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The performance of the constellations satellites based on reliability

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ABSTRACT

Most traditional satellite constellation design methods are associated with a simple zonal or global, continuous or discontinuous coverage connected with a visibility of points on the Earth's surface. A new geometric approach for more complex coverage of a geographic region is proposed. A method is developed for incorporating satellite reliability into a satellite system value model when satellites are used in constellations. The value model provides a method for trading reliability against cost, weight or other attributes. satellite constellations in circular orbits are currently used in many applications: communication, navigation, and remote sensing. Satellite constellation design for continuous single and multiple global coverage of the Earth's surface has been examined.

1. Introduction

One key attribute of the satellite design was reliability, expressed as mean time between failures. This paper describes the methodology used to assign a dollar value to satellite reliability when satellites are used in constellations. The method is applicable to navigation satellites, communication satellites, missile defense surveillance satellites, or any other satellites that operate in constellations. [3] Most of the previous work has focused on the satellite constellation design problem for a simple continuous coverage when it is merely ensured that for every point on the Earth's surface (global or a latitude band) at least one satellite is visible above a minimum elevation angle. For a simple discontinuous coverage, it also implies every point is viewed, but with a revisit time.

2. Background–Importance of value models

Optimal design of any system requires a value model to act as an objective function. Optimization means choosing the best, which implies a way to compare candidates and identify which is better. The value model scores candidate designs, such that the design with the highest score is the best or most preferred. As shown in Fig. 1, the value model computes net value (the score) of a system as a function of system attributes. During the design phase, the value model projects the value of a particular system design as a function of the projected attributes of the design. An array of designs can be evaluated and the best chosen for implementation. Under most optimal design methods, candidate designs are evaluated, and their values guide the search for better candidates. [4] Collopy [2001] addresses distributed optimal design enabled by value modeling. Cook [1997] addresses value modeling for design and product management. Value models simplify and regularize design trade studies: each case is evaluated, and the highest valued option is chosen. Value models have been used in many system domains for technology evaluation [Collopy and Horton, 2002]. A baseline system design is established, attributes are assessed, and the model calculates an overall net value as a function of the attributes. Each technology is injected into the design, changing the attributes and consequently changing the value. The change in system value is the gross value of the technology.

Another theory that is used to optimize reliability and safety is a Multi- Attribute theory.

Multi-Attribute Utility Theory (MAUT) is a structured methodology designed to handle the tradeoffs among multiple objectives. One of the first applications of MAUT involved a study of alternative locations for a new airport in Mexico City in the early 1970 s. The factors that were considered included cost, capacity, access time to the airport, safety, social disruption and noise pollution.

Utility theory is a systematic approach for quantifying an individual's preferences.

Early applications of MAUT focus on public sector decisions and public policy issues. These decisions not only have multiple objectives, they also often involve multiple constituencies that will be affected in different ways by the decision. Under the guidance of Ralph Keeney, a leading researcher in the field, many power

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Nomenclature

ϕ :	Normalized system cost rate.
ϕ^*:	Normalized cost rate of optimal system.
λ:	Mean number of satellite failures during a Replacement Launch interval.
C:	Expected rate of cost of satellite replacement and system failures.
i:	Number of spare satellites in orbit.
k:	Example integer.
L:	Cost of system failure normalized to individual satellite cost.
T:	Minimum number of satellites necessary for constellation function.
P:	number of orbital planes
S:	number of satellites per plane, T/P
n:	Number of operating satellites in orbit after one failure.
p:	Probability of a particular satellite failing during a particular Replacement Launch interval.
P(i):	Probability of system failure during a particular Replacement Launch interval.
Cycle:	Mean time between starts of successive Replacement Launch interval.
Replacement Launch:	The time interval required after asatellite fails to put a replacement satellite into orbit.
Sat Cost:	The cost of procuring and launching a replacement satellite.
Sat Reliability:	The mean lifetime of a satellite.
Sys Loss:	The cost inflicted on users of a system.failure
Sys Reliability:	Mean time between system failures.

plant-related decisions were made using MAUT. The military is also a leading user of this technique. The design of major new weapons systems always involves tradeoffs of cost, weight, durability, lethality and survivability. The federal government requires its defense contractors to use a structured method to make these design trade-off decisions. MAUT is one methodology in the broader field of Multi-Criteria Decision Making (MCDM). The Analytic Hierarchy Process (AHP) is a direct competitor to MAUT as an efficient technique for rank ordering alternatives. MCDM also encompasses

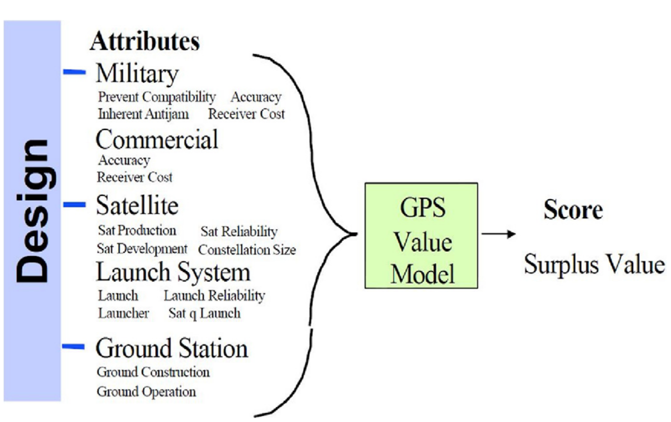

Fig. 1. The value model scores systems based on attributes.

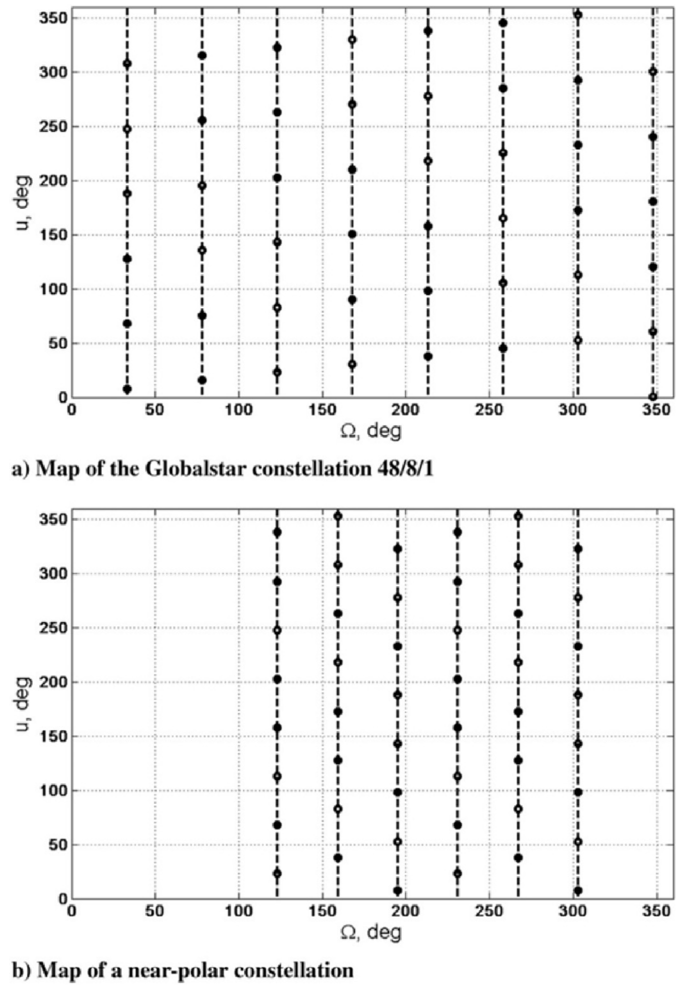

Fig. 2. Examples of satellite constellation maps.

Multi objective Mathematical Programming. [7] This technique is used to tackle complex problems involving a large number of decision variables that are subject to constraints. In aerospace and satellite, these theories can be used to optimize the reliability, cost and system performance.

3. Satellite constellations

It is evident that for time intervals on the order of several orbital periods, a satellite trajectory in the introduced two-dimensional space is a straight line parallel to the *y* axis. For the space, any satellite constellation with a number of orbital planes and an equal number of satellites in each plane can be presented as a uniform moving grid. The satellites are the vertices of the grid. Examples of such grids for Walker-type [1] and near-polar [2] constellations are shown in Fig. 2. For time intervals more than several orbital periods, a similar map can also be produced, but the regression of the ascending node should be considered. In this case, the lines are slightly inclined to the *y* axis. The further optimization is limited to symmetric Walker-type constellations [1]. The Walker approach uses symmetric arrangements of similarly inclined circular orbits at a common altitude. The standard notation *T*/*P*/*F* will be used in this case. Here *T* is the total number of satellites, and *P* is the number of orbit planes at the same inclination and spread evenly around the equator. There are *T*/*P* satellites evenly distributed in each plane. The integer parameter *F* describes the phasing of satellites in one plane relative to those in another.

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