Determination of the Evaluation Criteria Weights for a Commercial Communication Satellite Program by Using AHP Method

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Abstract

Selecting the most effective and appropriate solution, which involves critical and analytic thinking, is a key and vital part of a satellite program management; such as determining or opting satellite manufacturer, test subcontractor, communication module design scheme, propulsion subsystem, type of power generator solar cells or launch vehicle. Each solution has unique, complicated and interlinked attributes; therefore the owner or operator of the satellite needs to constitute a well-defined basis in multi-criteria decision making process. This paper aims to define top-level common evaluation criteria for multiple solution problems in a satellite program lifecycle from the viewpoint of a communication satellite operator as decision maker and proposes using Analytic Hierarchy Process (AHP) method in order to determine the weights of criteria. An illustrative example with computational study to check the consistency of the determined weights is also incorporated.

Key words: Communication Satellite, Satellite Operator, Multi-Criteria Decision Making, Analytic Hierarchy Process, Criteria Weight Determination

1. Introduction

A communications satellite is stationed in space often located in geostationary orbit at the high orbital altitude of around 36000 kilometers away from the Earth for the purpose of providing telecommunications. Communication satellites are commonly used for radio and television broadcasting, telephony signal transmission or data link between two points. Communications satellites are artificial satellites that relay receive signals from an earth station and then retransmit the signal to other earth stations or to end users in its coverage area.

A communication satellite is highly tailored high-tech product based on the customer requirements since each mission has different necessities. Based on the today's market condition, a geostationary communication satellite manufacturing takes about 28 to 36 months from effective date of the contract to in orbit delivery.

By considering a satellite project is running against certain technical and scheduler requirements, a commercial communication satellite program consist of various trade-offs at the decision points. Due to its high-complexity, long-term and multi-discipline structure and solidity to critical activity milestones, a critical and analytic evaluation approach is needed throughout the decision mechanisms within the satellite program lifecycle. In this paper major evaluation criteria for any decision that might rise in the course of the satellite program are highlighted and their weights are

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determined by using the Analytic Hierarchy Process (AHP) Method, developed by Thomas L.Saaty [1], as a critical and analytic evaluation tool. AHP method is also utilized so as to check consistency and validate the obtained evaluation criteria weights.

The paper is organized as follows. Section 2 summarizes the theory of AHP method to define priorities of criteria. The framework of the common evaluation criteria for a commercial satellite program is described in Section 3. Finally, an illustrative example consisting of computational study to determine and validate weights is provided.

2. The Analytic Hierarchy Process (AHP) Method

The Analytic Hierarchy Process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then [2].

AHP is an effective tool that may aid the decision maker to set priorities and make the best evaluation. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process. The AHP can be implemented in order to define the criteria weights in following steps [3]:

- Computing the vector of criteria weights
- Checking consistency

2.1 Computing the vector of criteria weights

It is assumed that *m* evaluation criteria are considered. In order to compute the weights for the different criteria, the AHP starts creating a pairwise comparison matrix **A**. Each entry a_{jk} of the matrix **A** represents the importance of the *j*th criterion relative to the *k*th criterion. The relative importance between two criteria is measured according to a numerical scale from 1 to 9, as shown in Table 1**Hata! Başvuru kaynağı bulunamadı.**, where it is assumed that the *j*th criterion is equally or more important than the *k*th criterion.

Table 1. Table of relative scores

Value of a_{jk}	Interpretation
1	*j* and *k* are equally important
3	*j* is slightly more important than *k*
5	*j* is more important than *k*
7	*j* is strongly more important than *k*
9	*j* is absolutely more important than *k*
2,4,6,8	Intermediate values of importance

Once the matrix **A** is built, it is possible to derive from A the normalized pairwise comparison matrix $\mathbf{A_{norm}}$ is computed as

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \tag{1}$$

Finally, the *criteria weight vector* ***w*** (that is an m-dimensional column vector) is built by averaging the entries on each row of $\mathbf{A_{norm}}$, i.e.

$$w_j = \frac{\sum_{l=1}^{m} \bar{a}_{jl}}{m} \tag{2}$$

2.2. Checking consistency

The AHP incorporates an effective technique for checking the consistency of the evaluations made by the decision maker when building each of the pairwise comparison matrices involved in the process. The technique relies on the computation of a suitable consistency index, and will be described only for the matrix **A**. *Consistency Index (CI)* is obtained by first computing the scalar $\lambda_{\max}$ as the average of the elements of the vector whose *j*th element is the ratio of the *j*th element of the vector ***A·w*** to the corresponding element of the vector ***w,*** i.e average of ***A·w/w***. Then,

$$Consistency\_Index(CI) = \frac{\lambda_{\max} - m}{m - 1} \tag{3}$$

A perfectly consistent decision maker should always obtain *CI*=0, but small values of inconsistency may be tolerated. In particular; if *CI/RI* ratio (consistency ratio) is less than 0.1, then the inconsistencies are tolerable, and a reliable result may be expected from the AHP. *RI* is the Random Index which implies the consistency index when the entries of **A** are completely random. The values of *RI* for small problems ($m \leq 10$) are shown in Table 2.

Table 2. Values of the Random Index (*RI*) for small problems

m	2	3	4	5	6	7	8	9	10
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

3. Common Evaluation Criteria in a Satellite Program Lifecycle

In this section the following criteria are utilized to evaluate major evaluation criteria for any decision that might rise in the course of the satellite program.

1. Heritage
2. Performance
3. Cost
4. Schedule
5. Programmatic Factors

3.1. Heritage

Heritage is one of the prominent criteria. It is being considered in the space and satellite industry to assess the inheritance based on previous experiences and history of design, process, equipment, part, materials, etc. in order to mitigate the risk associated with any action or decision to be taken in the frame of a project.

The heritage is defined by NASA, in the NASA Systems Engineering Handbook, "Heritage" refers to the original manufacturer's level of quality and reliability that is built into parts and which has been proven by (1) time in service, (2) number of units in service, (3) mean time between failure performance, and (4) number of use cycles. High-heritage products are from the original supplier, who has maintained the great majority of the original service, design, performance, and manufacturing characteristics. Low-heritage products are those that (1) were not built by the original manufacturer; (2) do not have a significant history of test and usage; or (3) have had significant aspects of the original service, design, performance, or manufacturing characteristics altered. An important factor in assessing the heritage of a COTS product is to ensure that the use/application of the product is relevant to the application for which it is now intended. A product that has high heritage in a ground-based application could have a low heritage when placed in a space environment [4].

Heritage demonstrates that how much the system is proven by previous experiences. The level of heritage play paramount role for the degree of verification, validation and testing that needs to be employed in the project. Therefore it is an important factor which is being evaluated in any decision point to appease the potential factors which might jeopardize the intended mission.

3.2. Performance

Satellite communication systems are playing a significant role in the exchange and delivery of various types of information, from voice communications to high definition television and Internet services to point-to-point data link. Satellites are particularly appealing whenever large coverage is desired, and when either collect or broadcasting applications are considered.

The performance is generally defined as the accomplishment of a given task measured against preset known standards of accuracy, completeness, cost, and speed. In a contract, performance is deemed to be the fulfillment of an obligation, in a manner that releases the performer from all liabilities under the contract [5].

The performance of a satellite communication system is primarily related to the type and strength of radio signal used between the transmitter side of earth terminal and the satellite. The power available in the satellite and the extent to which the satellite can focus on a geographical area are interrelated factors and determine the size and power requirements of the earth terminals.The spectral efficiency, defined as the bit rate transmitted per unit bandwidth, is another key performance characteristic of a satellite communication link.

The satellite system level components are all designed to satisfy the intended satellite communication mission. Various subsystems of the satellite such as electrical power, attitude control, propulsion, thermal and data handling, etc. are working together to achieve performance requirements of the satellite under the defined conditions.

In case of any decision point throughout the communication satellite program, the potential impacts on the performance of satellite subsystems and communication mission should be highly taken into consideration during decision making process.

3.3. Cost

While a decision is being tried to be made at any time in the course of the satellite project, the associated cost impact should be evaluated based on the best estimates. Not only the initial project cost but also the cost of time, resources, labor, and technology required to accomplish the decision needs to be assessed in order to sustain cost effective solution throughout the project.

3.4. Schedule

The communication satellite projects run against the schedule under the pressure of delivery deadline which serves either for owners who are eager to start service in the market or to maintain the continuity of the given service by an ancestor satellite or to fulfill the requirements of orbital rights where each operator should place their asset into orbit to attain continuous utilization of their orbital location. Since there are several interconnected series of activities in the satellite project starting from effective date of the contract to the delivery in orbit, the satellite manufacturing schedule also become crucial to maintain the delivery requirement.

An example to the sophisticated relation in the satellite project would be launching of the satellite to the space by using limited number of available rockets in the commercial market. By increasing market demand against limited number of launcher alternative which are entitled to place the satellite into designated orbital location in space, the manifests of launcher companies is becoming quite congested. Due to any reason if the allocated launch slot is missed in the long queue of satellite launch, it will cause substantial impact on the delivery date.

Under these circumstances for any decision to be taken for a communication satellite, schedule implications should be carefully analyzed.

3.5. Programmatic factors

There are other important factors which have remarkable implications to the whole satellite program; such as customer relation and quality assurance approach of the responsible company, project management strategy, government restrictions and regulations (particularly U.S based companies), human resource organization, technology transfer offerings, training policy, etc. Those programmatic factors should be taken into account during decision making processes and carefully handled in order to operate the whole program successfully.

4. Illustrative Example

As an illustration of the use of the AHP method to determine and verify the weights evaluation criteria for satellite manufacturer selection is presented. Five top-level evaluation criteria; heritage, performance, cost, schedule and programmatic factors have been processed. AHP method is applied not only to obtain weights of the evaluation criteria but also to check consistency in the frame of computational study.

Pairwise comparison which measures the relative importance between two criteria is performed according to a numerical scale from 1 to 9, as AHP method requires. Criteria pairwise comparison matrix **A** is built for those five criteria as the following:

Table 3. Criteria pairwise comparison matrix A

	Heritage	**Performance**	**Cost**	**Schedule**	**Programmatic Factors**
Heritage	1	1	2	4	6
Performance	1	1	2	5	7
Cost	1/2	1/2	1	3	5
Schedule	1/4	1/5	1/3	1	5
Programmatic Factors	1/6	1/7	1/5	1/5	1

It should be noted that pairwise comparisons have been implemented from the perspective of a communication satellite operator priorities over fairly common criteria in satellite industry. Priority levels may differentiate from operator to operator or even depending upon objectives of the satellite program for the same operator. For instance, if operator needs a satellite urgently if upcoming satellite is a replacement of an existing busy infrastructure, then the decision maker should be more focused on "Schedule" criteria.

Normalized matrix $\mathbf{A}_{\mathbf{norm}}$ is derived from **A** by making equal to 1 the sum of the entries on each column is given in Table 4:

Table 4. Normalized matrix A_{norm}

	Heritage	**Performance**	**Cost**	**Schedule**	**Programmatic Factors**
Heritage	0.343	0.352	0.361	0.303	0.250
Performance	0.343	0.352	0.361	0.379	0.292
Cost	0.171	0.176	0.181	0.227	0.208
Schedule	0.086	0.070	0.060	0.076	0.208
Programmatic Factors	0.057	0.050	0.036	0.015	0.042

The *criteria weight vector* ***w*** is built by averaging the entries on each row of $\mathbf{A_{norm}}$:

Table 5. Criteria Weight Vector

Criteria	Weight (*w*)
Heritage	0.32 (32 %)
Performance	0.35 (35 %)
Cost	0.19 (19 %)
Schedule	0.10 (10 %)
Programmatic Factors	0.04 (4 %)

Once weights are obtained, checking consistency as described in Section 2. In order to get consistency ratio the following calculations are done:

Table 6. Consistency check via AHP, Calculation of λ_{max}

Criteria	w	$A{\cdot}w$	$A{\cdot}w/w$
Heritage	0.32	1.69	5.26
Performance	0.35	1.83	5.31
Cost	0.19	1.03	5.33
Schedule	0.10	0.51	5.14
Programmatic Factors	0.04	0.20	5.03
		λ_{max}: *Average of* $A{\cdot}w/w$	**5.21**

Consistency index (*CI*) for 5-dimensional weight vector by using the equation (3) :

$$CI = \frac{\lambda_{max} - m}{m - 1} = \frac{5.21 - 5}{5 - 1} = 0.0534$$

Random Index (*RI*) is 1.12 for m=5 from Table 2. Then, consistency ratio, CI/RI = 0.0534/1.12= 0.0477= 4.77 %. Since consistency ratio is less than 0.1 (10%), then it can be assumed that, inconsistencies in the pairwise comparisons are tolerable and the obtained weights of criteria are verified and thus valid.

5. Discussion

AHP is applied to the defined common evaluation criteria for a commercial satellite manufacturer selection issue and it is verified that the obtained weights are consistent each other. AHP can be applied to any trade-off evaluation or multiple solution problems in a satellite program lifecycle regardless of content and number of criteria; also it can be applied sub-criteria if any.

Conclusions

In this paper**,** top-level common evaluation criteria for multiple solution problems in a satellite program lifecycle are outlined from the viewpoint of a communication satellite operator as decision maker. It is proposed to apply Analytic Hierarchy Process (AHP) method as Multi-Criteria Decision Making sub-process in order to determine and validate the weights of the evaluation criteria.

As described in the paper, thanks to AHP method, a systematic and generic approach may be applied for decision mechanisms throughout a communication satellite program lifecycle. AHP offers analytic, objective and easy to apply solution for determination of the evaluation criteria. Since it’s scalable, the method is unrelated with number of criteria and can be applied for the problems having higher number of criteria, including sub criteria. In addition, the created model’s self-consistency can be determined with consistency check calculation which is an indication of the objectiveness. Establishing a systematic and objective decision process will prevent wrong or inconsistent decisions and potential failures in any stage throughout satellite program

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