many documents [14-17]. Definition of quality in international standard ISO9000: quality is the degree to which a group of inherent characteristic meets requirement. In concept diagram of quality, quality is described as the capability of a group of inherent characteristic of product, system or process to meet requirement of customer and other parties involved. This is the concept of generalized quality, i.e. quality has contained all important characteristic of product.

2.2 QUALITY CHARACTERISTIC

Quality characteristic refers to natural attribute of product, and attribute, performance, function and nature of usage value of materiel, i.e. the comprehensive performance, function and nature embodied by materiel in an overall manner. The nature can be inherent or endowed, qualitative or quantitative, and quality nature is different for different types of characteristic. In accordance with different classification methods, quality characteristic can be classified as comprehensive characteristic, single characteristic, general purpose characteristic and special purpose characteristic, etc [18-19].

3 Quality characteristic metrics

Quality characteristic metrics provides a quantitative method to describe materiel quality, so as to control materiel development process and enhance materiel quality. From

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the point of view of categoricalness, theoretical model of materiel quality characteristics metrics should include definition and intension of materiel quality characteristic metrics, conceptual model, metrics system and process model, in which definition and intension of materiel quality characteristic metrics are the basis, conceptual model of materiel quality characteristic metrics, materiel quality characteristic metrics system and materiel quality characteristic metrics process model should be established by centreing on it.

3.1 DEFINITION AND DESCRIPTION OF METRICS

As a noun, metrics is a function of which the input is materiel data and the output is single value, and can be use to describe degree of influence of a given attribute upon materiel quality. Materiel quality metrics is a quantitative measurement of attribute of materiel quality.

For the purpose of this paper, metrics is described as a triad (Q, M and N), in which:

1) Empirical Relation System (Q = (Q, R)) is a description of attribute of thing under metrics. Q is a aggregate of objects under metrics, R={R1,R2,...,Rn} is a series of relationship on Q and Ri describes the attribute of things under metrics.

2) Numerical Relation System (N = (N, P)). N is a aggregate of values or symbols, P={P1,P2,...,Pn} is a series of relationship on N.

3) Mapping M:Q → N, M(x) is the metrics value of object x (∈Q) in terms of attribute under metrics.

3.2 CONCEPTUAL MODEL OF METRICS

Conceptual model of metrics is the key point in the evaluation system of materiel quality characteristic metrics, through which the objective relationship between extrinsic characteristics and inherent design characteristic of materiel can be established, and interference of objective factor can be reduced, so that evaluation results are in more compliance with actual quality condition of materiel. The conceptual model of materiel quality characteristic metrics was researched and established in this paper, as shown in Figure 1.

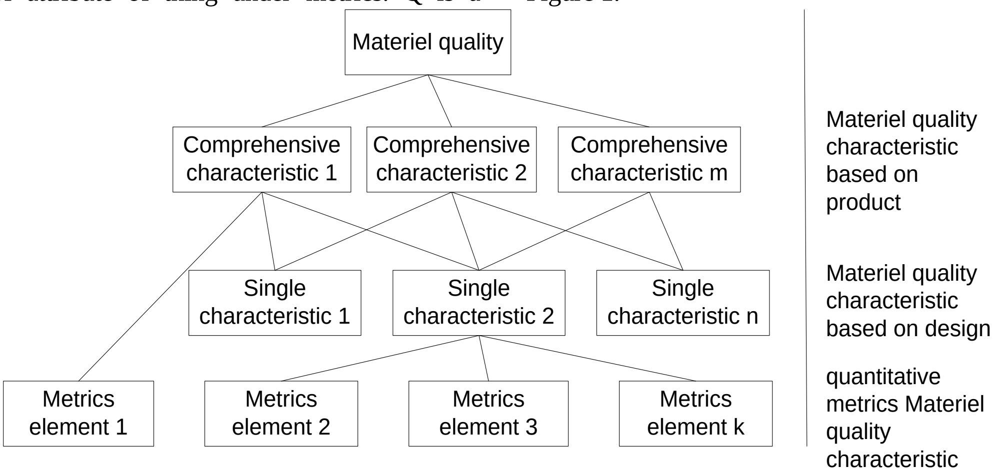

FIGURE 1 Conceptual model of materiel quality characteristic metrics

The model is a three-hierarchy hierarchical structure model. It classifies the concept of materiel quality into two major hierarchies: comprehensive characteristic hierarchy and single characteristic hierarchy, and introduces quantitative index for the bottom hierarchy characteristic, which is expressed by metrics element. Reflecting the capability of materiel to meet demand, comprehensive characteristic is the direct embody of extrinsic quality of materiel, and can be sensed directly by user. As a measureable design attribute that is closely related to materiel design, single characteristic is used by designer to design product. Reflected by multiple single characteristics, comprehensive characteristic can be decomposed into combination of multiple single characteristics, and can have its own metrics element. In accordance with character of metrics object of different hierarchies and its different development phases, optimized quality characteristic metrics system of materiel can be established by selecting relevant quality characteristic that is suitable.

3.3 METRICS REGIME MODEL

On the basis of conceptual model of metrics, from three dimensions of system dimension, characteristic dimension and process dimension, systematic analysis of materiel quality characteristic is performed [18], so as to establish overall and complete metrics system, as shown in Figure 2.

In which, characteristic dimension is the basis of conceptual model of quality characteristic metrics, therefore, quality characteristic metrics model is established regarding each coordinate of system dimension and process dimension, so as to form overall metrics system. Firstly analyze and determine quality characteristic in model, then design metrics element for each quality characteristic. Figure 3 shows characteristic description of materiel quality characteristic metrics system.

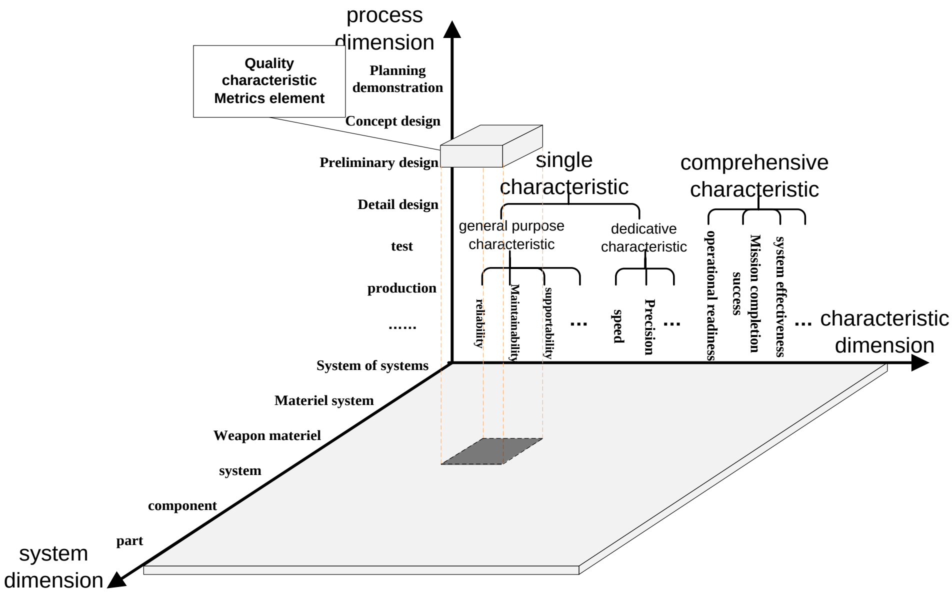

FIGURE 2 Three-dimension metrics system of materiel quality characteristic.

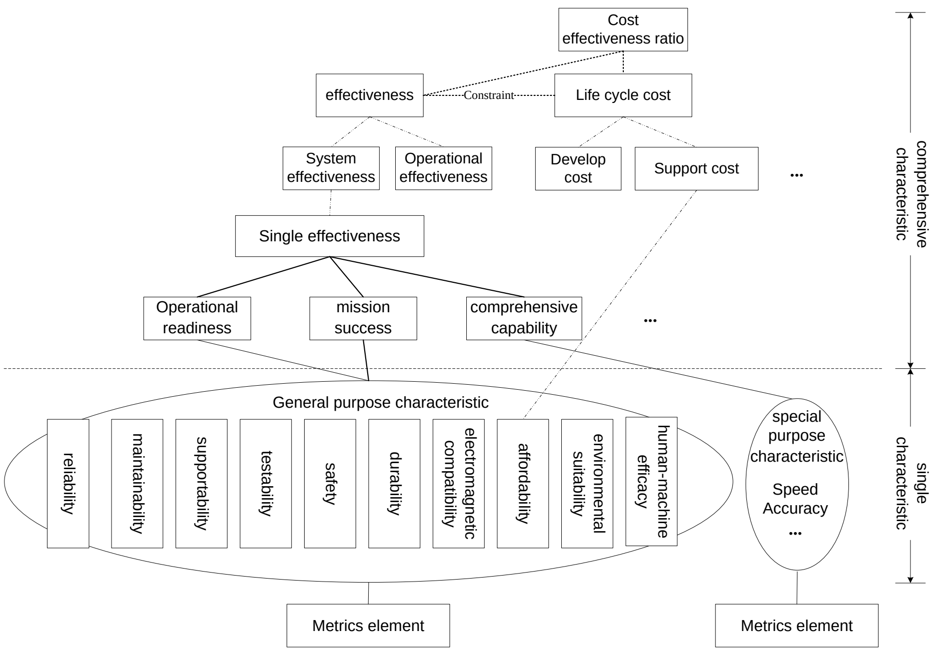

FIGURE 3 Characteristic description of materiel quality characteristic metrics system.

The upper half of the figure shows comprehensive characteristic. Reflecting characteristic of comprehensive capability of materiel system, comprehensive quality characteristic is the comprehensive characteristic reflected to user when materiel regime or materiel system is subject to effect of numerous factors such as mission, arrangement and extrinsic usage environment, including effectiveness, life cycle cost, cost/effectiveness ratio and operational readiness, mission success and comprehensive capability, etc. In which, effectiveness can be classified into single effectiveness, system effectiveness and operational effectiveness in accordance with difference of materiel mission, purpose and object. Single effectiveness refers to the degree to reach single usage target when utilizing materiel system, its corresponding operational action is single target action. System effectiveness refers to the degree to meet a group of specific mission requirements when materiel system is under a certain condition, it is a comprehensive evaluation of materiel system effectiveness, and is also referred to as comprehensive effectiveness. Directly related to availability and dependability, it is a description and embody of self-capability. For consideration of the effect of four major factors of materiel including regime, quality, quantity and configuration, it is necessary to use operational effectiveness for metrics.

The lower half of the figure is single characteristic, which reflects characteristic of specific capability or quality of materiel, and can be used for characteristic of product design, including two major categories of general purpose characteristic and special purpose characteristic. General purpose characteristic reflects character that is common for various materiel, including ten parts of reliability, maintainability, supportability, testability, safety, durability, electromagnetic compatibility, environmental suitability, affordability and human-machine efficacy, which belong to reliability engineering design field; special purpose characteristic reflects individual character of different materiel, including speed, range, accuracy and power, which belong to performance design field.

Metrics element is quantitative parameter (or index) rendered by the lowest hierarchy character of comprehensive characteristic and single characteristic of materiel. In order to describe materiel quality in an overall and reasonable manner through these metrics elements, it is necessary to determine materiel quality characteristic index set as per the following principle.

1) Categoricalness. The selected indexes are combined to describe all aspects of system index requirements.

2) Phase. In accordance with mission analysis, system mission process is classified into different phases, each mission phase should have relevant technical index and index value, and indexes of different phases use different index values.

3) Applicability. Index should correspond with work nature of system.

4) Hierarchy. Complicated system normally consists of subsystems of several different functions, subsystem consists of numerous sub-functions, and each sub-system can be decomposed continuously in accordance with its function. Relevant index regime should be given for subsystem in which each function exists.

5) Accessibility. Index acts as guidance for design, implementation and realization of system, the determined index value is basically identical with the (existing) level of actual system, so that the system meets the stipulated requirements.

6) Non-uniqueness. Different indexes that are interlinked with each other can be used to describe specific requirement of system on specific index. This non-uniqueness does not affect categoricalness of index set.

7) Gradual progress. Index set is not changeless, with the development of technology and method, it must adapt to requirement on development of new system.

Regarding different characteristics, metrics element can be designed respectively as follows:

TABLE 1 General purpose characteristic metrics element (partial)

Quality characteristic	**metrics element**
reliability	Mean Time Between Failures (MTBF) Mean Time Between Critical Failures (MTBCF) Mean Mileage Between Fault (MMBF) Mean Fly Hours Between Fault (MFHBF) …
maintainability	Mean Time To Repair (MTTR) Direct Maintenance Man Hours per Fly Hour (DMMH/FH) Engine Repair Time (ERT) Scheduled Maintenance Time Mean Preventive Maintenance Time Maximum Time To Repair (Mmaxct) …
testability	Fault Detection Rate (FDR) Fault Isolation Rate (FIR) False Alarm Rate (FAR) Detection time …
supportability	Mean Logistic Delay Time (MLDT) Support Equipment Utilization Rate Support Equipment Fill Rate Spares Utilization Rate Spares Fill Rate …

3.4 METRICS PROCESS MODEL

On the basis of clarification of materiel quality characteristic metrics and metrics regime, the whole process of materiel quality characteristic metrics is further planned, and all steps are expressed on the basis of flow procedure, so as to provide guidance for realization of metrics. The establishment of materiel quality characteristic metrics process model is shown in Figure 4, mainly including four steps.

1) Determination of materiel quality characteristic metrics demand: required to be defined in demonstration phase of materiel, quality demand is a precondition for effective establishment of materiel quality and objective evaluation of materiel quality. Quality characteristic metrics demand should clarify the direct metrics of comprehensive characteristic required by materiel and its direct metrics target value. Direct metrics target value is used to verify whether final product meets quality demand.

2) Preparation of metrics: it is usually impossible to directly measure materiel quality demand described by material quality comprehensive characteristic, therefore it is necessary to further determine relevant measurable characteristic (or metrics element). In preparation phase, it is necessary to determine appropriate measurable characteristic for materiel in accordance with different hierarchies of materiel object, establish relationship model of metrics element, single quality characteristic and comprehensive quality characteristic, and determine rational evaluation criterion.

3) Realization of metrics: collect data in accordance with actual conditions, and render metrics results of all characteristic by adopting different metrics methods.

4) Analysis of quality characteristic metrics results:

analysis of metrics results requires not only conclusion of metrics and evaluation, but also confirmation of metrics element, so as to determine which metrics elements apply to current materiel quality characteristic metrics action and can be used for prediction of materiel quality characteristic value, and determine whether it is necessary to perform further metrics and analysis of under-metrics object on the basis of these metrics values and the prediction value of direct metrics acquired through calculation of these metrics values.

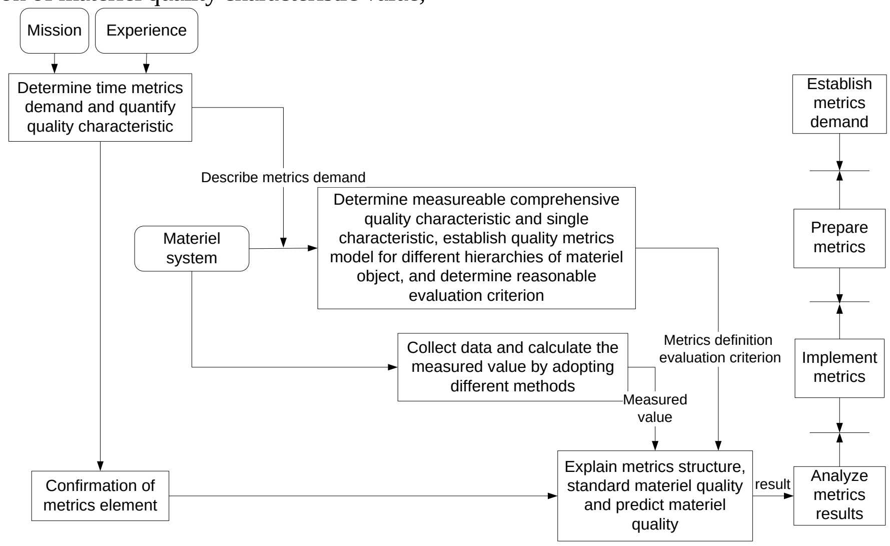

FIGURE 4 Materiel quality characteristic metrics process model

4 Example of quality characteristic metrics parameter regime

Figure 5 shows the quality characteristic metrics parameter regime of aircraft established by application of above mentioned method, in which description of partial metrics elements [19-23] is shown in Table 2.

TABLE 2 Example of aircraft quality characteristic metrics element (partial)

Category of characteristic	Serial No.	Name of metrics element	Description
Comprehensive quality characteristic	1	Aircraft system effectiveness E	$E = \alpha_1 E_{air} + \alpha_2 E_{ground}$ In which: α1-air-air mission allocation coefficient; α2-air-ground mission allocation coefficient, the total of the two of them is 1.
	2	Air-air mission system effectiveness Eair	$E_{air} = A \cdot D \cdot C_{air}$
	3	Air-ground mission system effectiveness Eground	$E_{ground} = A \cdot D \cdot C_{ground}$
	4	Sortie generation rate	Under specified usage and maintenance support scheme, number of sortie times of each aircraft per day.
	5	Mission reliability	The probability of product to successfully complete the specified mission within specified mission profile.
		……	
Single general purpose quality characteristic	6	In-flight shutdown rate (IPSR)	The total number of engine shutdowns occurred during one thousand flight hours.
	7	Mean time between failures (MTBF)	The ratio of total product life units to the number of failures under specified condition and within specified time.
	8	Mean fly hours between failures (MFHBF)	The ratio of accumulated flight hours of product within specified time to the total number of failures within the same period.
	9	Mean time to repair (MTTR)	Under specified condition and within specified time duration, for product of any specified repair grade, the ratio of total repair time duration to the number of repair times of products of the grade.
	10	Maintenance free alert time (MFAT)	The duration time when aircraft is ready to maintain good and alert condition free from any maintenance under specified usage condition.
		……	
Single special purpose quality characteristic	11	Maximum allowable overload of aircraft	
	12	Maximum stable circle overload	
	13	Maximum specific excess power (SEP)	The ratio of engine excess power to aircraft weight under certain speed of aircraft.
		……	

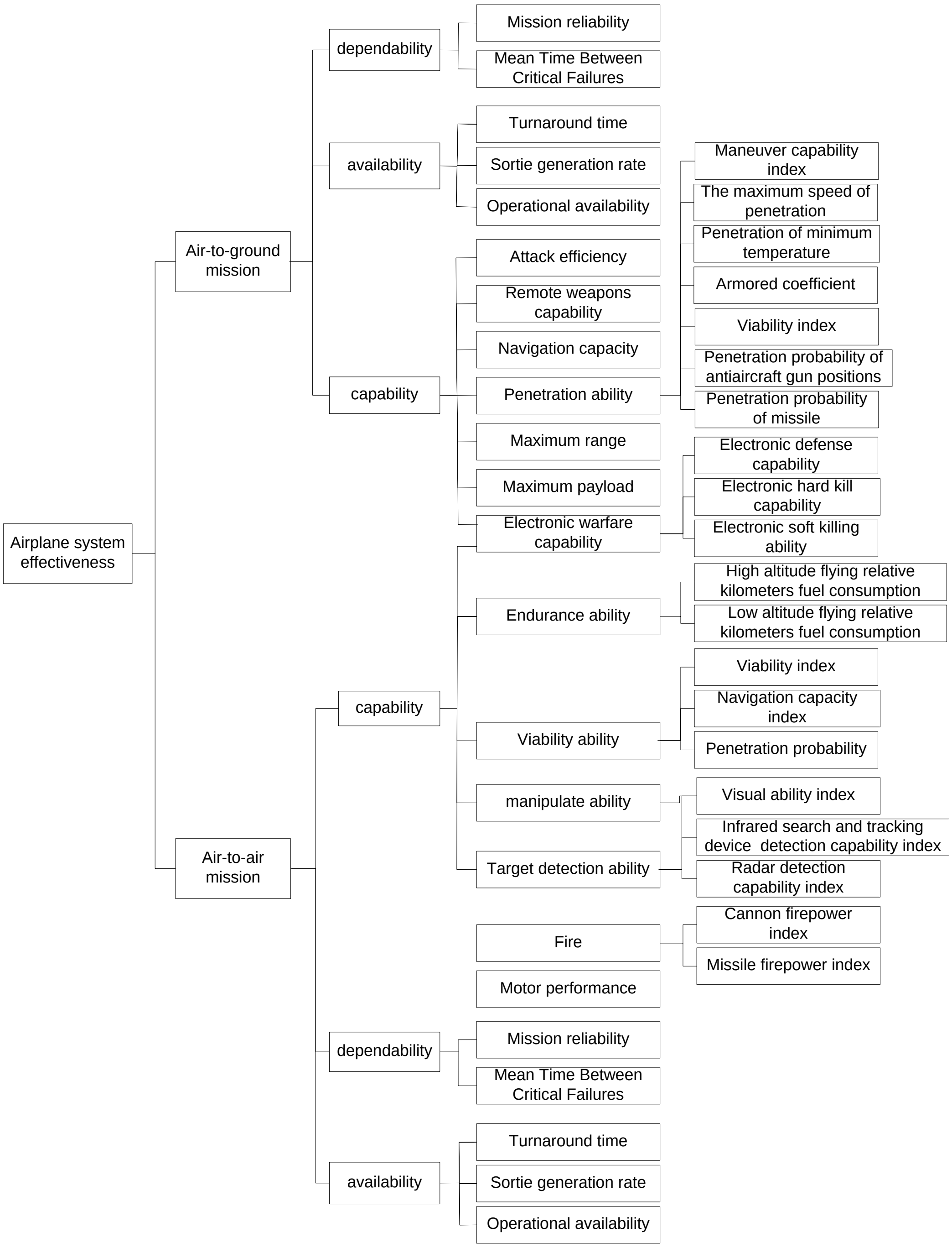

FIGURE 5 Quality characteristic metrics parameter regime of aircraft

5 Conclusion

From systematic point of view, theoretical model of materiel quality characteristic metrics has been established in this paper. Metrics is described by using mathematical model, so as to clarify intension and rule of metrics; conceptual model of materiel quality characteristic metrics has been established so as to lay a foundation for implementation of metrics; objective relationship between extrinsic characteristic and inherent design characteristic of materiel has been established through conceptual model of metrics, so that interference of objective factor can be reduced as much as possible, and evaluation results are more in compliance with actual quality condition of materiel; with consideration of all dimensions, materiel quality characteristic metrics regime has been established, and its characteristic have been described, so as to provide support for acquirement of overall and rational parameter set; through establishment of materiel quality characteristic metrics process model, the work flow of the entire metrics can be clarified, so as to provide guidance for realization of metrics. With a materiel quality characteristic metrics method rendered with consideration of different aspects, this model provides strong support for realization of metrics of complicated materiel quality characteristic, and plays an important role for improvement and enhancement of materiel quality.

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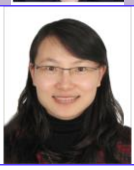

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