# A Control System for Space Solar Power

Jeremy Straub, Department of Computer Science, University of North Dakota

## Overview

This poster presents an algorithm for the implementation of a control system that accepts power requests and makes distribution assignments to maximize the performance of the overall space solar power (SSP) system and meet service level agreements (SLAs). This complex process involves projecting service-customer demand into the future, projecting power availability on each servicing spacecraft and implementing corrective measures should actual craft performance not meet with planning expectations. The control system is implemented as a planning problem with some deterministic elements (craft position and generation) and some probabilistically predicted elements (interference, drag and malfunctions). A heuristic solver is proposed that makes control plans based on the projected and predicted model. A second heuristic operations system is presented which implements corrective actions in response to performance divergence from projections and assumptions.

The requirement for having a robust control system of this type is discussed as are the benefits it provides in allowing maximization of spacecraft constellation utilization (as opposed to designated crafts for each separately serving customers). This system is also integral to allowing the constellation to operate from low-Earth orbit and thus reducing the level of free-space loss incurred by the system. We conclude by discussing the testing required for a mission-critical SSP control system (MCSSPCS). The level of reliability and security required for the MCSSPCS is considered and strategies for achieving this are discussed. Future plans for system (hardware) implementation and supporting software development are discussed.

## Mission Scenarios

Three mission scenarios were envisioned when designing this control algorithm:

- SPCS collects power throughout orbit and sends it to ground stations when overhead (based on [1])
- Space-to-space power transfer, including both direct and relayed transmission (based on [2-4])
- Combined servicing of both space and Earth-based customers via a single spacecraft.
- Servicing lunar industry and exploration missions (based on [5-7])
- Servicing Martian surface or craft in Martian orbit (based on [8])
- Creating a powered corridor for spacecraft to travel to Mars (based on [9])

## Key Considerations

Key considerations (depicted in Figure 1) utilized in forming the control algorithm include:

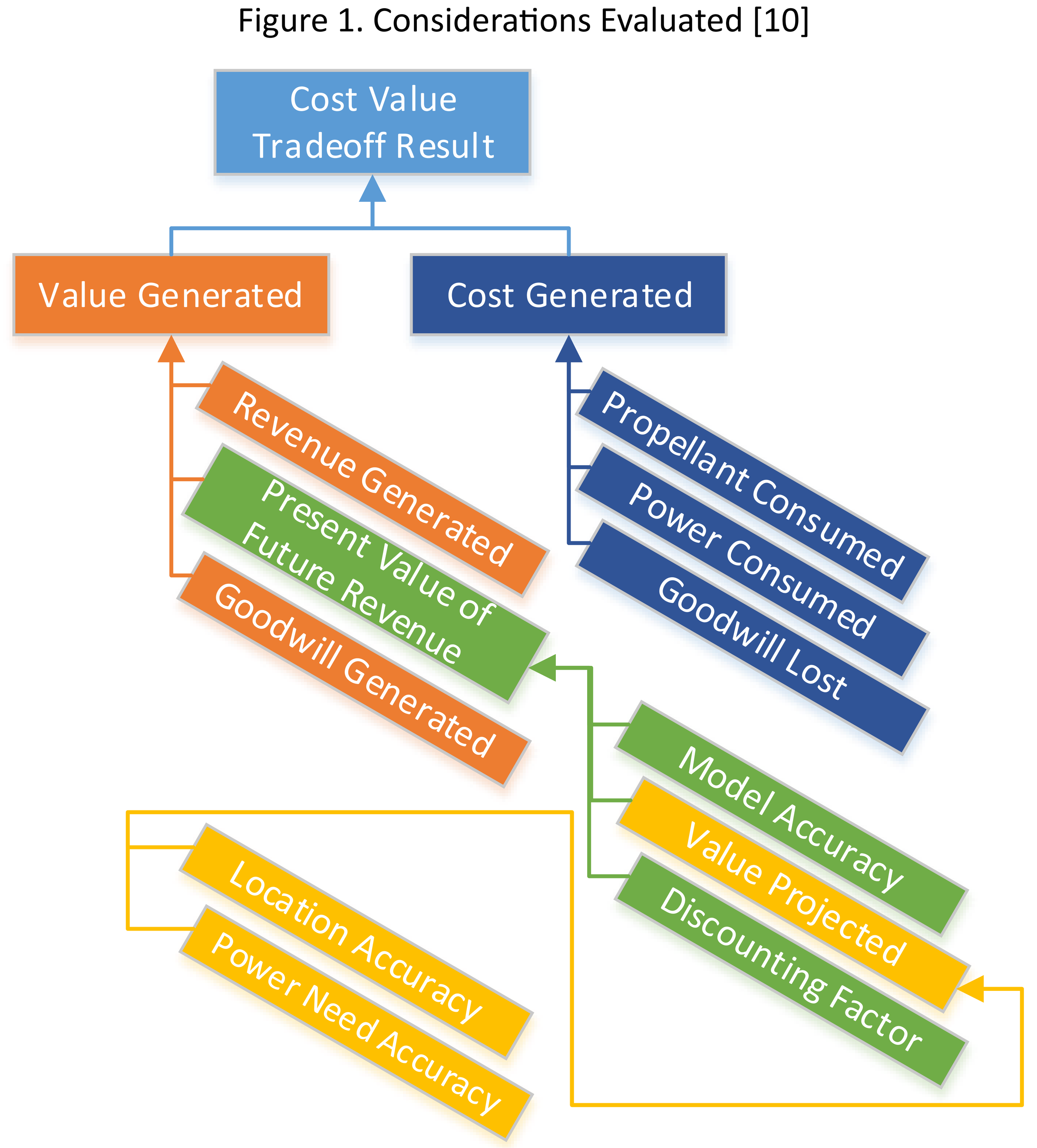
- ***Optimization of Service versus Fuel Consumption***
  Changes in customer base / user base from time to time will trigger a need to change orbit / orbital position to maximize service. These benefits must be offset against the cost of lifespan due to fuel consumption.

- ***Graceful System Degradation***
  SSP spacecraft will experience both planned (wear-based) and unplanned failures. The constellation must be able to provide suitable service levels after most types of system failure (while waiting for a new craft to be launched or repositioning)

- ***Re-Transmission***
  Retransmission may be utilized to allow some SSP units to provide more power than is possible with their local solar collection capabilities. The cost of retransmission (e.g., tying up to spacecraft) must be offset against the service benefits.

- ***Orbital vs. Orbital and Ground Service***
  Various customers may have different levels of priority based on the types of application that they are supporting (e.g., sustaining life vs. providing other service).

Figure 1. Considerations Evaluated [10]




## Methodology

The algorithm (shown in Figure 2) is based on the decomposition of a cost comparison function. Several complexities are introduced, including:

- ***The solution isn't as simple as choosing the solution with the highest value***
  Revenue maximization may require selecting one or multiple lower-than-best-proportionate-value solutions which are able to generate more revenue.

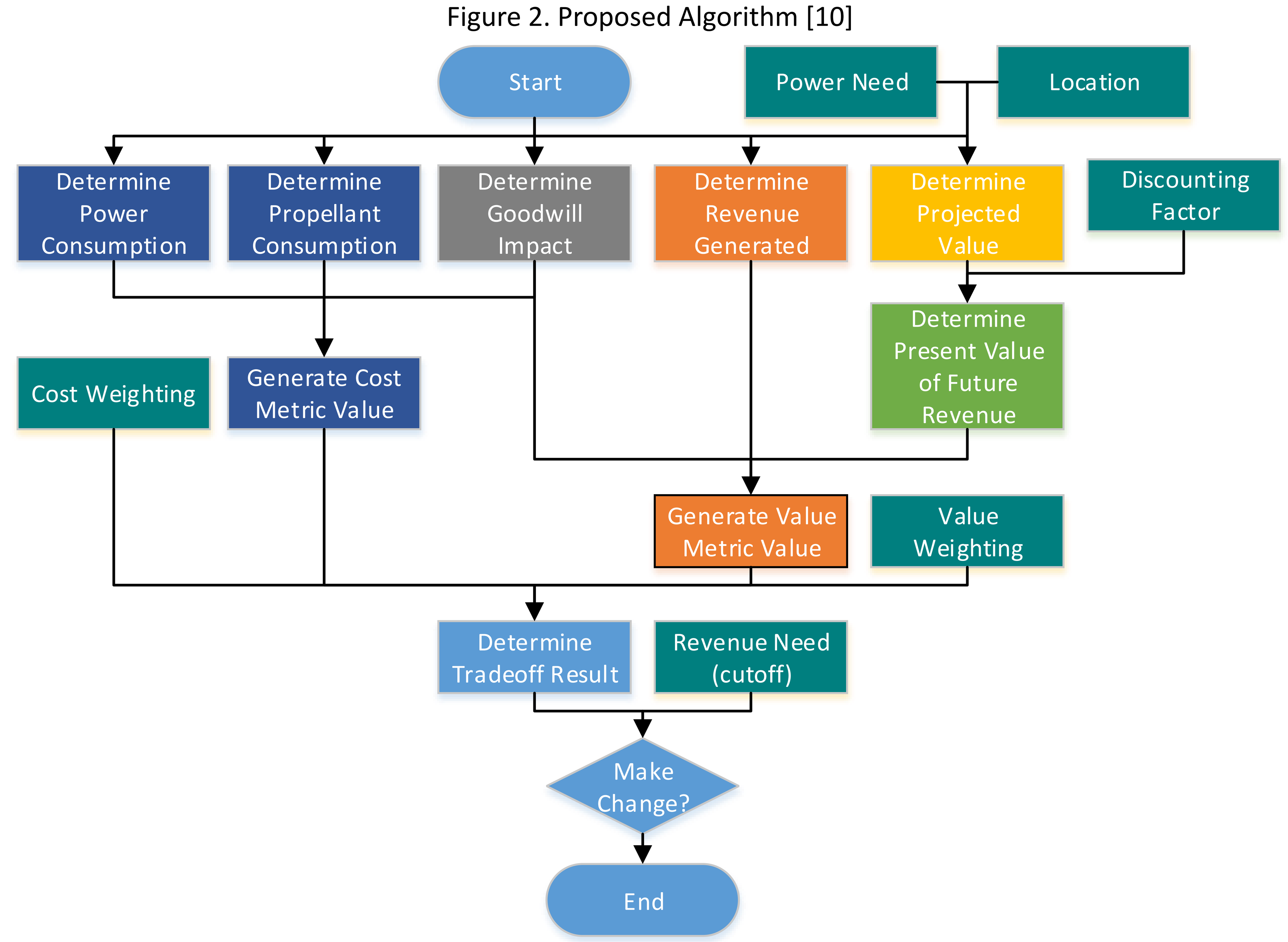
- ***Maximizing spacecraft lifetime is highly desirable***
  Each decision may preclude other future decisions and thus current benefit must be offset by future cost / lost benefits.

- ***Prediction of the needs and locations of future customers***
  Customer needs and usage patterns change. A less than optimal configuration now may be more future-proof.

- ***Weighting between different factors***
  The comparative importance of each of these factors must be assessed and (arbitrarily, perhaps) assigned.

- ***Behaving as a responsible utility***
  The SSP provider must act responsibly (not violating service agreements, etc.) to maintain/grow business.

Figure 2. Proposed Algorithm [10]




## Algorithm

Figure 2 presents the overview of an algorithm based upon the identified considerations (in Figure 1). The algorithm is designed to allow parallelization of computationally intensive elements (such as the determination of propellant consumption and impact on goodwill and revenue). Other subsequent tasks (that are not as parallelizable) are less resource consuming and faster.

A cut-off threshold is utilized to determine what tasks will be run. Alternately, these values could be utilized for ranking purposes to allow the comparison and evaluation of multiple prospective maneuvers that could be performed by the spacecraft.

## Conclusions & Future Work

This poster has presented a control algorithm initially discussed in [10]. Work on this algorithm and overall project is ongoing. Currently, the next planned step is to develop an in-space trial / demonstration mission.


## Acknowledgements

Small satellite development work at the University of North Dakota is or has been supported by the North Dakota Space Grant Consortium, North Dakota NASA EPSCoR, the University of North Dakota Faculty Research Seed Money Committee, North Dakota EPSCoR (NSF Grant # EPS-814442), the Department of Computer Science, the John D. Odegard School of Aerospace Sciences and the National Aeronautics and Space Administration.

Jeremy's work on the autonomous control of spacecraft and other robots has been supported by a Grant-In-Aid of Research from Sigma Xi, The Scientific Research Society, North Dakota EPSCoR (NSF # EPS-814442) and a Summer Doctoral Fellowship from University of North Dakota School of Graduate Studies.

The algorithm discussed in this paper was initially discussed in [10].


## References


1. Glaser, P. E. 3,781,647, 1973.
2. Bergsrud, C.; Straub, J. In *In A 6-U Commercial Constellation for Space Solar Power Supply to Other Spacecraft;* Spring 2013 CubeSat Workshop; 2013; .
3. Bergsrud, C.; Straub, J.; Casler, J.; Noghanian, S. In *In Space Solar Power Satellite Systems as a Service Provider of Electrical Power to Lunar Industries;* Proceedings of the AIAA Space 2013 Conference; 2013; .
4. Bergsrud, C.; Straub, J.; Clausing, M.; McClure, J.; Casler, J.; Noghanian, S. In *In Business Case for A Constellation of 6U Solar Powered CubeSats in LEO;* Proceedings of the 64th International Astronautical Congress; 2013; .
5. Bergsrud, C.; Straub, J.; Casler, J.; Noghanian, S. In *In Space Solar Power Satellite Systems as a Service Provider of Electrical Power to Lunar Industries;* Proceedings of the AIAA Space 2013 Conference; 2013; .
6. Torgerson, D.; Berk, J.; Straub, J.; Nervold, A. In *In Space Station 2.0: A Public-Private Model for International Space Exploration;* Proceedings of the 64th International Astronautical Congress; 2013; .
7. Berk, J.; Straub, J.; Nervold, A.; Whalen, D. Space Station 2.0: A Transformational Architecture for Space Development. *LPI Contributions* **2013**, *1719*, 1861.
8. Bergsrud, C.; Straub, J. In *In Space Solar Power as an Enabler for a Human Mission to Mars;* Proceedings of the AIAA Space 2013 Conference; 2013; .
9. Haque, S.; Straub, J.; Bergsrud, C. In *In An Interplanetary Mission Driven by Beamed Power and a Micro-Cathode Arc Thruster (uCAT) Subsystem;* Submitted for publication in the Proceedings of the 2014 IEEE Aerospace Conference; 2014; .
10. Straub, J.; Bergsrud, C. Orbital Position, Transmission Path and Spacecraft Attitude Determination for A Solar Power Spacecraft. Proceedings of the 65th International Astronautical Congress.