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ON-ORBIT SERVICING (OOS): ISSUES & COMMERCIAL IMPLICATIONS

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ABSTRACT

A major subset of on-orbit servicing (OOS) is unmanned satellite servicing missions using robotics and automation technologies, which is the focus here. To date various concepts for on-orbit servicing of satellites have been developed and investigated, mostly driven by the technological challenges involved. Now, under the label "OOS" such activities have a renaissance. However, no operational OOS business has developed yet, although many events (e.g. recent major satellite failures and the Columbia accident) indicate the potential value, of OOS particularly on the longer term and in light of a growing space infrastructure, debris problems etc.
This paper provides an overview on OOS and elaborates on its general issues, potential markets and business options by systematically looking at its drivers from a global perspective. A Special focus is on commercial implications of OOS in light of the overall future of the space sector.
Backgrounds of the findings presented are:

- **An DLR-initiated studies and projects (2001-present)**
- **Results of the OOS 2002 Workshop "Defining a Way Forward" (DLR-CSA, Germany Nov 2002)**
- **Work conducted in the framework of the central case project (CCP) of the SpaceTech 6 (2003) master class on space system and business engineering, as well as**
- **Follow-up investigations conducted by an international consortium led by the author.**

The aim is to provide the big picture of OOS and to have more space experts deal with this topic.

BACKGROUND

Servicing of space assets has been the topic of numerous projects, studies and hard and software tests for several decades. Especially since the successful Hubble repair mission conducted by astronauts in 1993. However, servicing of space infrastructure elements has not yet overcome its embryonic stage, although meanwhile the issue seems to undergo a renaissance.
On-orbit servicing (OOS): OOS theoretically covers all types of servicing of space assets (e.g. satellites, space stations, space probes, logistic depots, etc), be it human-supported (directly or remotely) or autonomously. Major rationale of all related activities is a general increase in efficiency of space activities. A major subset of OOS is unmanned servicing of satellites using means of space automation and robotics (A&R), which is the focus of this paper and activities described herein.
Despite the many OOS related work conducted over many years, no substantial, at least visible, progress has been made in terms of implementing OOS. Basically no real OOS missions were flown and the space community seems to be biased concerning the benefits and particularly the commercial feasibility of OOS. This may partly be because OOS has been promoted primarily by the A&R community, which has only a small voice in the space world, and because of proposed projects typically geared around technology, rather than focusing on the big picture of satellite operations. Several studies with technological or economic focus led to interesting results, but are mostly dealing with fragments of OOS, why no sound understanding of OOS, its drivers, commercial implications and potential impacts on the space sector in general is developed yet.
In 2001 the German Aerospace Space Center (DLR) launched a study to focus on developing such understanding of drivers and the market potential of OOS, which confirmed significant commercial potential, however also challenges at various levels. Follow-on activities, e.g. the "OOS 2002 Workshop – Defining a Way Forward" (in collaboration with the Canadian Space Agency CSA and international audience), and further studies are dealing with more detailed investigations of system engineering and business engineering approaches, programmatic and policy issues, international collaboration and demonstrations in space to develop a roadmap based on logical evolutionary steps. Interim results based on a dedicated market model and selected vertical work packages underline the potential of OOS. On the other hand OOS turns out as extremely complex and interdisciplinary and to a large extend driven by soft factors as culture, mindset and psychology. Several contractors, subcontractors and partners are involved in this pioneering activity aiming at broadening the understanding of OOS-related issues and at creating a dedicated community on international level for the benefit of the entire space community.

THE CASE FOR OOS

The feasibility of OOS depends primarily on its customer benefit, respectively on whether someone will pay for service. This may seem evident, but it is far more complex than just that. The satellite population and its associated failures provide the theoretical service demand. However, depending on the nature of failures and resulting kinds of services needed, the orbits and planes, the types of satellite and their operators (owners) decrease the number of service needs. Particularly the impact of a failure on a particular operator (owner) defines the potential service price. Taking into account that malfunctions occur at different phases of a satellite's orbital life and that they may be foreseeable (scheduled) or unforeseeable (emergency), adds another level of complexity and narrows down the demand for a special kind of service at a particular place and time.
An OOS solution becomes viable if its cost meets the price target. Depending on the kind of service needed to correct specific satellite failures requirements may even include certain logistics to be meet by optimized mission architecture. All in all a sound system and business engineering approach is mandatory. Additionally political and regulatory developments need consideration. On the A&R-technology side (service tasks: servicer-target interaction) sufficient capabilities are developed, while co-operative satellite design is not yet state of the art, hindering from correcting app half of the failures. In summary, only parts of OOS are understood and investigated so far.

SATELLITE POPULATION

An essential input to the OOS equation is the population of satellites. The above mentioned high-level market study considered non-military satellites of more than 500kg in GEO, MEO, LEO and LEO sun-synchronous orbit (LEO-SSO) in telecommunication, navigation, earth observation and science over the next 15 years, by distinguishing between current and dying satellites, and new satellites for new missions and new satellites for replenishment. Furthermore the forecast broke down into civil and commercial operators (owners). It was based on available data (useful up to 4 years max), expectations on satellites failures over economic conditions and trends, political forces and expected technology advances as well as on expert experiences. Although such forecast is of limited reliability, the methodology used provides an estimate and trends of the satellite population with sufficient detail.

SATELLITE FAILURES

In order to determine the theoretical service demand, sound information on satellite failures is needed, but unfortunately the most incomplete input to date when looking at OOS in its entirety.
Various dimensions of satellite failures need to be considered, e.g.:

- Cause
  - Technical (satellite breakdown)
  - Other (impact, collision, etc)
- Occurrence (life cycle)
- Probability
- Propagation route

It appears that satellite failures are not sufficiently understood, at least are very difficult to predict. The market study was based on a universal failure profile (5% launch failures, 5% early orbit failures and 50% end of life failures). Current investigations focus on more detailed assumptions for selected groups of satellites.

DEFINITION OF SERVICES

In order to best capture the entire potential OOS market is it useful to have a standard service definition, in the past confusing terminology led to misinterpretations and made comparisons of OOS-related projects difficult.
Assuming that technically almost everything was possible, potential services differ by the level of interaction between servicer and target. Therefore 3 distinguished service "classes" can be defined:

- Motion (servicer moves target in a particular way for a particular reason)
- Manipulation (servicer physically manipulates the target)
- Observation (servicer remotely gathers information from the target)

Manipulation services require co-operative satellite design. Observation does not. In case of motion service it depends on the technical solution.
Accordingly, each of the three service classes can cover various (and mutually exclusive) "kinds of service", which have been defined as follows:

- Re-Orbiting: move of target to/in its target orbit (motion class)
- De-Orbiting: move of target to graveyard orbit or initiation of destructive re-entry (motion class)
- Salvage: salvage of target to e.g. orbital station or re-entry (non-destructive) to earth (motion class)
- Maintenance: re-fueling or other re-supply of the target (manipulation class)
- Repair: diagnosis and correction or repair of failures or faulty units of the target (manipulation class)
- Retrofit: upgrade, update or exchange of orbital replacement units (ORUs) on the target (manipulation class)
- Docked Inspection: system and fault diagnosis of the target using physical connectors (manipulation class)
- Remote Inspection: remote system and fault diagnosis of the target (observation class)

This service definition can serve as building block covering all OOS projects (single or combined use). Individual services will differ in terms of their required frequency and logistic needs, which links into the mission architecture challenge.

MARKET POTENTIAL

Presumably not the entire theoretical service demand for will become a reality. Nevertheless, if only 25-50% of the needs were addressed, the potential OOS market would be in the app 100 service events translating into MEUR 500-1.000 p.a. (range due to effects of potential co-operative satellite design). This is equivalent to the planned space-borne revenues of projects as e.g. Infoterra or Galileo and therefore deserves appropriate attention. Pricing of services needs to take into account the nature of the operators (owners) of the target (civil vs. commercial) and their potential threat in case of loss of the satellite, which of course also varies by orbit, type of satellite, failure type etc. Service prices in the one-digit to 100^{+} MEUR seem possible depending on the individual case.

STATE OF TARGET

From a technical perspective it is important to take into account the state of the flawed satellite. Depending on whether it tumbles or not, to which extent it tumbles, whether e.g. station keeping and/or communication are still in tune etc. is important, since such state information qualifies as target or not, and directly influences the OOS potential.

OOS STAKEHOLDERS

The services mentioned above represent a variety of potential customer benefits, as primarily life extension, reduced liability, deferring capital expenditures, safeguarding of research project and know-how, enhancement of performance, pure financial upside etc. however there are potentially more OOS stakeholders as:

- Satellite operators/owners
- Insurance companies
- Satellite manufacturers
- Science community
- Governments & agencies
- International/regulatory bodies
- Launch industry
- Space A&R community,

which could benefit in various ways from OOS. Most obvious are direct benefits for operators. Furthermore e.g. insurance companies could reduce risks and change premium policies, satellite manufacturers could gather information to improve their products and eventually enter manufacturing of service vehicles, the launch industry could increase number of launches, and so on as stakeholder interviews partly confirmed. For the time being the attitude of those stakeholders is rather diverse, particularly because of lack of information and limited insight into the overall context of OOS.

OOS “COMPETITION”

Not all satellite failures need OOS. Some are too severe to be dealt with, while others may be corrected by other measures representing some sort of “competition” to OOS. Such alternative corrective actions may are of technical nature, e.g. on bus level (e.g. redundancy) or software workarounds or on operations level, as e.g. spares, switching capacity to another satellite etc. based individual operators business model. A complete overview of applicable alternatives is not yet available to the entire range of satellites.

OOS (ACTIVITIES) BUSINESS

In order to consider OOS for future space infrastructure its commercial potential needs to be verified, especially in current times of budget scrutiny. And in analogy to new business developments in other sectors, proof of concept (basically in-orbit demonstration) and first commercial endeavors (successes) are mandatory. Assuming sufficient market demand, OOS activities would have to be set up in light of:

Market Segmentation: although most commercially-oriented OOS projects focus on extending life of commercial GEO telecommunication satellites, it is not evident yet, that there was no potential in other segments as high-value government satellites, de-orbiting (regulatory issue: orbital clean-up), constellation servicing, inspection, etc.

Business Modeling: depending on who the customer and what the basis revenue is, OOS business models can differ significantly. The range may cover direct charge for services conducted to reservation fees or other upsides in the customers business. Another trade-off is between single and multi-servicing capabilities and requires different mission architecture and logistics (capital investments), which will result in different revenue and risk levels. The critical mass in terms of market will also depend on responsiveness (emergency vs. scheduled services), which may lead to fleet approaches or logistic platforms close to the “market” (orbits, customers, etc.). No matter which approach will be chosen, its cost-benefit must be obvious. Co-operative satellite design and standardization will definitely have a major impact on the OOS market, but are not yet predictable.

It becomes obvious, that business engineering for OOS will go beyond traditional space business. Interestingly OOS is the first commercial potential in space, which is exclusively based on space business requiring all accumulated internal know-how, while in telecommunication, navigation, earth observation and science space systems are only purchased as data source in a non-space value chain.

Management, Culture and Organizational Structure: also the corporate setup and culture for a successful OOS business will have to be entirely different from today’s space industry in order to meet the challenges involved. Most probably this represents an opportunity for the existing space industry, which could still serve as prime to such activities. In any case will OOS call for joining forces cross-national and cross-space industry-

wise, because of the complexity involved and the requirements to integrate such end-to-end system.
Financial Feasibility: Financing needs of OOS can be expected to differ from one-digit to several hundred MEUR. It appears obvious, that funding of precursor missions and first demonstrations are primarily agency responsibility due to the risks involved and to kick-off market demand. As for purely commercial projects a combination of agency support, entrepreneurial and strategic equity seems to be appropriate. Time-to-market will play an equally important role as cost-efficiency as drivers of profit and return. However, a convincing management team, a sound business plan and an appropriate financing strategy alongside with a supportive financial marketplace are pre-requisites for any new space commercialization project (such basic rules have often been violated in space!).
Regulatory Issues: different from other industries, space and OOS in particular rely strongly on regulatory bodies (debris, de-orbiting, frequencies, etc), where the space agencies can be of support.

OOS: THE STATUS QUO

OOS, which came under various labels in the past decades, has made major progress in technological terms (A&R etc.), but is not yet a real issue in the space community. Currently app 30 OOS or related projects are underway (18 in the US) involving app 1.500 man-years p.a. (estimate), which is more than one would have expected. However, only 2 companies were founded to exclusively target commercial OOS, namely Vanguard Space in Germany and Orbital Recovery Corporation (ORC; Cayman Islands: www.orbitalrecovery.com). ORC has a first mover advantage and a real chance to get off the ground. About half of the other projects are lacking either the big picture and should therefore be questioned or fight funding or technological problems. Nevertheless, OOS has become an issue in space and is now about being investigated outside its heritage (A&R) as well. It has to be mentioned that OOS, its issues and overall commercial implications are not yet fully understood and therefore major homework still needs to be conducted. Technology demonstration missions and ORC pioneering the OOS market play an important role towards paving the way for more efficient use of space. As for non-technical studies and projects on OOS, only few sources are available (primarily in North America and Europe), partly providing useful tools and results, but partly also apply to limited cases only. All of the above activities are appreciated and the recently launched website www.on-orbit-serivcing.com aims at serving as the one-step link to OOS on global level. On this website an “OOS logo” is available to help indicate relevant presentations, papers and events and thereby help create an OOS community combining necessary know-how, skills and assets.
It has to be mentioned, that there is also a strong “no-camp” against OOS based on some strong but many more weak arguments. It is definitely too early for a judgment of OOS unless insights are deeper.

THE OOS CHALLENGE & ISSUES

OOS in its entirety is challenging, but not only because of its technical complexity. Despite it seems obvious in the long-term to serve space assets rather than throwing them away, it is not yet evident how to close the commercial case due to lack of understanding. In addition traditional processes and structures in the space industry are not yet prepared for paradigm shifts requiring changes to culture and mindset (even if only looking at things!). From a government perspective it is sub-optimal that there is no such OOS policy with associated budget line (as e.g. for mars missions) and therefore streamlining of activities and collaboration is hindered due to current patchwork approaches lacking vision, strategy, commitment and continuity as required by any other focused space development. Another problem is the level of non-technical expertise (but with space insights) required to progress in OOS, which leads back to the overall structure of the space sector and necessary education and training, which counts for any space fairing nation.
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.
An important subset of challenges is to consider co-operative satellite design, which is addressed by some of the current OOS projects. It is widely believed that co-operative design would not pay off, which is probably not correct when looking at its potential overall impact.
In general numerous soft factors influence OOS progress, which need to be understood and considered appropriately. One being political (or national strategic), another being psychological (new perspective and approach?) and last but not least the structures, and therefore the system in space.

COMMERCIAL IMPLICATIONS

So far OOS as discussed here only exists on paper. However, for some projects it would not take much to become a reality. Since nowadays the term commerce represents the ultimate formula, commercial implications of any new space business venture are an issue. The same counts for OOS, but from the standard perspective it is a difficult assessment.
OOS could have the potential for major changes in the way space projects are conducted to date. Once OOS was considered already during the design phase of space missions and an element of their operations, then major processes would change.
As requirements for satellite reliability could be relaxed, cost and mass (volume?) might partially

come down leading to different launch demand. On the other hand servicers needed to be launched and logistic needs (supplies, consumables, etc) to be satisfied (supplies, consumables, etc). This would change the frequency of both satellite manufacturing and launches. Processes in the established space industry needed to be changed from one-of-a-kind to small series production, which could result in economy of scale effects. Such scenarios might be slightly cheaper on the long-term or would allow more space activities based on equal funding. This may be too much of a nice outlook, but is a useful exercise to challenge and maybe improve present activities.

More beneficial than pure monetary benefits might be the learning curve of breaking the rules and re-thinking the current status, which will support new visions and prepare next generation space leaders. OOS and its issues are worthwhile to pay attention to and will foster creativity. Developing OOS be it for government or commercial missions will take some up-front effort, but will probably pay off in various ways.

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