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On-Orbit Servicing (OOS) Concept Trades Based on the S@tMax System

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ABSTRACT

This paper examines On-Orbit Servicing (OOS) from both technical engineering and business case perspectives as an enhancing element in a specific case study called S@tMax, a proposed new business plan for a satellite-based two-way mobile data communications system.

S@tMax was developed by the Delft University of Technology (TU Delft), SpaceTech 8 master's program in Space Systems and Business Engineering. S@tMax provides an Internet Protocol (IP) based data, mobile communications hybrid space/terrestrial network system aimed primarily at vehicles, for ubiquitous and total coverage of the continental United States (US). High bandwidth data is proposed along the US federal and state highways via a GEO hybrid satellite and terrestrial tower network, and low bandwidth data will be provided directly from the satellite to a stationary or moving vehicle. The end result is a variety of total IP data connectivity solutions for the mobile user in a vehicle (resulting in increased information, productivity, safety/security and convenience) as well as telematics data for the vehicle manufacturers who will benefit from total product lifecycle data acquisition and related services and products.

OOS has been investigated to evaluate and improve the S@tMax business, its candidate architecture and to evaluate OOS and associated techniques. In a dedicated systems engineering process key stakeholder requirements have been developed and nine potential OOS concepts have been analyzed.

The study provides an end-to-end perspective and partly new insights to OOS and its potential impact on satellite missions.

INTRODUCTION

On-Orbit Servicing (OOS) is an emerging field of space technologies and operations, which provides opportunities for new ways of implementing satellite systems designs, and also can increase flexibility and efficiency of systems architectures and associated business plans. Satellite problems can be fixed on orbit, systems can be upgraded, mission flexibility can be increased and entirely new missions may be enabled [1]. An associated field is On Orbit Assembly (OOA), which can be used in conjunction with OOS to allow innovative solutions outside the traditional boundaries of the space industry.

For GEO satellites, all of these OOS services imply automation & robotics (A&R) technology development and system integration. The satellites must be designed with the object of enabling OOS or OOA in a later stage of the life cycle. "Design for OOS" is an immature discipline and will vary with each satellite implementation. In order to actualize OOS through "Design for OOS" then it is implied that there are certain standardized interfaces and parameters. The use of modularity and standardization will greatly simplify the implementation of OOS, and in fact, it is a requirement for effective servicing through the use of Line Replaceable Units (LRU) and other simplified configurations. If the satellite is not designed in this way then the systems will be too complex to be handled by A&R methods (ref. JKIC Definitions of OOS service classes and services [8]). Given these issues, an OOS realization implies:

- Satellite Modularity
- Design for Servicing
- Flexible Satellite Systems Design is Enabled
- New Architecture & Design Options
- New Launch Options
- Assembly options for Satellite System Implementation

Similarly, on the business engineering side, consideration must be given to the systems architecture, risk, financing, equity and phasing of capital expenditures (CAPEX). OOS has significant advantages when it comes to the question of risk mitigation strategies, in particular the decision to buy insurance and its associated cost. OOS can provide alternate solutions when a satellite is placed in the wrong orbit, or if a system or part malfunctions. Life extension is also a valuable option and can result in significant revenues and increased efficiency and cost effectiveness of the satellite system capital expenditure.

OOS CAPABILITY & PROVIDERS

OOS with A&R (i.e. non-human assisted) is a relatively immature technology area, which has not had many flight demonstrations. Since the technology has not been proven, then there is reluctance for mission planners and businesses to risk using OOS in new satellite systems implementations. Hence there is a "chicken and egg" problem with OOS technology development. In addition there have been no commercial successes that have actually flown as of 2006. There is a lack of real understanding in the space industry of how OOS should be implemented and what the risk benefit ratios are.

Refueling satellites will enable frequent maneuver to improve coverage, change arrival times to counter denial and deception and improve survivability, as well as extend satellite lifetime. Electronics upgrades on-orbit can provide regular performance improvements and dramatically reduce the time to deploy new technology on-orbit. [5].

In the current planning at NASA for human missions to the moon, consideration is being given to using elements of OOS in Low Lunar Orbit (LLO) or on the lunar surface in order to refuel an ascent /descent crew vehicle with either propellants brought from the Earth or locally produced "in-situ" propellants.

OOS needs close links between A&R, mission architecture and satellite operations (systems engineering) and in parallel to be based on sound business engineering principles involving all potential stakeholders." [4]

The A&R technology readiness level for OOS is fairly advanced (at the prototype stage), but very few systems have been successfully flown in space. The Russian Progress module for the International Space Station is a notable exception as it has demonstrated good automated rendezvous and docking performance except for one collision with the Mir space station in 1997, however it should be noted that it was being used in manual control mode at the time.

In summary, it is fair to say that there are no proven commercial providers of OOS in existence yet. Orbital Recovery Corporation is the most promising commercial venture and it will be compelling to see if their business model becomes viable in the near future.

OOS AS APPLIED TO ENHANCE A BUSINESS CASE: "S@TMAX"

The S@tMax business case study is a proposed new business plan for a satellite based two-way mobile data communications system. This business plan was developed in the course of the TU Delft, SpaceTech 8, Master Program on Space Systems & Business Engineering (www.lr.tudelft.nl/spacetech). S@tMax provides an Internet Protocol (IP) based data, mobile communications hybrid space/terrestrial network system for ubiquitous and total coverage of the continental United States (US). High bandwidth data is proposed along the US federal and state highways via a hybrid GEO satellite and terrestrial tower network, and low bandwidth data will be provided directly from the satellite to a stationary or moving vehicle. The end result is a variety of total IP data connectivity solutions for the mobile user in a vehicle (resulting in increased information, productivity, safety/security and convenience) as well as telematics data for the vehicle manufacturers who will benefit from total product lifecycle data acquisition and related services and products. [12, 13, 14]

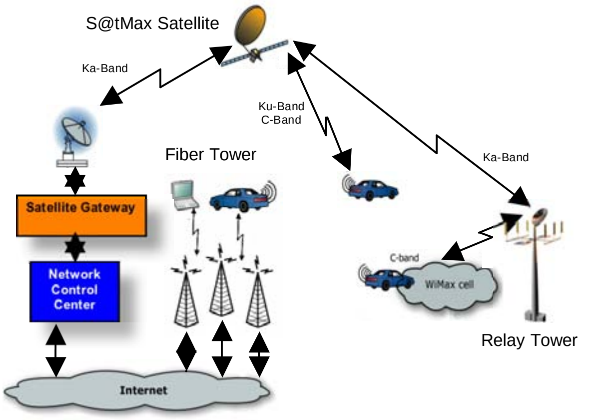

Figure 1: Overall S@tMax Architecture

The S@tMax concept is described in brief below:

The S@tMax system will provide vehicles in the USA with direct, transparent communications to wireless data and the Internet. Transparency means that a given communications service (IP over WiMAX), can be supported by the same user device in both terrestrial and satellite modes in a manner that is transparent to the end user. The user can connect to S@tMax in three different ways, depending on the environment where the user wants to get connected and take advantage of the S@tMax products and services.

User in Urban Areas

When in urban areas the user can access the Internet from his car computer by means of the WiMAX signal provided by S@tMax operated and fiber optic connected towers.

Since the car is equipped with a WiMAX transponder it can establish and maintain a connection with the WiMAX ground stations and provide content to the user by means of wireless coverage inside the car and other services. In this environment the user expects the best quality of service in terms of reliability and data rates.

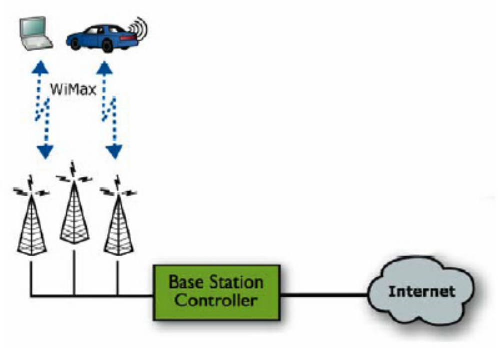

Figure 2: Configuration for Users in Urban Areas

User on Highways

When the car leaves the urban areas and moves to a highway it will leave the coverage area of the fiber towers and enter the coverage area of the satellite relay towers. By means of standalone and fully automatic antenna relay stations linked to the S@tMax space segment (i.e. the relay towers), placed in proximity of the highways, the users in their vehicles can maintain connectivity in a transparent manner without loosing the connection. This concept is shown in the figure below.

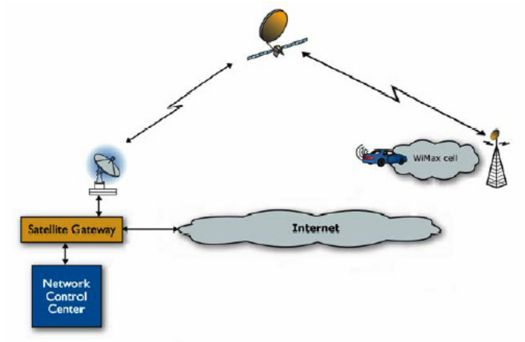

Figure 3: Configuration for Users on Highways

User in Remote Areas

The services in urban areas and highways provide the best quality of service, but are limited to areas where WiMAX coverage is provided by a terrestrial network infrastructure. By means of the S@tMax satellite, even in remote areas the S@tMax customers can maintain their always-on connectivity with a reduced quality of service. This is achieved by using the direct to satellite link as shown in the picture below.

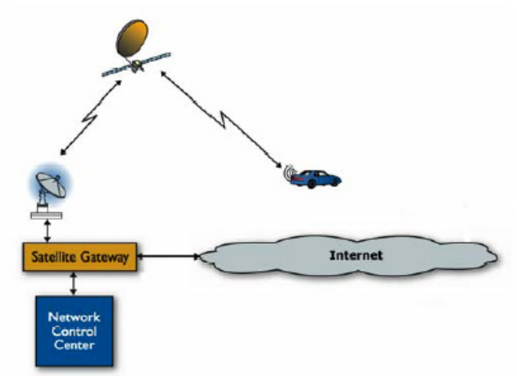

Figure 4: Configuration for Users in Remote Areas

The ubiquitous and enhanced S@tMax IP based services are the key advantage of the S@tMax system which are achieved by means of the architecture available in urban areas, highways and remote areas.

The integration and availability of the 3 types of services are critical to the success of S@tMax and the transparency concept. The terrestrial and satellite components of the S@tMax hybrid network provide complementary coverage. The terrestrial component ensures service availability in major urban areas, where satellite-only systems suffer blockage from buildings. Likewise, the satellite component provides coverage to those areas that are impractical or uneconomical to serve terrestrially. The ubiquitous coverage enabled by hybrid networks substantially enhances the value proposition for safety and security applications in a variety of wireless segments, most importantly among public safety, consumer telematics, and fleet management.

S@tMax will operate two geosynchronous satellites over the USA to provide the required IP capacity needed for both the relay cells of the Infrastructure Segment and the mobile users. The S@tMax satellite is a next-generation mobile satellite system; its unique capabilities will enable high-speed data networking, enable groundbreaking applications, and unlock a wealth of value-added IP based services over highways and remote areas over the USA. The space segment will consist of 2 satellites to be launched in 2010 and 2013 and located respectively in 85.5° W and 86.5° W. The satellites design is inherited from the Anik-F2 Boeing 702 platform and it has a lifetime of 15 years. A concept view of the folded and deployed configurations is shown below.

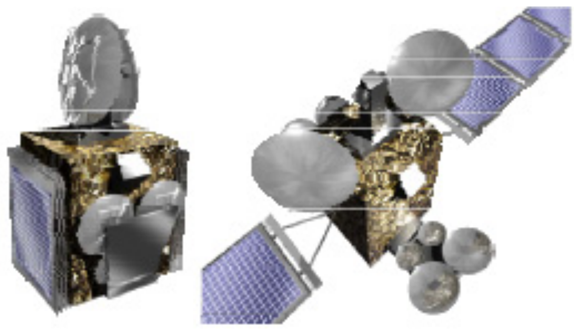

Figure 5: Satellite Platform Concept

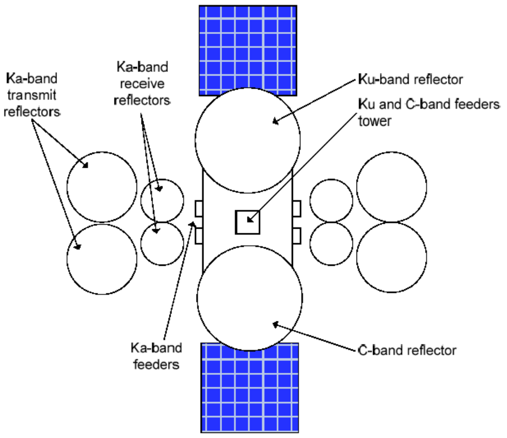

Figure 6: Satellite Platform Antenna Configuration

Business Engineering

The following figure shows the high level S@tMax implementation model. [12]

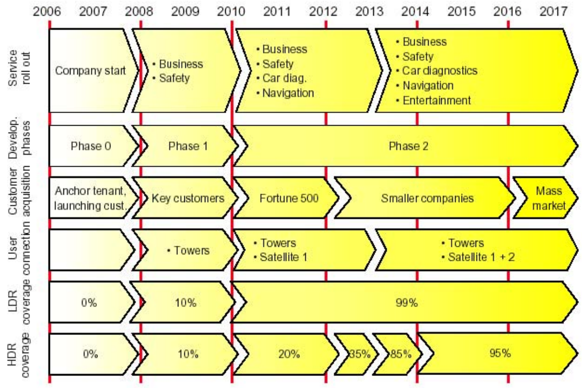

Figure 7: Business Rollout Roadmap

For the financial plan, the following assumptions were made (for the year 2017):

- Revenues
  - o Service: $7.4 B
  - o Revenue per user equipment sold: $20
  - o User equipment: $1.2 B
  - o Total revenue: $ 8.6 B
- Investments
  - o Satellite 1 (incl. launch): $430 M
  - o Satellite 2 (incl. launch): $280 M
  - o Ground segment: $50 M
  - o Infrastructure segment: $207 M
- Cost of Goods Sold (COGS)
  - o Strategic partner cost: 75% of service revenue
  - o Customer acquisition cost: $180
  - o Cost of user equipment per new user: $180
- Operating expenses
  - o Cost of personnel: $38 M (493 people)
  - o Marketing and sales: $381 M
- Other
  - o Depreciation: 15 years
  - o Interest Rate: 7.5%

The implementation plan leads to a financial result. This result is given in the profit and loss account summarized in the figures below.

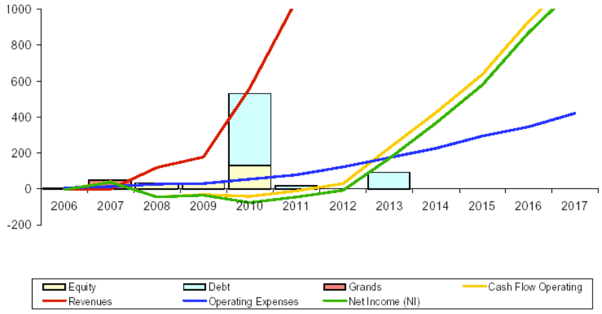

Figure 8: S@tMax Financial Projections

As can be seen in the figures above, the J-curve of the net income reaches a positive number in 2012, which is rather late. This can be explained by the conservative market penetration curve assumptions and by the high investment needs of the company. However, from an investor point of view, this can be overcome by the fact that the equity is also raised late in the business development, so that the invested years are not so many, and by the potentially excellent return on investment. Some of the performance indices for S@tMax are given in the table below.

Year	*2008*	*2013*	*2015*	*2017*
COGS (%)	117.4%	85.9%	83.1%	81.5%
Operating Expenses (%)	20.4%	5.6%	5.2%	4.9%
Personnel (%)	10.8%	0.8%	0.6%	0.4%
Depreciation (%)	1.4%	1.9%	1.1%	0.7%
Profit on Revenues (%)	-39.2%	5.5%	8.0%	9.2%
Return on Capital Employed (%)	-127.7%	84.9%	226.5%	396.0%

Table 1: S@tMax Predicted Performance Indices

Since the costs of the strategic partners are 75% of the service revenue, these indices give a somewhat slanted representation of the company. The following table shows the indices where the revenue is corrected for the high service cost.

Year	*2008*	*2013*	*2015*	*2017*
COGS (%) *	81.4%	32.6%	28.2%	25.6%
Operating Expenses (%) *	31.9%	11.9%	11.5%	11.0%
Personnel (%) *	55.4%	2.8%	2.1%	1.5%
Depreciation (%) *	2.2%	4.0%	2.4%	1.6%
Profit on Revenues (%) *	-61.4%	11.7%	17.8%	20.7%
Revenue per Capita (M$) *	40.7%	386.5%	470.3%	658.3%

*: Corrected for service partner cost.

Table 2: S@tMax Corrected Performance Indices

These indices show that the business can be profitable, strong and sustainable. The business engineering analysis shows that this business plan has a high potential return on investment (ROI) and is a good investment opportunity. Please consult Ref [12], Ref [13] and Ref [14] for details of the business plan and candidate architecture.

The Central Case Project (CCP) or business plan, for S@tMax was investigated with respect to the feasibility of IP and OOS at the request of the Customer, TU Delft and DLR, the German Aerospace Center. Figure 9 shows the process that was used in order to derive a feasible and credible business plan. Both OOS and IP were considered enabling technologies and OOS service providers were assumed to be commercially available with S@tMax filling the role of an OOS customer.

Figure 9: Central Case Project Execution Strategy

As it turned out, it was important to investigate technical, business and OOS-technology issues in parallel due to strong interrelations of these areas from a satellite operator's perspective.

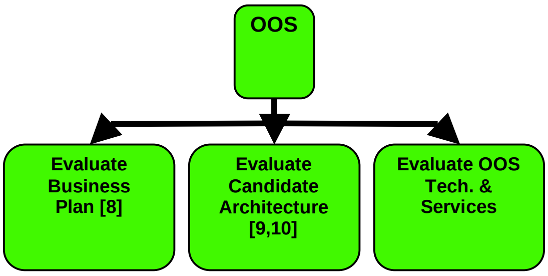

Figure 10: OOS Preliminary Assessment

An initial value assessment of the case for OOS resulted in the following table:

Service Class	Kind of Service	S@tMax Value	Price
Motion	Rescue / Re-Orbiting De-Orbiting Salvage	High Low Low	$50 M $25 M $50 M
Manipulation	Maintenance Repair Retrofit / Upgrades Docked Inspection Life Extension	High Med High Low High	$75 M $100 M $75 M $10-25 $75 M
Obser-vation	Remote Inspection Non-Destructive Evaluation (NDE)	Med Low	$1-5 M $5-10M

Table 3: Initial Assessment of viability of OOS for S@tMax Business Plan & Architecture [1]

The most promising areas of OOS are highlighted in yellow in the table. The associated costs are also listed and were accounted for in the S@tMax Business Engineering trades.

THE S@TMAX OOS SYSTEMS ENGINEERING APPROACH

With the encouraging identification of several areas that would enhance the S@tMax business case, the S@tMax team proceeded down a disciplined systems engineering process in order to identify viable concepts and to do a technical and commercial analysis on which type and level or combination of OOS would make a difference.

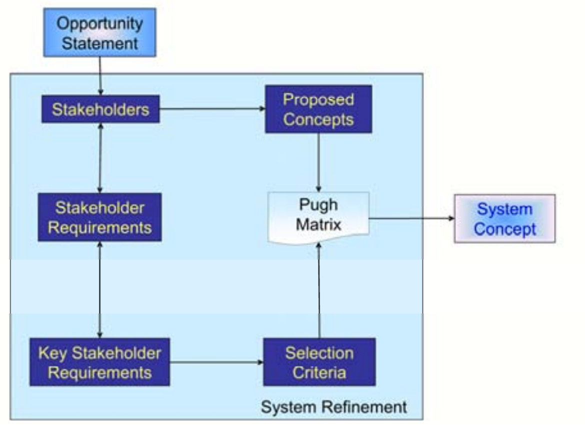

Figure 11: S@tMax OOS Systems Engineering Process for Concept Evaluation

Considering the needs of each active stakeholder generated a set of requirements encompassing both technical and business objectives. The primary active stakeholder is the satellite owner/operator which in this case is the S@tMax business.

The <u>success criteria</u> for using OOS in the S@tMax business case are:

Increase S@tMax shareholder value by:

Enhancing or enabling the S@tMax systems design, architecture and business case.

The active stakeholders were identified and are shown in Figure 15.

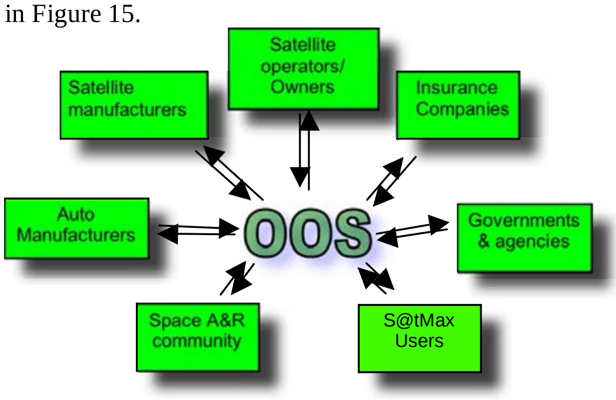

Figure 12: S@tMax OOS Active Stakeholders

Analyzing the end state desired and the operations use cases for the key stakeholders can identify a list of stakeholder requirements.

The key Owner/Operator stakeholder requirements for OOS are:

1. OOS shall enhance or enable the S@tMax business case
2. OOS shall reduce the lifecycle cost of the S@tMax system
3. OOS shall allow satellite and space segment large capital expenditures to be deferred and split into smaller amounts spread over a longer period of time
4. OOS shall provide an insurance mitigation strategy
5. OOS shall provide a positive benefit as compared to the overall risk of using OOS
6. OOS shall increase the flexibility of the systems architecture
7. OOS shall increase the data communications link budget efficiency of the S@tMax system

The key requirements for the remaining active stakeholders are:

8. OOS shall enhance the ability to reduce the cost per bit of data to below the cost per bit of the competition
9. OOS shall enhance the ability of the S@tMax system to provide continuous and reliable quality wireless communications service

OOS PROPOSED CONCEPTS

In this case study it was assumed that OOS services will be available by 2010 which is the assumed launch date of the first S@tMax satellite. The S@tMax system does not include OOS servicing capabilities and it is assumed that all such services will be procured from commercial OOS vendors.

Concept #1: Orbital Rescue & Re-Orbiting

This concept is in the Motion service class and uses the capability of rescue and/or re-orbiting. If the launch vehicle, kick stage or circularization burn does not perform properly, then the satellite may be left in a stranded orbit even though it is in a functioning state. The satellite propellant must be conserved so an OOS tug service is procured to place the satellite in the correct orbit.

The rescue/re-orbit capability allows a reduction in insurance rates to be negotiated, or insurance can be eliminated and replaced with an OOS rescue contract. In this concept a trade study must be done to determine what is more cost effective: (1) Launch a new satellite with insurance, (2) Launch a new satellite without insurance or (3) use an OOS Rescue Service.

Concept #2: Satellite Salvage

This concept is in the Motion service class and uses the capability of salvage. There are numerous satellites that have been recently lost or stranded in the wrong orbit. This concept evaluates the capabilities of any telecommunications satellites that are stranded and salvages one or more of them to be used for the S@tMax business case. If an appropriate satellite is available it will be procured from the owner at a minimum price. An OOS tug service places the salvaged satellite into the correct GEO slot and S@tMax service starts immediately.

Concept #3: Modular Incremental Satellite System

This concept is in the Manipulation class of service and involves retrofit / upgrades. A modular satellite is developed with a separate satellite orbital bus, separate solar array power systems, a separate payload consisting of transponders with a spot beam capability and a separate antenna system. Mr. Manfred Wittig (ESA) has proposed such a system in the Sky Kit concept. The bus is launched first with a minimum payload for low data rate services, 2 years later, the revenues from the low data rate products are used to launch the next modular payload and associated antenna and solar arrays. Two years later spares are sent up which loiter in orbit. Then, two years later the system is upgraded with more power and better antennas as well as redundant transponders for reliability. The modular satellite sub-systems are controlled via IP – each element is IP addressable and the modular system is highly flexible for upgrades and repair. The business case allows for distributed and time phased lower value capital expenditures and smaller, cheaper launch vehicles can be used.

Concept #4: On Orbit Re-Fueling

This concept is in the Manipulation class and uses the capability of Maintenance. The satellite is designed in order to facilitate maintenance. For example, a satellite that needs propellant for station keeping can be undersized since a percentage of the satellite consists of propellant tanks and wet mass. The smaller satellite can then be launched on a smaller launch vehicle bringing down launch cost and other mass multiplier effects. Contracting an OOS refueling service to periodically refuel the satellite then compensates for the lack of stored propellant. This may result in lower initial costs, and novel architectures that may enable the business case by spreading out the capital expenditures.

Concept #5: Satellite Obsolescence Avoidance

This concept is in the Manipulation class and involves a life extension philosophy. The satellite is designed for a shorter life span to account for technology obsolescence and higher reliability of components due to lower age. The obsolete components are then swapped out in Line Replaceable Unit (LRU) fashion by a robotic OOS servicer. This ensures that the satellite is always in a state of the art and new condition

Concept #6: Satellite End of Life Extension

This concept is in the manipulation class and involves satellite end of life extension. The satellite uses an OOS servicer that latches onto the satellite at the end of life and provides north-south station keeping. This reduces drift and extends the life of the satellite by a number of years as the original satellite is relieved of station keeping functionality.

Concept #7: Laser Linked Formation Flyers

This concept is in the observation class and the manipulation class. A small swarm of formation flying satellites with laser optic communication maintains visual communication with each other. The swarms are powered by laser power transmission from a central power hub solar array satellite. The swarm forms a giant array node antenna that has superior power characteristics resulting in an enhanced link budget. Electric propulsion thrusters power the swarm satellites. An OOS servicer periodically refuels and maintains the swarm flyers. A defective swarm node is replaced with a spare that is standing by. There is IP communication via each satellite using the laser communications link. The swarm is launched on many smaller launch vehicles of Pegasus class size. They spiral up with solar electric propulsion in GEO and meet on location.

The S@tMax team conceived other OOS concepts such as:

- De-Orbiting of Satellites to Graveyard Orbit

- Salvage Satellite and Return To Earth With an Inflatable Heat Shield, for Refurbishment

- Design For Servicing – On Orbit Repair As Required

These concepts may have merit in other business cases but they were not considered further in the S2TMax business case due to a lack of compatibility.

One concept that was identified as having significant potential merit for S@tMax was:

- GEO Super Bus Platform, which hosts S@tMax and other payloads.

This concept will de discussed later, but was not included in the preliminary trades for S@tMax since the team felt that this capability would not be commercially available by 2010.

FIGURES OF MERIT

The proposed concepts must be evaluated according to a set of selection criteria and figures of merit that directly reflect the stakeholder needs. The Quality Function Deployment (QFD) matrix analysis process is being used to generate the following selection criteria.

1. Time to Market
2. Number of Launch Vehicles Required/Cost
3. Size and period of Discrete Capital Investments
4. Insurance Cost
5. Risk
6. Technical Feasibility
7. Regulatory Issues
8. Finance Needs
9. Partnership Needs
10. Life of Satellite
11. Operational Flexibility

PUGH CONCEPT EVALUATION MATRIX

Concept		1	2	3	4	5	6	7
FOM #	Weight							
1. Time to Market	5	0	☾	0	0	0	0	0
2. Number of Launch Vehicles Required/Cost	5	0	☾	0	☾	--	0	--
3.Size and period of Discrete Capital Investments	4	0	--	☾	☾	☾	0	☾
4. Insurance Cost	2	☾	☾	0	0	0	0	☾
5. Risk	4	0	--	--	--	--	0	--
6. Technical Feasibility	4	☾	--	0	0	--	☾	--
7. Regulatory Issues	2	0	--	0	0	0	0	0
8. Finance Needs	3	0	0	☾	☾	☾	0	0
9. Life of Satellite	2	0	--	☾	☾	☾	☾	☾
10. Operational Flexibility	2	☾	0	☾	0	☾	0	☾
Total		+8	-4	+7	+14	-2	+6	+1

Table 4: Figures of Merit Evaluation

DISCUSSION OF THE CONCEPTS

Concept 1, orbital rescue, scored well with respect to the figures of merit. This concept has a good application with any architecture since it directly mitigates the possibility of GEO insertion failure and implies reduced or eliminated insurance.

Concept 2, salvaged satellite, is a risky proposition since there is no guarantee that a satellite can be found in an errant orbit that meets all of the S@tMax requirements. Furthermore – its condition on orbit is unknown.

Concept 3, modular incremental satellite, is an attractive proposition, but carries some technical risk since many interfaces and connections must be made in space with A&R.

Concept 4, Small Re-fuelable Satellite, scored well in the requirements FOM's. There is some risk involved in the re-fueling operation, but the use of a smaller launch vehicle may have significant cost advantages. In a satellite with traditional wet propellants and lots of maneuvering, the concept would be highly desirable. However in the S@tMax design the use of ion propulsion means that there is not much propellant on board and the mass fraction savings are not significant. This puts into question whether the cost of re-fueling ($75 M) can be saved in smaller launch vehicle cost savings. This concept was not useful to S@TMax but has high value in other architectures

Concept 5, LRU Satellite, involves many launches to continually upgrade the obsolete or "end of short life" components. The cost of these launches and the multiple risks from the many LRU swap outs make this concept technically risky and financially expensive.

Concept 6, end of life extension is useful to increase the total earning power of the satellite, but should be used as part of an overall satellite replacement strategy.

If concept 7, formation-flying swarm, could easily be implemented and operated then this concept would be a leading contender. However, the FOM's reveal that this is a very advanced design concept and the technical capability has not been fully demonstrated yet. If the technology does mature, then the formation flying swarm of node satellites should be carefully considered.

PROPOSED TECHNICAL TRADES, BUSINESS ENGINEERING TRADES AND SENSITIVITY ANALYSES

One of the fundamental trades regarding OOS involves the number of launches and the associated launch cost and risk. An OOS strategy can potentially reduce the launch mass each time, but will increase the number of launches. There is a cost and risk trade off and an analysis must be done to find the exact nature of the relationship and to identify any "break points".

The satellite design must be analyzed and divided into logical modular units. There is a bus level capability that must exist regardless of the payload. If the modular upgrade is of low value then it may be best to include the upgrade in the original satellite. Such issues must be investigated.

A trade study regarding insurance cost versus salvage costs and benefits must be performed. At a rescue cost of $50 M it seems that as long as the insurance cost is higher than the rescue service then this may be a favorable trade. However there are other technical risks and business arrangements that must be considered. A combination of insurance for a rescue capability is an interesting option that should be explored.

Other trades can also be identified which are specific to each candidate concept. Each trade must have a sensitivity analysis, which identifies the critical boundary parameters.

S@TMAX OOS CONCLUSIONS

This paper has presented a background of OOS and established an OOS baseline or point of departure scenario. The S@tmax case study was analyzed with respect to OOS functionality and business engineering advantages and a systems engineering framework and methodology was applied to the S@tMax case study. The systems engineering method was used in order to show how the introduction of a new capability such as OOS can be introduced into a traditional satellite architecture and design and subsequently evaluated. A clear success criteria statement established the S@tMax end state. The evaluation criteria have direct traceability to the stakeholder needs and subsequent requirements. Then a set of concepts were conceived and proposed for the use of OOS in the S@tMax plan. The concepts were verified against all requirements and then these concepts were evaluated and ranked against appropriate figures of merit.

The important principle is that the framework for evaluating new concepts has been established and future OOS concept evaluation iterations will be easily accomplished by comparing them against the S@tMax business plan baseline, so that the best possible OOS methods can be incorporated into the S@tMax system design, architecture and business model.

As a result of the concept evaluation process, the following OOS concepts were selected for further study in the S@tMax systems design and Business engineering sub-teams:

Concept # 1 Orbital Rescue/ Insurance Mitigation
Concept # 3 Modular Incremental Satellite
Concept # 6 End of Life Extension

Technology maturity, development requirements and the lack of commercially available OOS servicers restrict the number of realistic OOS concepts for this business plan and other more advanced OOS concepts should be considered in future S@tMax next generation satellites.

POTENTIAL OOS IMPACT ON SATELLITE OPERATIONS ECONOMICS

The S@tMax example has shown one of many potential OOS effects. OOS can therefore be considered in several ways:

- Business enabler for satellite operations
- Mission architecture optimization
- Development, assessment and improvement of OOS/OOA/A&R techniques, technologies and services

New satellite missions – especially commercial GEO – requiring high-value assets could benefit from deferred capital expenditures. In the case when service roll-out would require only staged availability of satellite capacity (when time-to-market with fully capacity is not crucial) then OOS provides new options. In such cases modular incremental satellites regarding power and payload upgradeability would ease business development based on CAPEX spread over time.

The fundamental trade is in the business engineering area. The capital expenditures should be spread over as much time as possible to have smaller discrete capital outlays which will allow for a better self sustaining business plan. The technical feasibility of dividing a satellite into discrete modules must be investigated. For S@tMax this was investigated on the basis of an equivalent small modular satellite system that can be incrementally assembled over time in order to use smaller launch vehicles and phase the capital expenditures over a long period of time to improve the feasibility of the business case without requiring large external investments with their associated dilution of founder shareholder value. It was found however that the requirement for a quick time to market (by 2013) in order to beat the terrestrial based competition, did not allow a modular assembly and financing, since a system of 2 large GEO satellites with 46 Ka band transponders would have to be replaced by a system of 12 smaller satellites to have the equivalent capacity. These 12 satellites could not be launched by 2013 since that would require 4 launches per year and the scaling caused larger mass fractions, which caused mass inefficiencies. The conclusion therefore was that the modular incremental satellite had a positive benefit to the business case but caused a technical penalty due to increased risk of assembly and larger total system mass. If the S@tMax system could have been deployed over 12 years then this may have been a desirable strategy, but with a 2013 full system implementation requirement, then the modular incremental satellite system was not desirable for S@tMax.

A rather revolutionary approach based con OOS and OOA would be a platform park providing capacity to today's and potential future satellite operators and thereby changing the economics of e.g. satellite telecommunications. Operators and businesses as e.g. SES, PanAmSat or S@tMax requirements would be met by a large platform. A separate business would maintain the platform and either own payloads and lease them to its customers, or the customers would own and manage their payload themselves. In both scenarios payloads could be upgraded or changed supported by means of OOS and OOA, re-leased or sold. Any of these implies manifold impacts on the economics and legal situation. This may be supported by an expectable increased number of smaller launches, economy of scale effects and partly by very favorable subset business opportunities.

This concept could be called e.g. "GEO Super Bus Platform". It is assumed that a commercial OOS provider has established a standardized GEO "Super Bus" that has modular and standard interfaces so that many payloads can be hosted on one bus. The Super bus provides all power, GN&C, propulsion, avionics and structure, and, an OOS servicing robotic arm grapples a payload that is delivered by itself or by an OOS tug and installs it on the Super Bus. At end of life, the payload can be un-installed and disposed of by the OOS Tug. The Super Bus is then free to host a new payload. This concept would establish a valuable GEO infrastructure element that can share the overhead cost of visiting payloads. The benefit to a payload such as S@tMax is that the launch mass could be reduced from 6,000 kg (Payload plus Bus) to 3,156 kg (Bus and GEO circularization stage). This could allow the satellite to be smaller in mass and complexity and launched on a smaller size launcher, therefore resulting in design, manufacturing and launch cost savings.

In conclusion, satellite operations, and especially commercial endeavors can benefit from OOS depending the individual case. However, sound judgment is only possible if technical, system and economic factors are understood and relevant trades are carried out properly.

This paper has shown that the OOS sensitivities with respect to stakeholder requirements must ultimately determine the system architecture and business plans, in order to maximize shareholder value, which is the stated S@tMax success criteria.

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