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A Method for Systems Analysis and Specification with Performance, Cost and Reliability Requirements

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Foreword

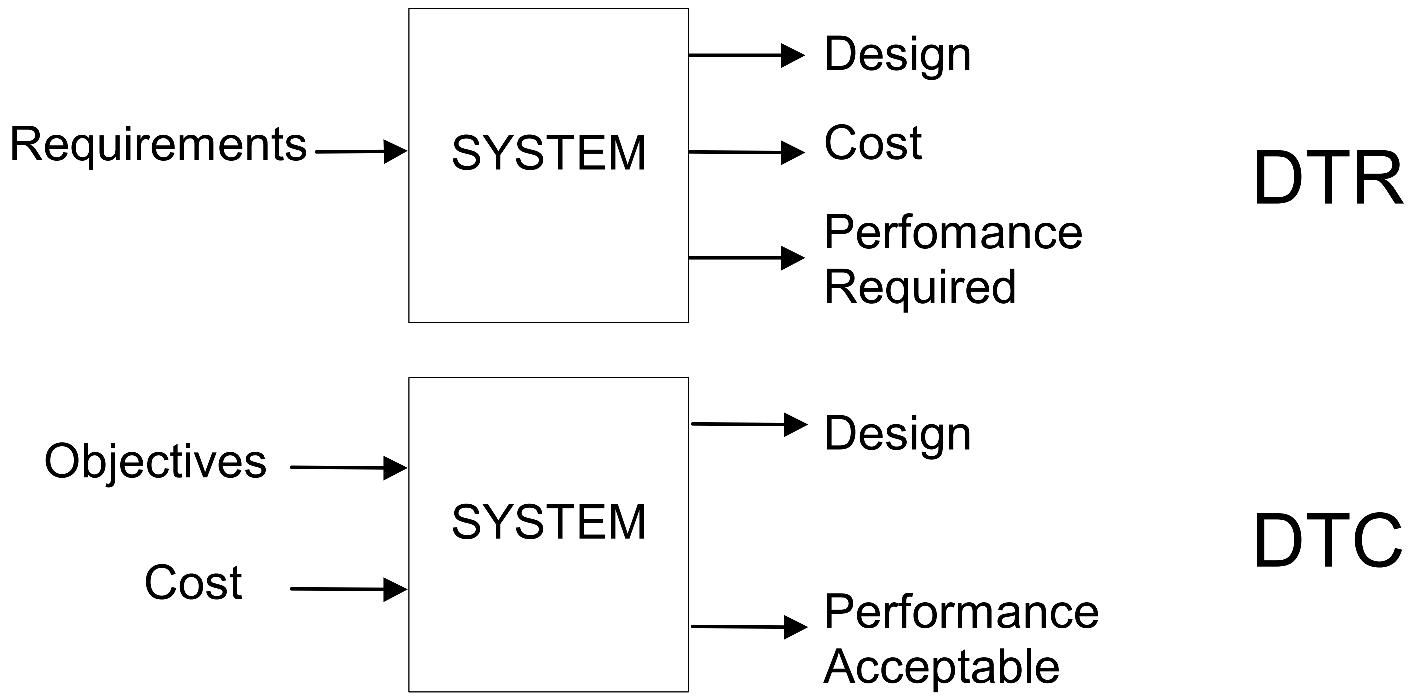
- This paper is based on a Master Dissertation previously developed by the first author.
- The original motivation behind the work was to learn, evaluate, adapt and (perhaps) improve current methods of design management generically known as Design-to-Cost (DTC).
- At the time the work was developed, INPE was heavily involved in the development of very small scientific satellites and the idea was to have a first foray on the methods that pursue low cost solutions suitable for sensors and actuators of attitude control systems.
- This paper focus on the method presented in the original work. A follow-on paper will present the results of its application to an actual design case (a small reaction wheel).

Objetives

- The original design-to-cost (DTC) method was developed to include the cost as a parameter of the design. The “faster, better and cheaper” *motto* at NASA during the 90’s was one of the incentives to develop this sort of methodology.
- The objective is to depart from the conventional Design-to-Requirements (DTR) methodology, in which the resources are generally allocated in such a way to satisfy a set of functional specifications, “almost” regardless of the final cost.
- In this work we propose an extension of the DTC method for systems analysis and specification able to deal simultaneously with **performance**, **cost** and **reliability** requirements.

A comparison of the DTR and the DTC methods

- According to J.W. Wertz, the DTC consists "*in the choice of a set, maybe among many others, of technical parameters of performance and attributes of design that represent an alternative capable of satisfying the objectives aimed by a system within a program and a range of costs*".



General aspects of the method

- The model DTC is formed by the integration of various models and tools. They include: models of cost, models of performance of subsystems, models of reliability, and tools of analysis and decision.
- The analysis based in **objects** was inserted in this method for having a direct correspondence with physical elements that constitute the system, which makes it more clear and practical than a **functional analysis**. **Objects** are defined as some data in the system, together with the operations that can be performed on the data during the activity of the system.
- The method has two major steps: the **Global Analysis** and the **Specific Analysis**.
- The first one treats an object to be acquired/designed as a unique element characterized by its attributes. The second one constitutes a refinement of such object.

The Global Analysis

- Starting on a higher hierarchical level, a **frame** is built with a list of **attributes** of the product with information obtained from several sources.
- These **attributes** are then filled with values needed for the accomplishment of the objectives of the mission, resulting from a preliminary study. Such data constitute the **initial base model**.
- The values of the **attributes** are normalized with regard to the **initial base model**.

$$Vr = \frac{Vn}{Vb} \times 100$$

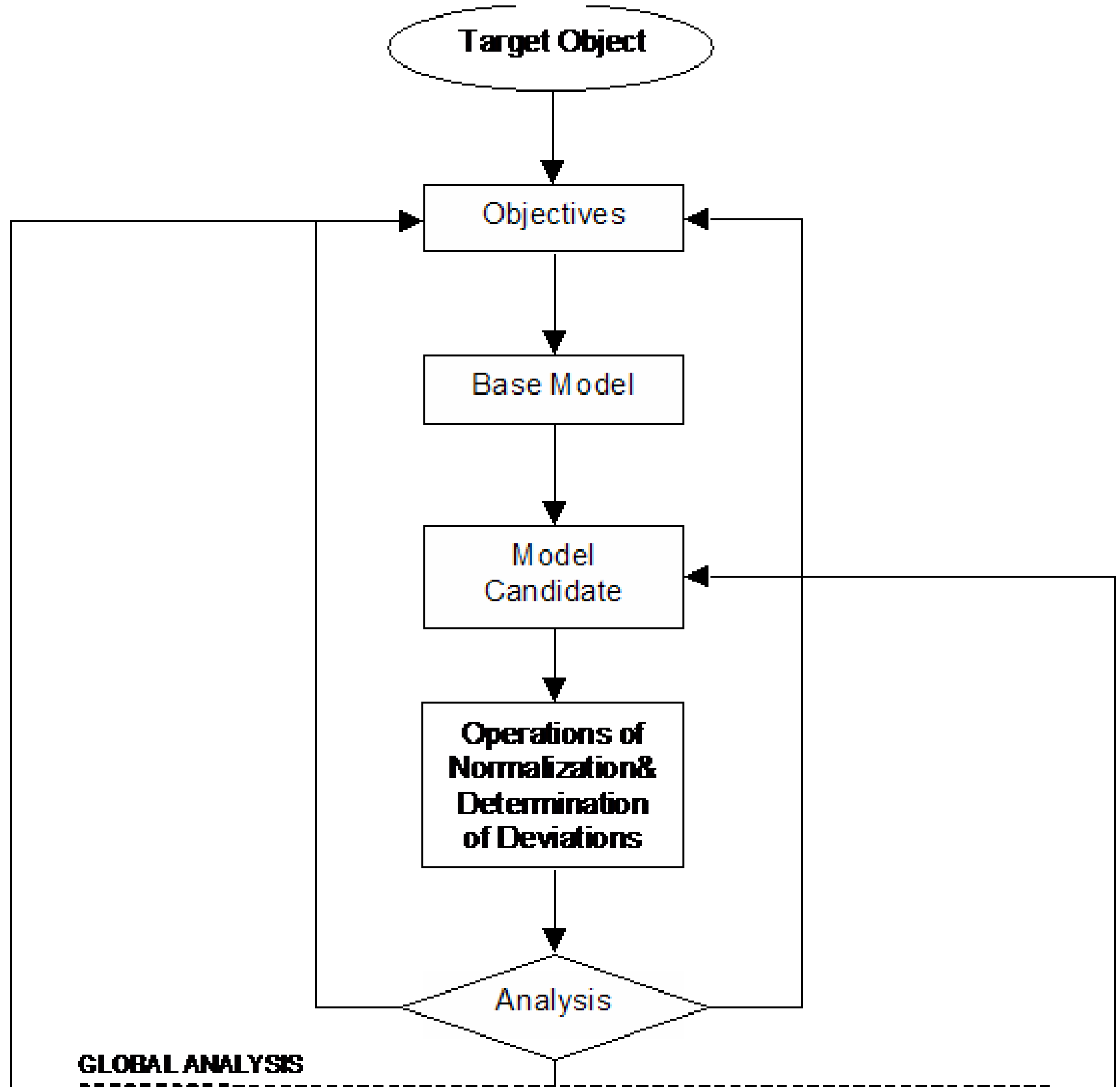
- To indicate a variation or dispersion of the *n* relative values of a model, except cost, around the base value, 100, it is defined a deviation inspired in the standard deviation definition.

$$Desvio = \sqrt{\frac{\sum_{k=1}^{n} (Vr_k - 100)^2}{n}}$$

The Global Analysis (cont.)

- The costs associated to each model are represented by a fraction 1/1000 of a monetary unit and are assumed invariant in time.
- The cost of the base model is a value previously stipulated that will serve as one of the parameters of acceptance of the project. It is desirable to establish a level of tolerance above which the project is rejected.
- With the **global analysis** we intend to provide subsidies to the design teams in the choice of a system or other equivalent in a rapid and systematic way.

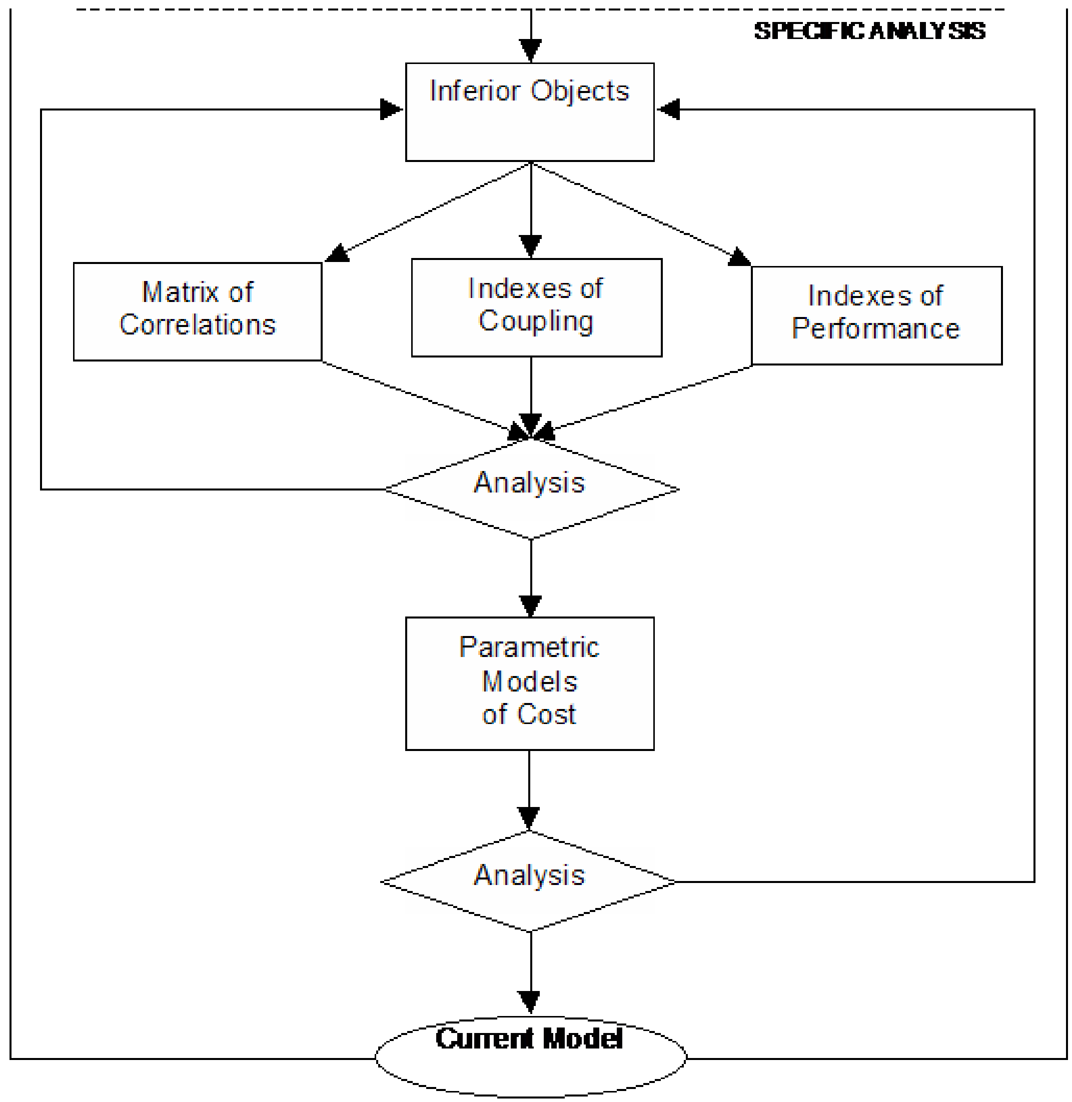
Conceptual flow graph for the Global Analysis



The Specific Analysis

- Having as a reference the **base model**, we proceed with the identification of the **objects** that constitute the system and the disposition of the attributes of these objects in **frames**.
- Over the attributes are defined concepts and indexes for evaluation of performance, cost and reliability of these inferior objects and, therefore, of the product in question.
- All these parameters are related in such a way that the system can be evaluated and optimized. Since the attributes of the smaller objects do not have the same numerical values as the base model, they pass to be named the **current model**.
- The **current model** presents the same attributes of the **base model**, regardless of the differences on the numerical values.

Conceptual flow graph for the Specific Analysis



The Specific Analysis (cont.)

- **Frames of the inferior objects**: In this step the major objects of the system are presented in their respective frames. The quantity and specificity of the selected objects depend on the design team. The attributes can be expressed as quantitative or qualitative variables.
- To each value of an attribute is associated a numerical **concept**, *C*.

Attributes	**Units**	**Value**	**Concept**
Attribute A	cgs	1,7	5
Attribute B	-	bom	3
Attribute C	mks	3000	2

- **Reliability** is considered as one of the attributes and adopted as the useful life of each object.

The Specific Analysis (cont.)

- **Correlations among attributes of objects**: The information on the influence that each attribute exerts on other is expressed in the matricial form.
- The cell correspondent to a pair (attribute-row, attribute-collumn) and is filled with a value, the degree of correlation, that expresses the relation among them.
- The degree of **correlation** (*r*) adopted is designated by an integer number belonging to an interval previously specified.

			Object	
		Attribute A	Attribute B	Attribute C
Object	Attribute A	0	1	3
	Attribute B	1	0	5
	Attribute C	3	5	0

The Specific Analysis (cont.)

- **Evaluation of Performance** – for the present case two indexes are proposed:
  - the index of coupling (α)
  - the index of performance (η)
- These indices make use of the **concepts** of the attributes and of the **correlations** among them.
- These relative indexes can be used in comparisons among different alternatives of a design.

$$\alpha i = \frac{\sum_{j=1}^{n} rij}{n}$$

$$\eta i = \frac{\sum_{j=1}^{n} C_j{}^2 .rij}{n}$$

The Specific Analysis (cont.)

- The total cost is given by the weighted sum of the estimated costs of each object of the system.
- Two factors of adjustment of cost are inserted (based on Wertz):
  - The **level of knowledge of the team**
  - The **degree of technological qualification of the system**
- Upon varying the parameters of the system, the cost also alters. To relate such variations the concept of **sensitivity** is introduced. The sensitivity (*S*) of the cost of an object (*c*) in relation to a given attribute (λ) is given by:

$$S_{\lambda}^{c} = \frac{\partial c}{\partial \lambda} \frac{\lambda}{c}$$

The Specific Analysis (cont.)

- Starting from the frames of the objects formed and the tables of performance, cost and reliability, the **current model** is structured.
- The attributes of the **current model** are extracted directly from the attributes of the smaller objects or obtained through simulations and/or experimentations with the data of these objects.
- Having one or more candidates to **current model** resulting from the **specific analysis**, we shall submit them to a **global analysis** to select a new **base model**, closing the loop of the method.

Conclusions

- In this work it was presented a method for the analysis and specification of systems with requirements of performance and cost, according to the model DTC.
- This method was then applied to the case of a reaction wheel (results to be presented in another paper).
- A flexible tool was proposed that aggregates different modes of treatment and modeling of complex systems with the same objectives.
- This tool is capable of assembling information of diverse kinds and treat them globally.