MCTP

Title:
In-Orbit maintenance: the future of the satellite industry

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"It is not the strongest of the species that survive, nor the most intelligent, but the one most responsive to change."

- *Charles Darwin*

Contents

I. Executive summary

Space exploration has been one of the biggest aspirations of mankind. From the very first mission in space to the exploration of the Martian surface, the human space odyssey has shown successive progress thanks to the vision, persistence and dedication of passionate people.

Investments in space related activity has always been capital intensive and technologically challenging. One may consider these as obstacles but for us the main obstacles are the naysayers and cynics, who say such projects are impossible to achieve. In-Orbit maintenance is one such space activity faced with such a dilemma as only a handful of people believe in its realization. Maintenance in space, if materialized will be as revolutionary and disruptive to the space value chain as the moon landing was in the sixties.

Our team believed that In-Orbit maintenance as a topic of study is worth exploring in order to formulate an informed opinion on the subject. This report shows the result of our studies gathered from an initial research phase to a set of interesting interviews. The literature concerning satellite maintenance is very limited and we thought that the reason for this was perhaps due to biased opinions among academicians and the industry. Hence, we wanted to investigate further to understand the reason for the bias and perhaps through this exploration identify opportunities and provide convincing arguments which will make In-Orbit maintenance a widely accepted concept.

For this journey we used a formal academic approach in order to gather information from all possible sources and we tried to avoid any bias in our thinking process which might interfere with our conclusions on the study. We studied the space market, performed a top-down strategic analysis of the topic, we identified the pros and cons from our research and interviews, focused on the topics that are usually set aside when considering space activities such as the legal and environment aspects and finally we proposed a set of recommendations that would allow In-Orbit maintenance activities to develop.

Through our research we found out that In-Orbit maintenance can actually be a viable activity. The market for In-Orbit maintenance is niche but will eventually expand over time to the next generation of spacecraft. Targeting the right customer, the right satellite (based on orbit type) and the right application with the influence of an encouraging legal environment and a sound business plan can make satellite maintenance a profitable enterprise.

What is interesting is that the mindset regarding space activities is changing. This change is certainly welcomed and is required for space maintenance activities to thrive. Overtime, standardization which is identified as one of the obstacles, would evolve over the years as In-Orbit maintenance becomes a reality.

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iii. Definitions

Satellite maintenance (or satellite servicing): Activities performed on a satellite in order to extend its life or to restore a better operational state. Satellite maintenance includes refueling, re-positioning or other type of maintenance.

Reactive maintenance: Reactive maintenance is repair done after the occurrence or detection of a breakdown.

Preventive maintenance: Preventive maintenance consists in trying avoiding a repair on a satellite by performing a systematic action taken early enough to prevent a breakdown on a satellite.

Predictive maintenance: Predictive maintenance actions consist in taking preventive actions only if warranted.

CubeSat: The term "nanosatellite" or "nanosat" is applied to an artificial satellite which is built according to standard dimensions of 10x10x11 (called Units or U). They can be 1U, 2U, 3U, or 6U in size, and typically weigh less than 1.33 kg per U.

Nanosat: The term "nanosatellite" or "nanosat" is applied to an artificial satellite with a mass between 1 and 10 kg.

Telecommunications satellites: A telecommunications satellite is an artificial satellite that relays and amplifies telecommunications signals via a transponder. Many everyday activities relies on telecommunications satellites in orbit: radio, television, and internet.

Space democratization: Along this this report, space democratization refers to the easier access to space which is made possible nowadays through the use of better technologies and low-cost equipment.

Miniaturization: Miniaturization is a technology trend in regard of the Moore's law. The number of integrated transistors can be doubled every two years over the same chip size. Therefore, performance of any electronic device such as a satellite can increase without increasing the mass. Miniaturization is also allowed through the use of new materials.

iv. Abbreviations

CNES: Centre National d'Etudes Spatiales

DARPA: Defense Advanced Research Projects Agency

DRL: Demand Readiness Level

EO: Earth Observation

GEO: Geostationary Orbit

GNSS: Global Navigation Satellite Systems

GPS: Global Positioning System

GSV: Geostationary Servicing Vehicle

IADC: Inter-Agency Space Debris Coordination Committee

ICAO: International Civil Aviation Organization

IRNSS: Indian Regional Navigation Satellite System

ISS: International Space Station

ITU: International Telecommunication Union

LEO: Low Earth Orbit

LTSSA: Long Term Sustainability of Space Activity

MEO: Medium Earth Orbit

MEV: Mission Extension Vehicle

MIFR: Master International Frequency Register

NPV: Net Present Value

QZSS: Japanese Quasi-Zenith Satellite System

RCM: Reliability-Centered Maintenance

RRM: Robotic Refueling Mission

RSGS: Robotic Servicing of Geosynchronous Satellites

SME: Small Medium Enterprises

TRL: Technology Readiness Level

UN COPUOS: United Nations Committee On Peaceful Uses of Outer Space

USC: Union of Concerned Scientists

WACC: Weighted Average Cost of Capital

II. Methodology

The methodology of the study is comprised of two phases, the research phase and the interview phase where we interview a list of industry players whose names can be found at the end of this section.

The first phase is the research component, which consisted of reading journals, books, monitoring announcements made by the space/satellite industry and also utilizing information gathered from the lectures of the AeMBA program.

The second phase is the interview process: The goal of this section is to hear the real voice and to acknowledge the response of professionals towards In-Orbit maintenance. The process of conducting the interviews required us to identify different actors to be interviewed, derive a set of questions to be asked to the potential candidates, conduct the interviews and to analyze the outputs. We did not want to overwhelm the candidates, and so we decided to keep the number of people conducting the interview to a maximum number of three per candidate.

Part of the process was to start from an open field as the initial topic was related to “the business value of space data” and then we had to narrow the topic down to a more specific topic where our research could make a difference in the space domain.

From the open field, we moved towards the topic of “the predictive maintenance in the satellite industry” because this topic was rarely encountered. This topic seemed to be very interesting due to the contrasting opinions from the different space actors we had the chance to interview. Considering the information given on this specific topic we could gather information about the opinion of the different actors and their vision of the space industry for the coming years.

Running an interview is a process that has to be organized and consistent with the different interviewees. We decided to set up a process methodology that will be applied in order to reach a congruent approach when interviewing the candidates. The interview methodology details are available in Appendix XI.I.

We identified three main steps in the interview’s process:

- **Before the interview**: through the screening process and the organization to be put in place (place and time of the interview, way of recording, number of persons attending, etc.),
- **During the interview**: We called it a “semi-structured” interview as our set of questions was accurate enough on the field we wanted to explore, but was flexible enough to give our interviewees enough freedom to express their own views,

- **After the interview**: This step is the core of our work as it represents the analysis of the information given by the candidates, the organization and categorization of ideas, the writing of this final report, and also thanking the different candidates.

Find hereunder the exhaustive list of people interviewed during this research project:

- **Jean-François GENESTE**, Airbus Defense and Space, Group VP Chief Scientist, interviewed on March 8th, by Abhishek and Florent.
- **Philippe LATTES**, Aerospace Valley, Deputy for Space& European projects domain, interviewed on March 2nd by Qingqing and Florent.
- **Lei HUANG**, China Academy of Space Technology (CAST), Associate Director, interviewed on March 4th done by Qingqing and Ryota.
- **Laurent CARELLE**, Noveltis, Director Marketing and Sales, interviewed on March 2nd by Abhishek, Muzi and Florent.
- **Cornelius ZUND**, SATELLITE^2, Founder, Director, interviewed on February 25th by the MCTP team,
- **Yusuke MURAKI**, Japan Aerospace Exploration Agency (JAXA), Associate Senior Administrator, Mission Planning Department, interviewed on March 4th by Ryota.
- **Delphine MIRAMONT**, Sirius Chair, SIRIUS Chair, PhD. student Space Law, interviewed on March 8th by Abhishek, Muzi and Florent.
- **Sylvain MICHEL**, CNES, Spacecraft Operations Specialist of Future concepts, interviewed on March 16th by Ryota, Qingqing and Florent.
- **Dominique PONCET**, Airbus Defense and Space, interviewed on March 25th done by Hoang and Florent.

From the set of interviews conducted, we have identified two main categories of thinking and apprehending the concept of satellite maintenance of the satellite industry. The first one is that maintenance is irrelevant for the satellite industry at this stage and that it may not be an economically viable solution. The second way of thinking believes in the maintenance of a specific type of satellite under certain conditions.

III. Introduction

In this report we will explore if In-Orbit maintenance is a viable solution for the satellite industry. When it comes to maintenance, most mature industries such as the automotive and aviation sector have evolved over the years. This evolution entails three phases- reactive, preventive and predictive maintenance. Based on their evolution, they are currently sitting on the predictive phase. The satellite industry is structured in a different manner. Today's satellites are not built to be maintained. They are built with a lot of redundancies in preparation for failures that might occur whilst In-Orbit.

The satellite industry is currently divided into three sectors namely- civil, military and commercial. Civil and military are currently the biggest influencers in the satellite industry. In the commercial sector, satellite communications sector is one of the biggest.

For the purposes of this report we will be looking at the overview of the satellite industry, defining the ecosystem and how important a player is the commercial sector in the satellite industry. Whilst exploring In-Orbit maintenance as a solution to the satellite industry we will be conducting a market analysis (section VIII) through various sources and views from industry stakeholders. In the market analysis we will be investigating the strategic approach towards In-Orbit maintenance.

What is In-Orbit maintenance?

In-Orbit Maintenance also known as On-Orbit Servicing can be defined as follows:

"*... a service offered for scientific, security or commercial reasons that entail an in-space operation on a selected client spacecraft to fulfill one (or more) of the following goals: inspect, move, refuel, repair, recover from launch failure, or add more capability to the system*" [1]

The concept of In-Orbit maintenance has been around for quite some-time. During the initial exploration phase of the topic we found a contrast between the academic community and industry players. Through academic research In-Orbit maintenance has been identified as a feasible solution for the future of the satellite industry. Industry players have different views on this matter. For the purpose of the study we will embark on a journey to explore if any of the views mentioned above from academia and industry are justified. If the view from academia is confirmed, what are the possible barriers that are hindering the realization of In-Orbit maintenance?

We will also be conducting a strategic analysis (section 0) to explore the influences of external factors such as political (section VI.I), legal (section VI.V) and environmental (section VI.VII) which have an influence on the satellite industry value chain.

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[1] International Space University (2007).DOCTOR: Developing On-Orbit Servicing concepts, Technology options and Roadmap, International Space University. Strasbourg.

Is there a need for In-Orbit maintenance? We will be looking into insurance claims that have been lodged from 1968 to 2014. Part of this analysis we will look into the causes/reasons for the claims.

After all the analysis has been done we will be concluding with our findings, recommendations and proposals that may be applicable in order to realize In-Orbit maintenance as a solution for the satellite industry.

IV. Overview of the satellite industry

IV.I. Value chain in satellite services

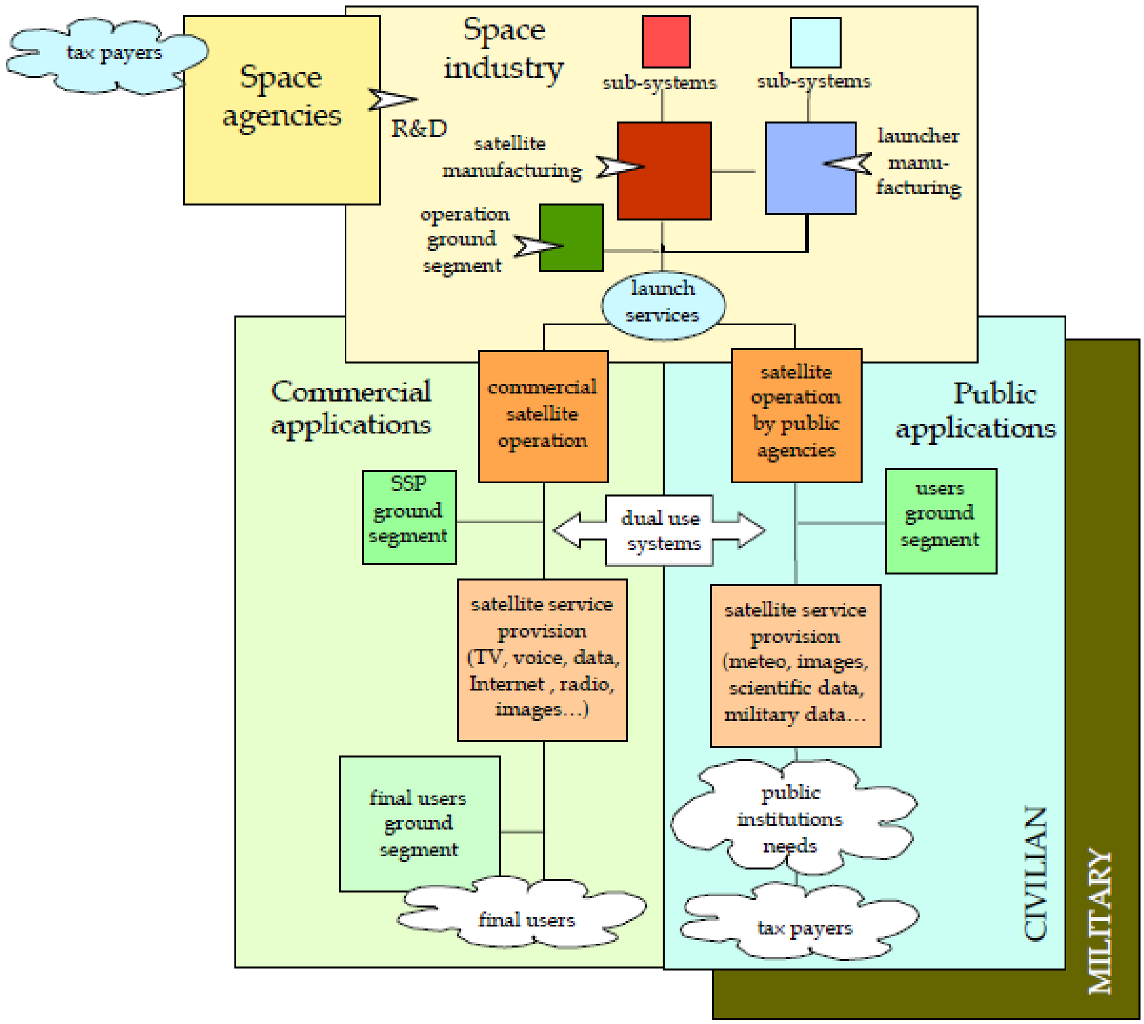

Figure 1 Satellite value chain (Euroconsult)

The value chain in satellite services[2] is described in the above figure. The value chain begins from space agencies that are funded by government through taxes. Then we have the space industry with different actors namely, satellite manufacturers with its suppliers, launcher manufacturers with its suppliers, ground segment operators and launch services provider.

Once the satellite is in orbit, it begins to relay data to the ground segment. The ground segment will provide different services such as television, voice, data, Internet, radio,

[2] Pacôme Révillon, Euroconsult. (2016). ECONOMIC ASPECTS OF THE SPACE SECTOR.

images, weather, scientific data and military data services etc. It will also channel the services to the final users or tax payers. There are three types of applications: commercial, public and military. Those three applications can be combined to form “dual use” systems (Public civilian + commercial, Public civilian + military, Military + commercial) or “triple use” systems (Public civilian + military + commercial).

IV.II. European satellite ecosystem

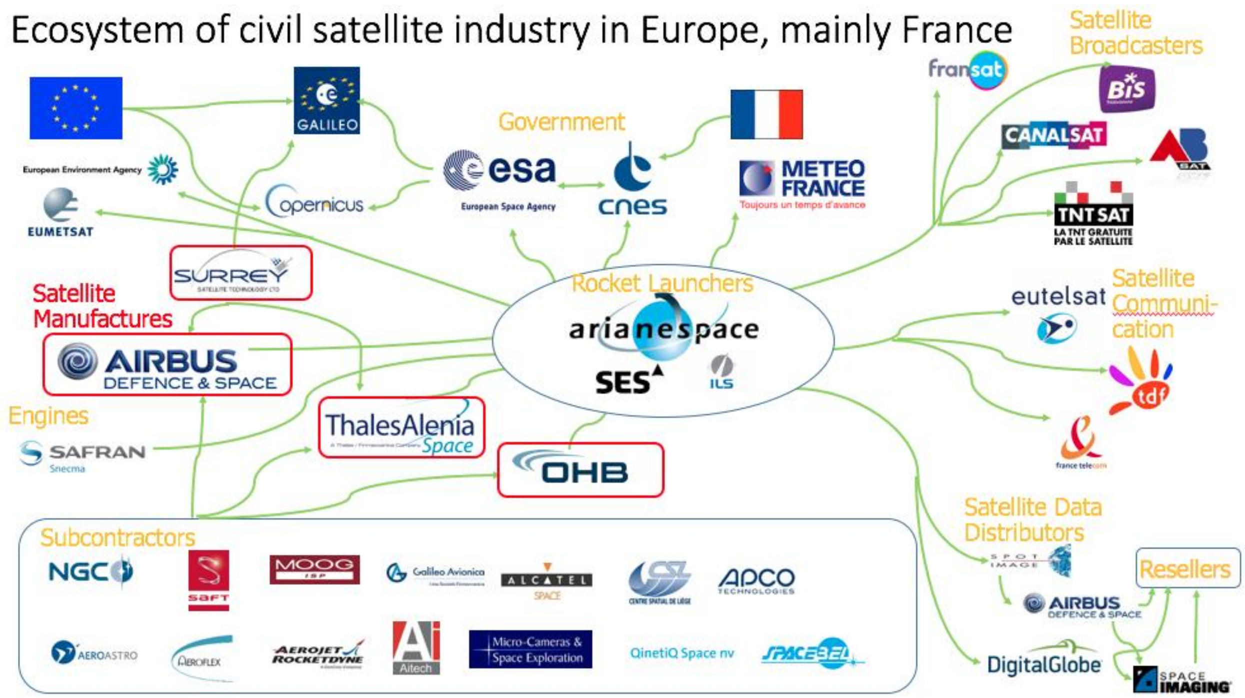

Figure 2 Ecosystem of civil satellite industry in Europe

The ecosystem of civil satellite industry in Europe is composed of:

- Satellite Manufacturers
- Engine manufacturers
- Subcontractors
- Rocket launchers
- Operators
  - State owned operators
  - Satellite broadcasters
  - Satellite communication
- Satellite data distributors and resellers

The US satellite ecosystem is similar to the European one. However, from our analysis, we can see the emergence of newcomers like SpaceX and Blue Origin are pushing towards innovation and disruptive business models. These newcomers want to break the current market and well established business models.

IV.III. Satellite phases

Satellite industry is divided into different phases:

- **Mission definition**: this is the first phase of satellite activities. Satellite mission and the main functionalities are defined during this phase. The satellite missions can be science, remote sensing, R&D, piloted, navigation and communication.
- **Satellite manufacturing**: the second phase is about satellite production. This includes the payload, the launch module part and involves a lot of suppliers.
- **Launch service**: this phase goes from the launch pad phase on ground until the separation between the launch module and the payload module.
- **Satellite operation**: this phase involves the different stages that will allow the satellite to be fully operational. It goes from orbit positioning steps in order to cover the right area on Earth to the solar panels deployment.
- **Service provider**: this is when the satellite is fully operational and starts to provide the services like telecommunication services.
- **Consumer**: the services are open to the consumers who can start using the different services provided.

The below figure is an example of the satellite program phases in the Japanese space communication satellite industry.

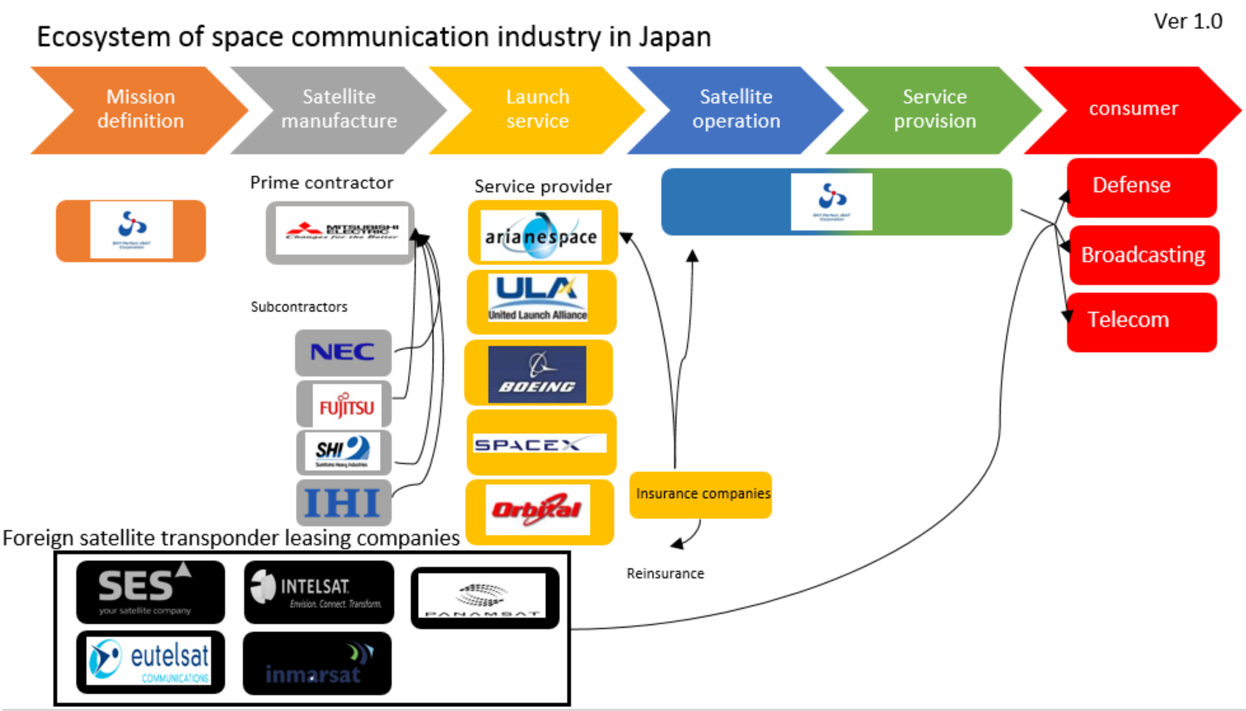

Figure 3 Satellite phases in the Japanese communication satellite industry

V. In-Orbit maintenance: The future of the satellite industry?

V.I. Maintenance and predictive maintenance concepts in aviation.

From the beginning our MCTP group wanted to work on Big Data and its application in the aeronautical industry. One of the most remarkable concepts is the one of predictive maintenance[3]. The first maintenance concepts in aviation industry were developed and implemented in the 1960s. The RCM (Reliability-Centred Maintenance) was successfully implemented on the McDonnell Douglas DC-10 and Boeing B-747 programs.

While maintenance operations are getting more and more mature, predictive actions are being developed at the same time. Traditionally, predictive maintenance is used solely as a maintenance management tool. In most cases, this use is limited to preventing unscheduled downtime and/or catastrophic failures.

Over the last fifty years, systems have become more and more complex and the number of sensors in the aircraft has increased drastically. This system complexity and this multiplicity of sensors result in making data more and more numerous and complex. That is why the ability to extract, organize and analyse data has become more and more critical. In recent years, this concept has quickly developed by combining Big Data competences and traditional predictive maintenance. General Electric has been one of the pioneers in predictive maintenance known for its engines monitoring services. GE has created an analytical platform called "Predictivity"[4] dedicated to "Megadata" coming from the thousands of engines in service.

Based on this initial analysis of the aviation industry, we decided to analyse the current situation in the satellite industry regarding maintenance, to see whether we could draw parallels and derive some business concepts from the aviation industry into the satellite industry. We had the following questions in mind:

- Is maintenance applicable to the satellite industry?
- If no, are there any business opportunities for maintenance in the satellite industry?
- Could In-Orbit maintenance be the future for satellite industry?

V.II. Concept of In-Orbit Maintenance

[3] R. Keith Mobley. (2002). An Introduction to Predictive Maintenance. (USA); Butterworth-Heinemann.

[4] Oliview James, Les big data ouvrent l'ère de l'aéronautique de service, L'USINEDIGITALE, Available at: http://www.usine-digitale.fr/article/les-big-data-ouvrent-l-ere-de-l-aeronautique-de-service.N334101 [Accessed on 31 03 2016]

The space industry has been growing rapidly in the past decade and one of the main reasons for the growth is the democratization of space. Technological advances have helped reduce costs and hence more players are entering the industry. The industry although largely dominated by governments/ space agencies, new players such as private companies have joined the pool.

Democratization of space has also opened doors for new business opportunities in the satellite industry, with In-Orbit maintenance as one of the future businesses in this domain.

V.II.A. Classes of In-Orbit Maintenance

In-Orbit Maintenance can be divided into three classes or missions:

1. Inspection Mission

This mission is used to collect additional information on the cause of a satellite failure. This information is used for analysis and diagnosis.

2. Manipulation Mission

This mission helps to manipulate a spacecraft in order to refuel, repair or replace parts.

3. Maneuvering Mission

This mission is used to change the position of the spacecraft. For instance, moving the spacecraft from the wrong orbit to its designated orbit or moving a spacecraft which has reached the end of its life to the graveyard orbit.

V.II.B. In-Orbit Maintenance process

In his dissertation, Brook R. Sullivan gives a good summary of the chronological steps of any maintenance mission[5]:

Maintenance missions are divided into a number of different phases. The types of maintenance missions follow the below chronological order. Here we refer to the satellite or the spacecraft providing the service as the servicer and the satellite or the spacecraft to be serviced as the client.

1. **Launch**- The first step is to launch the servicer into orbit.

[5] B.R.Sullivan. (2005). Technical And Economic Feasibility Of Telerobotic On-Orbit Satellite Servicing.

2. **Rendezvous**- From some initial orbit, the servicer needs to maneuver to the client spacecraft.
3. **Inspection** - An initial inspection is usually required. Here the servicer spacecraft orbits around the client spacecraft. Some clients just require an inspection mission.
4. **Docking**- For any repair or refueling mission, the servicer must dock on to the client to begin operations.
5. **Relocation**- In some cases the servicer will relocate the client spacecraft to a new orbital location.
6. **Dexterous**- For a number of maintenance scenarios, the servicer must perform dexterous operations to repair or resupply the client spacecraft.
7. **Departure**- At the conclusion of servicing, the servicer will undock and depart from the area of the client spacecraft. This phase could also include final inspection.

While a variety of spacecraft services can be conceived, they can all be identified as belonging to one of three general categories, which include failure mitigation, lifetime extension, and other services. In other words, the three main categories of In-Orbit maintenance are repair, refueling and relocation.

V.II.C. Types of earth orbits

1. **LEO (Low Earth orbit):** Geocentric orbits ranging in altitude from 160–2000 km (100–1240 miles).

2. **MEO (Medium Earth orbit):** Geocentric orbits ranging in altitude from 2,000 km (1,200 mi) to just below geosynchronous orbit at 35,786 km (22,236 mi). Also known as an intermediate circular orbit. According to Wikipedia "Most commonly at 20,200 km or 20,650, with an orbital period of 12 hours". [6]

3. **GEO (Geostationary orbit) / GSO (Geosynchronous orbit):** Circular orbits with an altitude of approximately 35,786 km (22,236 mi). A geostationary orbit is a geosynchronous orbit with an inclination of zero. To an observer on the ground this satellite would appear as a fixed point in the sky.

4. **HEO (Highly Elliptical Orbit) and DHEO (Deep Highly Elliptical Orbit):** Orbit of low perigee (about 1000 km) and a high apogee over 35,786 km). These orbits have an inclination between 50 and 70 degrees.

[6] Wikipedia, a free encyclopedia, "List of orbits", [Online], Available at: https://en.wikipedia.org/wiki/List_of_orbits [Accessed 19 04 2016]

5. **GTO (geosynchronous transfer orbit or geostationary transfer orbit):** Highly elliptical orbit used to reach geosynchronous or geostationary orbit.

6. **DSO (Deep space orbit):** sometimes referred to as HEO (High Earth orbit). Geocentric orbits above the altitude of geosynchronous orbit 35,786 km (22,236 mi).

7. **CLO (Cis-lunar orbit):** Elliptical orbit which has an apogee greater than 318,200 km.

V.III. Overview of current maintenance activities in the satellite industry

During the life of the satellite in orbit, the satellite is controlled by the ground operations. This is what we call “the monitoring of satellites”. This involves a systematic control of all the key parameters of the satellite such as energy level, solar panels activity etc. When a failure is detected, an analysis will be performed by the ground operations, a potential solution will be proposed and maintenance actions will be performed if possible in order to recover the satellite functionalities. This type of maintenance is reactive and not predictive. It is done remotely and not directly on the satellite.

In order to know the potential market for In-Orbit maintenance business, we performed an analysis[7] based on the insurance claims from 1968 until 2014[8]. Insurance claims gives us a visibility of the types of failures that a satellite might encounter during its life. Around 1890 satellites have been launched in this period and about 240 insurance claims have been issued which represents around 10%.

[7] USC Satellite Database, Union of Concerned Scientists, Available at: http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.VwZpE3kgpMt [Accessed on 31 03 2016].
[8] Hideyuki Kawamoto. (2015), Overview of space insurance. In: Koku to Uchu No. 735. Tokyo: P. 1-8.

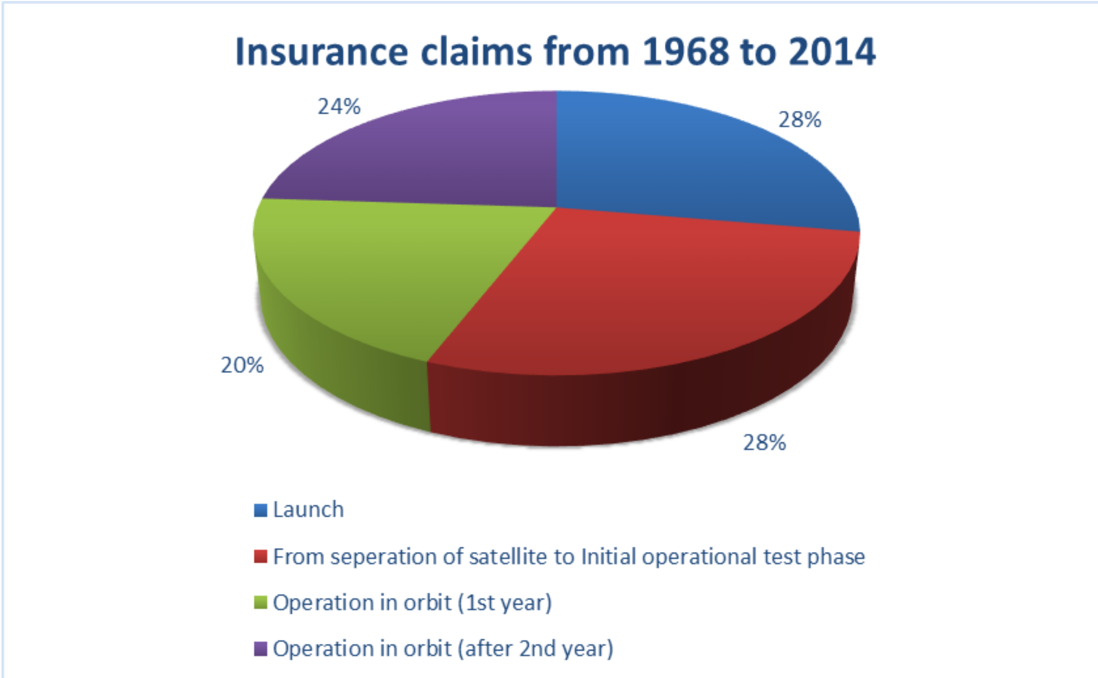

Figure 4 Insurance claim from 1968 to 2014

The above figure is showing the insurance claims from 1968 to 2014 and from the launch to the operational life in-orbit. We can note that 72% of the claims concerns the phases from separation of satellite to the operations in-orbit.

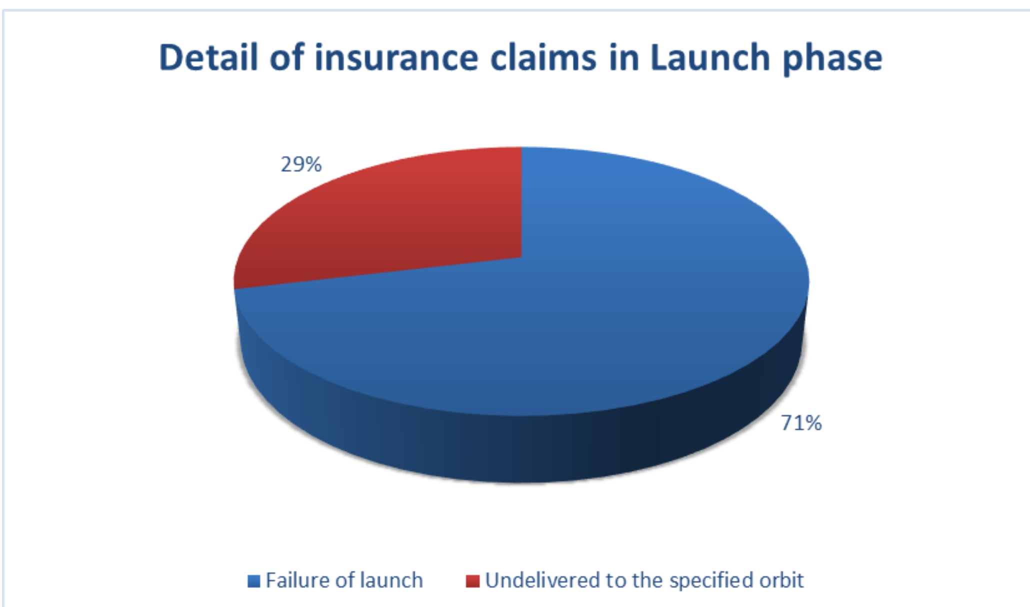

Figure 5 Insurance claims in launch phase

In the launch phase, the claims are mainly on the failure of launch. The satellite is thus lost. However, for the satellites that are not delivered on the right orbit, we can imagine a maintenance action. A maintenance satellite can help this satellite getting to the right orbit. More on this will be covered in the Insurance section (section VII).

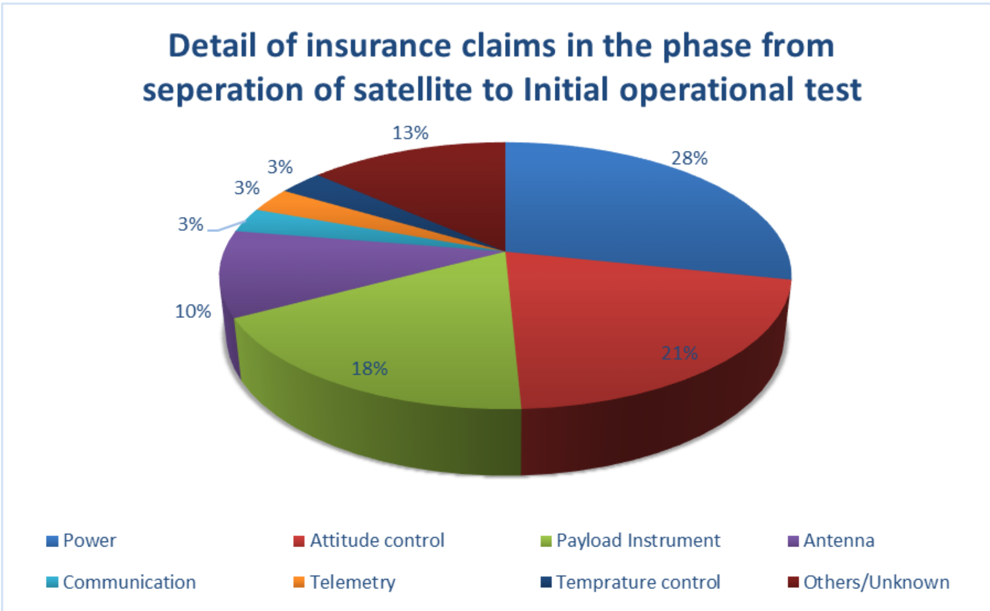

Figure 6 Insurance claim until initial operational test

From separation to the initial operational test, the main causes of failures are:

- Power: 28%
- Attitude control: 21%
- Payload instrument: 18%
- Antenna: 10%
- Others: 13%

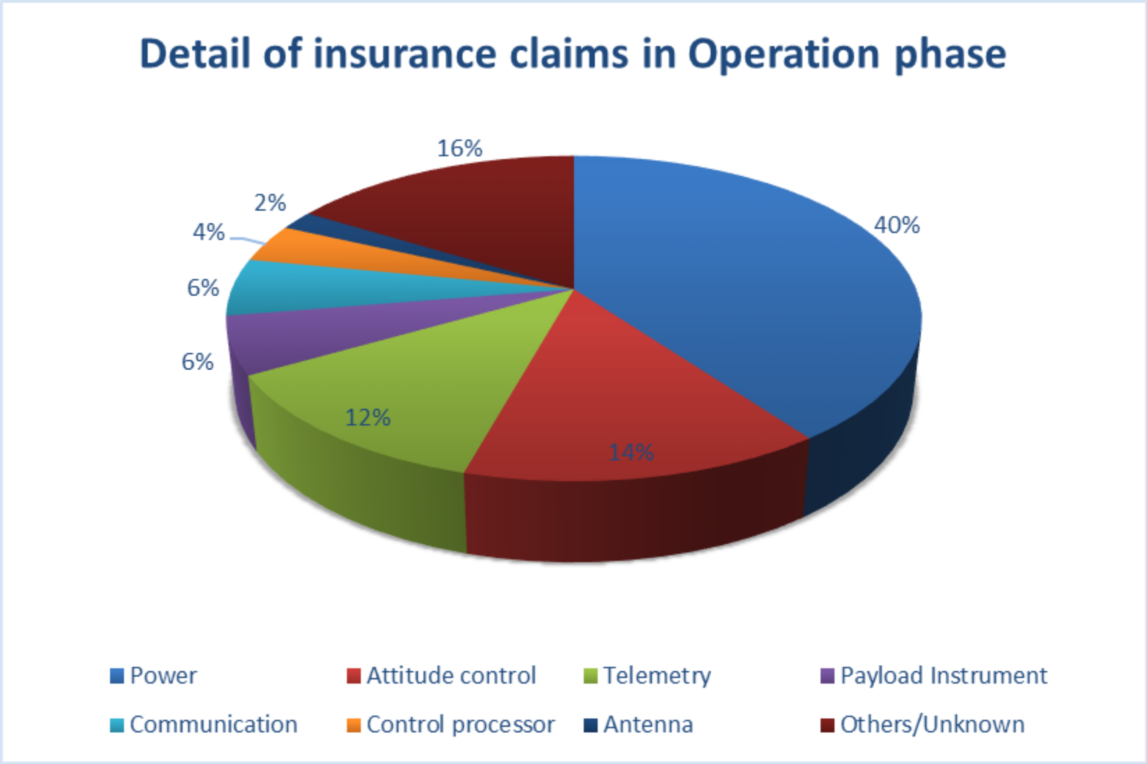

Figure 7 Insurance claims in operation phase

In operation phase, the main causes of failures are:

- Power: 40%
- Attitude control: 14%
- Telemetry: 12%
- Others: 16%

We can see that the main causes of failures during In-Orbit phase are power, attitude control, payload instrument and telemetry. If In-Orbit maintenance was possible, we can recover most of the satellites mentioned above. The current analysis is showing that the space business is accepting a 13% failure rate of its satellites.

For the 87% remaining portion of satellites, the current plan is that they are re-routed to the cemetery/graveyard orbit after the 15-year life span. However, those satellites are still operational and their life can be extended thanks to In-Orbit maintenance also. For example, as fuel depletion is the main cause of the end of life of a satellite, we could imagine a refuelling service that can help in extending the life of satellites.

There are several measures for protection against failures of satellites in space except In-Orbit maintenance. The most common one is purchasing insurance. Insurance covers various failures in satellites and compensates for it afterwards. In most cases this compensation is used for procuring another new satellite in order to replace the lost or broken satellite.

If insurance is considered as a post-measure against failure, a pre-measure is redundancy. The most common redundancy[9] is double redundancy. This is required as a mitigation so as to eliminate or reduce any failures and thus making the customers happy. Triple redundancy is limited due to limited weight of the satellite.

The main principles of double redundancy are the following:

- All components and wiring should be redundant.
- Single point failure should not affect the whole system.
- A function to switch between main and redundant system is especially important.

A double redundancy is needed when the reliability of one system is below the requested level. This extra redundancy acts as either a backup or to enhance performance. Some systems have systematic redundancy like computers of attitude control system, sensors of the attitude control system and actuators.

There could be some exceptions to redundancy if the system is meeting the safety criteria without a requirement of a redundancy in case of a large antenna, the detector sensor, and solar panels.

There are several ways of setting up redundancies. It can be done by setting redundancy to the same function by using devises which have completely different design, by controlling attitude, by using different attitude sensors and by transferring telemetry data to ground station via different routes.

Now that we have briefly explored the various aspects of In-Orbit maintenance, failures and redundancies for satellites, let's move to the next section on strategic analysis of the satellite industry. This section will help us understand how external factors affect In-Orbit maintenance.

[9] Takashi, Hamazaki. (2011). Dependability of satellite system and expectations to dependable VLSI. In: Dependable VLSI system Workshop 2011. Tokyo. Available at http://www.dvlsi.jst.go.jp/topics/11ws/11DVLSIWS%20hamasaki.pdf [Accessed on 11 04 2016].

VI. Strategic analysis of the satellite industry

For the purposes of this report we will be conducting a PESTLE analysis to identify challenges which In-Orbit maintenance faces and to assess the viability of In-Orbit maintenance as a solution for the space industry and in particular the satellite sector.

The PESTLE analysis of the satellite industry is illustrated and derived from the table below for the purposes of this project. Several of the ideas that appear in this section are further developed in subsequent sections. It is important to note that some of the items reappear in more than one section of the PESTLE analysis and therefore explored separately from each perspective.

Table 1: PESTLE analysis of the satellite industry

PESTLE analysis of the satellite industry		
P	**Political**	The current and potential influences from political pressures
E	**Economical**	The local, national and world economy impact
S	**Social**	The effects of changes in society
T	**Technological**	The effect of new and emerging technology
L	**Legal**	The effect of national and international legislation
E	**Environmental**	The local, national and world environmental issues

VI.I. Political

Most space programs are government funded. Most people might assume that governments have endless budgets to fund space programs, you will soon realize that this is not the case. All governments are susceptible to world economic pressures as they operate in an interlinked (globalization) environment (i.e. not in isolation). With that being said, all governments are duty bound to their citizens for social responsibility (this will be explored further in the social section of the PESTLE). So most space agencies are under pressure to reduce costs, this move opens a room for new innovative ideas to emerge. Agencies such as NASA have been experiencing this pressure for quite some time, hence they are working on many new innovative areas such as the refueling of satellites, nano-bots for the maintenance of satellites etc.

Governments across the globe have begun incentivizing citizens and companies that employ green strategies, so as to encourage others to follow suit. The main idea here is that governments are finding themselves more and more inclined to work towards a green future, so that they can sustain and secure our future resources.

What are the key political drivers of relevance? Worldwide, European and Government directives, funding council policies, national and local organizations' requirements, institutional policy etc.

VI.II. Economical

Although maintenance in the satellite industry is for the future, it requires radical innovation in order for it to be acceptable to the industry. The space industry is a cost driven sector, where, in order to get a satellite into orbit, hundreds of millions into billions of dollars would have been spent. Governments alone are not able to sustain these costs and so private sector players have immerged in the United States of America such as Orbital ATK who are planning to invest in this area.

Demands for low cost space solutions are on the rise for the space industry. What are the important economic factors? Funding mechanisms and streams, business and enterprise directives, internal funding models, budgetary restrictions and income generation targets.

Funding for maintenance in the satellite industry would have many knock on effects to the aerospace industry by supplying investments in and encouraging development of both existing and new technologies. Areas that could directly benefit from this project are satellite integrators, OEM's, robotics research, insurance, defense and launch companies.

For example, companies such as NASA and the European space agency are researching on the option of refueling satellites in orbit. Also attached to this are the environmental issues, the use of a more environmentally friendly fuel source and the management of space debris.

It is argued that to integrate maintenance into the satellite industry, there needs to be radical change in how future satellites are built. Maybe we can look into collaborations with other companies outside the space industry, where satellites would have to be built with easily removable parts and that are also easy to replace. We have seen that the trends in the satellite industry is moving towards smaller, cheaper satellite options. Options such as nano and cubic satellites, indicate the need for radical innovation in order to reduce pay load and extend the life of the satellite in order to realize maximum gain.

The first step in order to sell maintenance as a solution to the satellite industry would be to ensure that the manufacturing costs of the maintenance satellite is cheaper than the going rate in the market. This satellite has to demonstrate its versatility in terms of the options that it offers as a solution.

- **The Space Economy**

According to the Space Foundation report (2015): “The global space economy [10]overall was good in the year 2014. Comprised of launch and ground services, satellite manufacturing, satellite television and communications, government exploration, military spending, and other interests, the global space economy **grew by 9% in 2014**, reaching a total of $330 billion worldwide. In 2014, the commercial space activities made up 76% of the global space economy and grew by 9.7%. The remainder was composed of government investments in space, which experienced a combined growth of 7.3% in 2014”.

The U.S. government and military space budgets in aggregate comprised about 54% of space spending compared to the world governments in 2014. NASA’s budget, grew 4.6% over the 2013 budget, was 22% of what governments around the world invested in space in 2014. Non-U.S. government space spending grew 12.9%, outpacing space investment growth in the United States, as nations invested in new capabilities or expanded existing ones.

Revenue from commercial space products and services, which constituted more than a third of the global space economy, grew modestly—slightly less than 2.5%. Direct-to-home television services dominate this sector, making up more than three-quarters of the global commercial space products and services market in 2014.

The biggest growth in 2014 occurred in the commercial infrastructure and support industries sector, which also constitutes more than a third of overall global space revenues. Industries such as launch, ground stations and equipment, and satellite manufacturing were some of the mainstays that helped increase commercial infrastructure and support industry revenues to nearly 18% in 2014. High-value military satellite launches decreased, but the number of launches conducted in 2014 increased significantly, rising to levels not seen in more than a decade.

- **Stakeholder’s vision for satellite maintenance**

Ultimately, the new comers in the space industry are changing the deal. Companies such as SpaceX and Blue Origin are showing revolutionary and innovative ways to see space whereas such companies are new in the space business but came with an entrepreneurial spirit which shakes the old mindset. Space is becoming a playground for Internet billionaires who see it as a future business opportunity and provides a fearless view of new entrants. SpaceX is working on the reusable launcher technology that may reduce the price of the space ticket, dividing it by approximately ten times. The table below gives an approximation of cost per kilo that are being put in orbit.

[10] Space Foundation, (2015), The Space Report. Colorado Springs: p.2.

Table 2: Cost per kilo to be put in orbit

Technology	Cost per kilo ($/kilo)
Ariane	20000
New Ariane Safran launcher	14000
SpaceX (current techno.)	12500
SpaceX (targeted objective)	4000
Competition in the coming decade	Around 1000

The goals of SpaceX are extremely high. The table above shows the direction in which pricing for space launchers is heading. We can infer that by the year 2020, the price of launching would have reached around 10000$/kilo.

- **Stakeholder's vision against satellite maintenance**

Some space actors believe in the maintenance of satellites. It seems that the market is a very specific one and cannot be applied to any type of satellite. The types of satellite that are most likely relevant for this type of business are geostationary telecommunications satellites. They represent massive investment and are in orbit for around 15 years. Today's telecommunications satellite weight up to 6 tons and hosts numerous type of equipment. Two main factors are the most obvious to be considered when willing to extend the life of a satellite: the fuel remaining and the degradation of the solar panels. Solutions have been studied either to refill the fuel tank of the satellite or to extend the degrading performance of the solar panel.

We got the chance to interview the founder of a newly created company whose purpose is to service the solar panels of satellites and improve their output. His business case is based on the fact that the biggest players that are telecommunications companies, governments or defense are keeping satellites in space for very long period of time. Telecommunications satellites or defense satellites are expensive enough to allow the possibility of maintaining them. The first customer of this newly created company may be the DARPA (Defense Advanced Research Projects Agency, US).

Additionally, some companies have proposed services for extending the life of a satellite through:

- Satellite positioning and re-positioning: positioning from a low orbit to a higher orbit, or re-positioning of a satellite who has not enough fuel and is drifting in space,
- Space buses, carrying a set of satellites from a low orbit to a higher orbit,
- Propulsive capabilities, maintaining the satellite into a specific orbit,
- Relocation, moving a satellite into different orbit or into space cemetery for example,
- De-orbiting satellites, moving the satellite out of its orbit for collision avoidance for example,
- Rescue satellites, getting back satellites drifting in space at the correct location,

Vivisat[11] and Orbital ATK[12] are the two main private players in this field.

VI.III. Social

Sustainability has become part and parcel of our daily lives, Governments of the world have taken a lead in this aspect as indicated in the political section above. This has also sparked the emergence of non-governmental organizations such as “Green Peace” etc. which illustrate the importance of securing our future resources. Global warming and climate change have been around us for quite some time, COP conferences have kept a steady awareness going through government initiatives and these have begun to gain traction i.e. have meaningful and practical realization by the public.

In our days we have a more informed society, a society that takes responsibility with their pockets. A society that choses to buy brands that are environmentally friendly e.g. organic food, electric cars etc. Some consumers choose to buy products because of the corporate social responsibility that a particular organization is involved in, this further illustrates how informed today’s consumers are as compared to yester years.

Today’s organization’s derive their corporate social responsibility from the triple “P” or “PPP” strategies; which are: People, the Planet and the Profits. These triple “P’s” talk to the core and the foundation of sustainability. Organizations should be committed to sustainable development in order to eliminate negative externalities which have an impact on the environment.

These emerging organizational and social attitudes could mean or create the gap required in order to place maintenance as a future solution for the satellite industry.

What are the main societal and cultural aspects? Societal attitudes to education, particularly to government directives and employment opportunities. Also general life style changes, changes in population, distribution and demographic and the impact of different mixes of cultures.

The third world countries are experiencing a high rise in the middle class, standards of living are rising at a rapid rate. For example; the consumption of energy is linked to the living standards of a population and so the per capita consumption of energy per person is on the rise.

Today satellites amongst other applications are used for weather prediction, e.g. to focus events such as drought, flooding and so on. These events have a direct impact on the

[11] Vivisat, (2015). Vivisat’s Official Website. Available at: http://www.vivisat.com [Accessed on 08 04 2016]
[12] Orbital ATK, (2015). Orbital ATK’s Official Website. Available at: https://www.orbitalatk.com/ [Accessed on 08 04 2016]

society at large. One of the negative externalities that can be drawn from this is the rise in food costs as a result of the above mentioned events.

From interviews conducted, it is interesting to apprehend the opinions of different industry actors concerning space businesses have related to the maintenance topic. Once again, we distinguish two main trends on the business aspects of maintenance.

One vision, given by space agencies or governmental related institution, is that funding of maintenance project make sense. The research oriented mind of these actors, considers that, if the financial aspect is put aside, the maintenance of satellite will allow improvements in space equipment and devices and will also allow to a more sustainable satellite sector. From the interview, there is willingness to avoid sending “junk” to space. Furthermore, space institution especially in France are one of the first to work on the legal aspects of space debris and space sustainability (cf. section VI.VII.C).

From private manufacturer’s point of view; the considerations may be more business oriented, and the set of considered priorities are different. The business value of satellites and the selling opportunities are the first lever to decide whether maintenance is worth it or not? The consideration of space debris and space sustainability will be followed in accordance to the space laws put in place by space agencies and governments.

Private companies may accuse governments or space agencies to have unconsidered usage of their funding for purpose that are not economically viable. Projects whose purpose is to provide maintenance in space are still in a research phase, none have been realized yet, and these companies are sometimes being accused of financing such projects on huge public funding. On the other side, companies such as Orbital ATK have recently proven that this is incorrect by marketing a satellite for maintenance totally free of public funding.

VI.IV.Technological

Space exploration is highly dependent on R&D and the cost of technology remains a challenge in the space industry. In order for maintenance to take place there needs to be a collaborative effort amongst all space industry players including collaborations with institutions of higher learning e.g. universities. Radical/disruptive innovation is a must for this to happen.

There is a lot of coopetition in the satellite industry as the industry is huge according to its turnover but small in community in terms of the people employed by industry. In most large projects there is a lot of “cross pollination” / collaboration between companies. For example, in Europe there is a lot of companies who are cooperating/aligning on some levels and competing on others.

What this means is that; there can be no single entity or government that can pursue maintenance as a concept on their own. This will require extensive collaboration with all the industry players as mentioned above. Furthermore, it will be interesting to bring in companies or players that are from outside the satellite industry to inspire and spark thinking that is out of the box for permanent and lasting solutions.

Such technological shift may require the satellite industry to adapt to a standard, as the industry currently lacks in standardization. This may further ease the adaptation of new technologies. One of the offsets of standardization is that it can hinder innovation. Industry players should ensure that standardization is applied in such a way that innovation is not compromised.

From the set of interviews conducted, the vision of space given by some of the actors is that the future of satellites resides in their **miniaturization** and **democratization**. Miniaturization is already a trend which has started through the usage of very small satellites such as cubesat or nano-satellites. These very small satellites may not be sent in a geostationary orbit but in low-earth orbit, however, it shows a coming trend for the coming decades in the satellite industry. These small satellites allow to reduce the overall cost of the satellite and may be able to fulfill the same mission than much bigger one. Some tests have even been done sending cellphones into space in order to show feasibility and to demonstrate how accessible space has become. Cubesat can be ordered[13] online and a full payload can be assembled for around 100k$ which represents very light cost in the satellite industry.

These trends that are making space more and more accessible are related to the Moore's law. The technology allows to reduce the size of transistors in a circuit and therefore to reduce considerably the size of electronics by half every two years. Moreover, the usage of new materials, lighter and more efficient, adds to the space accessibility. Among the technology that represents a disruption for accessing space, the electric propulsion is a major one.

Electric propulsion principles have been known for years but the technology readiness level is now high enough to allow a broader usage in space. The principle of electric propulsion is, in a way, similar to the classic propulsion using propellant; some particles of matter have to be expelled in order to generate an opposite force that will push the satellite (the same way a balloon full of air is propelled on earth). In the case of electric propulsion, the fuel is Xenon (Xe, periodical element 54), the thrust is generated by ejecting Xenon ions, and this technology allows to drastically reduce the weight of the fuel by more than half compare to propellant. For example, reaching geostationary orbit for a big telecommunication satellite requires either 3 tons of fuel or 400 kilograms of Xenon. To sum-up the electric propulsion [14]shows great perspectives just looking at the mass

[13] CubeSatShop.com, (2015). Innovation Solution In Space's Official Website. Available at: http://www.cubesatshop.com/ [Accessed on 10 04 2016]
[14] NASA – Ion Propulsion (2015). National Aeronautics and Space Administration's Official Website. Available at: http://www.nasa.gov/centers/glenn/about/fs21grc.html [Accessed on 10 04 2016]

that can be saved; saving mass allows easier and cheaper launching, and cheaper movements in space regarding fuel consumption.

Even if electric propulsion represents great expectations for space movements and exploration, the thrust still has to be improved and the technology will become more mature. Nevertheless, it represents a great way to reduce the weight and then the overall cost of a satellite. Once again, the less the cost of a satellite, the less willing its operator will be in order to maintain or repair it. Indeed, it can be more cost effective to send a new one.

To conclude on satellite propulsion, it is also interesting to see that research is being done on another type of propulsion which may be even more efficient than the use of the electric propulsion. The race for space will also be won by the manufacturers that know how to provide the best engine and therefore, these manufacturers have already started to work on the technologies for the engines of the next 20 or 30 years.

Another lead that allows to think that maintaining satellite is not relevant, is related to the trend of the usage of **satellite's constellation**. Constellations consists in sending a set of similar satellites in space. It allows a standardization of devices and mass production. The production of satellites being part of a constellation may not be maintenance oriented as mass production will reduce production cost and then influence the willing to send new satellites than to repair them. Such constellations are usually used for LEO orbits. Maintenance in low-orbit is less likely to happen. Such satellites usually have shorter life and shorter missions at such orbits.

VI.V. Legal

VI.V.A. Introduction of space law

Space law is comprised of two layers, the first layer being **International Space Law** and the second being **National space law**. It is not all the countries that have national space law, the countries that have will be listed in the national space law section below.

- **International Space Law**

Space law can be described as the body of law governing space-related activities. Space law, much like general international law, comprises a variety of international agreements, treaties, conventions, and United Nations General Assembly resolutions as well as rules and regulations of international organizations.

The term "space law" is most often associated with the rules, principles and standards of international law appearing in the five international treaties and five sets of principles governing outer space which have been developed under the auspices of the United

Nations. In addition to these international instruments, many states have national legislation governing space-related activities"[15].

Space law addresses a variety of matters, such as, for example, the preservation of the space and Earth environment, liability for damages caused by space objects, the settlement of disputes, the rescue of astronauts, the sharing of information about potential dangers in outer space, the use of space-related technologies, and international cooperation. A number of fundamental principles guide the conduct of space activities, including the notion of space as the province of all humankind, the freedom of exploration and use of outer space by all states without discrimination, and the principle of non-appropriation of outer space.

- **National Space Law**

In addition to the implementation of international instruments of space law, states have developed national regulatory frameworks that governs the conduct of space-related activities.

States that have enacted national space legislations have taken a number of different approaches in dealing with national space activities. National space legislation can be contained in unified acts or a combination of national legal instruments. Furthermore, some States have adapted their national legal frameworks according to the specific needs and practical considerations of the range of space activities conducted and the level of involvement of non-governmental entities.

Issues which States may consider when enacting regulatory frameworks for national space activities range, for example, from the launch of objects into and their return from outer space, the operation of a launch or re-entry site and the operation and control of space objects in orbit to the design and manufacture of spacecraft, the application of space science and technology, and exploration activities and research.

National space-law making is also important in view of increasing participation of non-governmental entities in space activities, appropriate action at the national level is needed, in particular with respect to the authorization and supervision of space activities.

The Office for Outer Space Affairs[16] hosts a collection of national space laws and regulations which is based on submissions made by States. The texts are reproduced in the form and in the language(s) in which they were received from States, and were not formally edited and/or translated by the United Nations.

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[15] Space law (2016), United Nations Office for Outer Space Affairs' Official Website. Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/index.html. [Accessed on 04 04 2016]
[16] Space law (2016), United Nations Office for Outer Space Affairs' Official Website. Available at: http://www.unoosa.org/oosa/en/ourwork/spacelaw/index.html. [Accessed on 04 04 2016]

Below is the list of countries that have their own national outer space acts or law (National Law): Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, France, Germany, Japan, Kazakhstan, Netherland, Norway, Republic of Korea, Russian Federation, South Africa, Spain, Sweden, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America.

VI.V.B. Legal challenges

Although no new treaty has taken discourse since the last 5 treaties were established. Dramatic increase of space objects have triggered new discussions for sustainability of space activities. The below figure shows how congested space is currently.

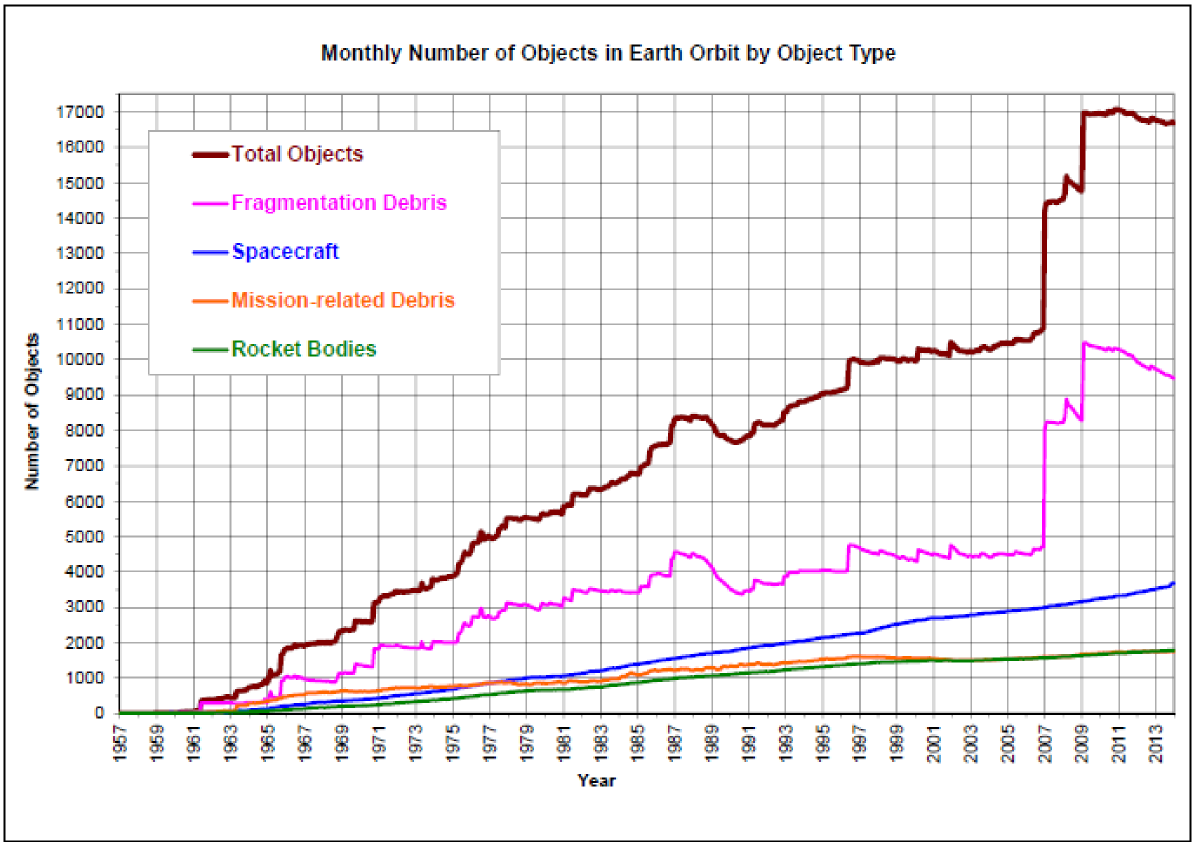

Figure 8 Monthly number of Objects in Earth Orbit by Object Type[17]

[17] National Aeronautics and Space Administration (2014). Orbital Debris Quarterly News, [online] Volume 20, Issues 1&2, p.14. Available at: http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html [Accessed 20 04 2016]

Various international bodies are considering this issue. When we consider In-Orbit maintenance of satellites, the following aspects are now being discussed in international bodies which are related to sustainability of space activities, namely:

- Mitigation of space debris
- Security of frequency
- Increase of human space travel flight
- Increase of satellites' asset value

VI.V.B.1. Mitigation of space debris

In the past two decades, the amount of space debris has been on the rise. Particularly, the demonstration experiment of ASAT (Anti satellite weapon) by China in 2007 and the collision of American and Russian satellites in 2009 caused significant increase of space debris. In fact, international society responded quickly to these incidents. Space fairing nations actively participated in establishing soft laws and their national laws whereas developing countries were less active because it seemed to them that this problem was caused by space fairing nations.

- **International law**

According to space treaties, there is no apparent laws against space debris. The main reason is that the promotion of space development was positioned as first priority until recently. In 2002, the Inter-Agency Space Debris Coordination Committee (IADC) established the first guideline against space debris. Additionally, United Nations Committee On Peaceful Uses of Outer Space (UN COPUOS) set a new agenda called Long Term Sustainability of Space Activity (LTSSA) in 2010 and established a special working group against mitigation of space debris with regret from two huge incidents mentioned before. Although the discussion in WG is still undergoing, the abstract of measurement for mitigation of space debris is mentioned in table below[18].

[18] Akira KATO. (2014). Current situation of space debris issue and global challenges, Study Reports for measurement of space debris. In: Koku to Uchu No. 731. Tokyo: P. 19-26.

Table 3: Main measurements against space debris

Major classification		Minor classification	Details
Parts emission		Control of parts emission	Parts which are planned to be remained in orbit after separation of satellites should not be emitted unless serious trouble
		Solid motor / Pyrotechnic composition	Rockets or satellites should be designed or operated to avoid emitting solid products of the combustion
Destruction in orbit		Prohibition of destruction	Destruction of rockets or satellites in orbit should be prohibited
		Accidents while operation	Accidents while operation of satellites should be prevented. Measurement should be taken quickly after detecting abnormality.
		Emission of remained propellant	Remained fuel in rockets or satellites should be removed.
Collision		Prevention of huge assets collision	The possibility of collision with other assets should be detected. And collision should be prevented
		Prevention of small assets collision	Estimation of the damage occurrence ratio which makes satellites impossible to dispose after collision with space debris should be evaluated
Disposal after finishing operation	GEO	Re-orbit distance	Satellites should be lifted in order to preserve within 200km above and below the GEO when finishing operation
	M/LEO	Shortening of the period in orbit	Satellites should be removed by various ways (being shortened its life in orbit, falling by gravity, being lifted to over 2,000km, being re-entered, being recovered) to preserve orbit below 2,000km.
		Transporting to graveyard orbit	
		Salvaging in orbit	
		Prevention of damage on the ground when re-entry	Risks of damaging the ground should be estimated before launching and operators have to make maximum efforts to avoid accidents

- **National laws**

There are few acts which require space actors to mitigate space debris. The aim of these acts is not to restrain space activities but to promote these activities. Among these acts, French law is one of the strictest laws which requests space actors to eliminate space debris[19]. It is highly probably believed that the number of governments will enact regulations against emitting space debris as strictly as French law to react against extreme global concern. Thus, French law is described underneath as an example of challenge against space debris.

In June 2008, the French Congress enacted “LOI F N°2008-518 du 3 juin 2008 relative aux opération spatiales”, in English “Space Operation Act”. In December 2010 and put it in force in December 2010. The article 5 in chapter 3 mentions that permission based on this law can be required to secure safety of persons and properties as well as protection of health and environment which especially includes space debris[20]. This act is valid for all French-nationality operators and operators which do business in France. According to this article, Centre National d'Etudes Spatiales (CNES) has to investigate compliance of all space assets from technical aspects before its launch or critical operation.

The aim of satellite maintenance is to extend satellites’ life. At the same time, maintaining satellites decrease the number of satellites abandoned and minimize space debris. In this sense, satellite maintenance is fully consistent to mitigation of space debris.

VI.V.B.2. Security of radio frequency

Geostationary orbit is not limitless space. If more and more satellites are deployed, the space which should be allocated for new satellites is getting gradually less. Furthermore, there is a radio frequency problem. Radio frequency is used for transmitting data (telemetry, space imageries, broadcasting, etc.) between satellites and ground stations. Radio frequency has the property of interfering harmfully if satellites which transmit signals with similar band come close to each other inadvertently. Consequently, radio frequency is also limited resources in space.

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[19] Sylvain MICHEL. and Ryota YOSHIDA. (2016). Interview CNES.

[20] CHAPITRE III : OBLIGATIONS DES TITULAIRES D'AUTORISATION
Article 5 Les autorisations délivrées en application de la présente loi peuvent être assorties de prescriptions édictées dans l'intérêt de la sécurité des personnes et des biens et de la protection de la santé publique et de l'environnement, notamment en vue de limiter les risques liés aux débris spatiaux. Ces prescriptions peuvent également avoir pour objet de protéger les intérêts de la défense nationale ou d'assurer le respect par la France de ses engagements internationaux.

International Telecommunication Union (ITU) which is the sole organization that is coordinating board-band of radio frequency. Through ITU, countries which wants to launch satellites negotiate with others to secure radio frequency and avoid harmful interference. However, the reality is “first come first served”. The country applies the position of a satellite in GEO and the allocation of radio frequency to ITU. Then, ITU registers in its list which is called Master International Frequency Register (MIFR) after technical qualification. This system caused two main problems. First problem is “Paper satellites” which is being solved currently. Problem of paper satellites is that countries recklessly over-apply radio frequency to ITU and sell or lease that rights of frequency to other countries or companies. However, ITU has made a rule of time bar against unused frequency. The second problem is lack of ITU’s leadership. ITU did not take enough leadership for international coordination and has fully relies on countries concerned. Therefore, ITU is not expected to be a coordination board with strong initiative. Security of radio frequency will be a big problem in the future with high probability.

If satellite maintenance is realized, operators are able to utilize frequency longer because they can use their satellites longer. This fact makes a lot of benefit to satellites operators and its mother countries because ensuring new frequency for a new satellite is getting more and more difficult. Customers and their countries can avoid complicated and political struggles for frequency.

VI.V.B.3. Increase of human space “travel” flight

International Civil Aviation Organization (ICAO) announced that they would start to establish guidelines for commercial space tourism[21] in order to respond to a high probability of space transportation on commercial and regular basis across sub orbit. They also set a deadline of discussion until 2019. They hold a symposium in annual basis to inspire industry and regulatory communities. This challenge just started and ICAO call on countries to share any information related to this topic[22]. This is due to the fact that there is no existing legislation for space transportation. Therefore, the regulation especially regarding safety of spaceplane will be formed rapidly in the next few years.

The challenge in ICAO has just started and the influence of the guideline cannot be estimated. Thus, their movement should be paid attention to on a continuous basis. However, it is not probable that this guideline will have an influence on the satellite maintenance business.

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[21] Andy PASZTOR. (2016). U.N. Aviation Arm on Mission to Craft Guidelines for Space Tourism. THE WALL STREET JOURNAL, [online], Available at: http://www.wsj.com/articles/u-n-aviation-arm-on-mission-to-craft-guidelines-for-space-tourism-1458030598 [Accessed on 31 03 2016].
[22] Space Transportation (2016), International Civil Aviation Organization (ICAO)’s Official Website. Availble at: http://www4.icao.int/space [Accessed on 31 03 2016].

VI.V.B.4. Increase of satellites' asset value

When purchasing an expensive product, consumer has to finance a lot of capital. There are some options for consumers to purchase that in less expensive money such as lending money by using another product as collateral or leasing the product. Furthermore, if the consumer purchases the product especially across border, this financing problem becomes more serious. Financing rules or priority of collateral can be sometimes different between the two or more countries. To avoid this difference and to promote international trades by securing stability of rule, Cape Town convention was enacted. Thanks to the aircraft protocol to this convention, financing for purchasing aircraft is very famous and promoted for aviation sector nowadays.

In the Cape Town convention, another challenge being taken is to adopt the best practices from the aviation sector into the space sector especially when purchasing satellites. That is called the Space protocol to the Cape Town convention. Space protocol was adopted in March 2012. This protocol enables countries including companies in them to set interest to their space assets such as satellites. That interest is registered for providing evidence of claims and proof of its international interest [23]. This protocol provides consumers stability and promotes commercial transaction when procurement of space assets. What is the tragedy of this protocol is that no country has ratified this yet so that this is not come into force. The estimated reason of this situation is there are still a few points to be considered. The most significant point is which organization should supervise the transaction cycle. It is said that ITU is the most appropriate organization but ITU still vacillates. Although there are still issues to be overcome, this protocol will be emphasized in the near future. The commercial transaction of satellites is done on a more frequently basis.

Satellite maintenance will contribute to enhance the value of space assets because this service can expand the life of satellites. Customer can finance for their space assets in longer period or set mortgage for theirs longer than now. More to this, satellite maintenance may create new business model such as second hand satellites. In other words transaction of satellites in orbit will be more frequent.

[23] PROTOCOL TO THE CONVENTION ON INTERNATIONAL INTERESTS IN MOBILE EQUIPMENT ON MATTERS SPECIFIC TO SPACE ASSETS (2016), International Institute for the Unification of Private Law (UNIDROIT)'s Official Website. Availble at: http://www.unidroit.org/instruments/security-interests/space-protocol [Accessed on 01 04 2016].

VI.VI.Summary of legal challenges

Space law has not matured over time. At this moment there are only few laws to be obeyed and space industries are not strictly regulated. However, some new rules regarding sustainability of space activities are being considered. It has become apparent that in the creation of such laws, the commercial sector is not a participant. The commercial sector cannot be ignored any longer as they are putting up huge investments into the industry. The commercial sector investments are slowly catching up to that of governments and this has a direct impact on global space activities.

VI.VII. Environmental

Environmental legislation still remains a challenge for the space industry. There are a few legislations in place e.g. terrestrial uses, but if you look at the issue of space debris, how retired satellites are handled/managed, there is still room for improvement in this regard. Increased focus on the sustainability of the industry, steps to meet the green criteria is no longer an option but a must.

As the satellite industry moves towards a maintenance, this may spark new developments in the legal framework and change the structure of how spacecraft are insured at present.

VI.VII.A. Satellite maintenance and space debris

The mission of satellite maintenance aims to extend the life of a satellite. Looking at the topic with a broader angle, extending the life of satellites in space can be done in different ways. The maintenance of space itself may actually contribute to the welfare of the fleet of satellites that are in orbit. In a clean space we will have less collisions. Any collision in space is often fatal or has a very huge impact on the satellite mission. This could also result in the reduction of insurance premiums for satellites.

Debris are generated by previous collisions that occurred in space and these debris may collide and damage satellites in operation generating even more debris. Today, the concept of cleaning space debris is still new as satellite operators' do not face many collisions. However, space orbits may become more and more crowded, with the democratization of space and the trend of satellites constellations.

The miniaturization of satellites with cubesats and nanosats and recent examples of sending cellular phones, shows what space agencies may call as "junk" is contributing to the space debris problem. Cheaper materials, miniaturization of satellite, increasing accessibility may open doors to launch satellites that are not reliable enough to be sent to space. Based on the fact that space law is permissive enough to let unreliable devices reach space that may become dangerous debris for other satellites.

Space agencies have a very strong will to limit access to launching such types of unreliable satellites. Most of these types of satellites are sent in LEO and may not be able to reach higher orbits such as GEO. Another issue is that LEO satellites can be sent into the atmosphere in order to disintegrate and not trigger any collision on their orbit at the end of their life. Such type of disintegration could cause pollution of the atmosphere as the burnt parts of the satellites are ultimately falling on earth through rains for example.

VI.VII.B. Missions for space debris

Some manufacturers are marketing solutions for removing space debris. These solutions include sending spacecraft to either capture debris using nets or robotic arms allowing to pick up drifting satellites. Airbus Defense and Space is already promoting such type of innovative clean solutions. The maintenance of space is becoming an important topic as the access to space is becoming easier than before and will get even easier in the future. Additionally, general public awareness is increasing regarding pollution and clean companies. Therefore, companies may enter the business of space maintenance as it is an easy to promote social responsibility towards the environment. One way to differentiate from others.

VI.VII.C. From satellite maintenance to space maintenance

The unique characteristics of GEO makes it the most crowded orbit around earth. In January 2002 there were 900 reported objects in GEO of which only approximately 28% were controlled, operational satellites. Cleaning space may have a direct impact on the amount of satellite maintenance required in space. Reducing the number of debris allows less collisions. Considering that a single collision can generate thousands of additional debris, reducing the number of debris by cleaning space could be a way to reduce the maintenance required in space.

Another point of view, could be to say that satellite maintenance companies may not want to reduce the number of space debris as they represent an indirect way to create the need of satellite maintenance through collisions.

The next section will help us to understand the various types of space insurance coverage and the affect In-Orbit maintenance will have on insurance.

VII. Insurance

Risks are involved in every industry and the satellite industry is no different. Space insurance is a specially designed insurance tailored for the satellite industry. Space insurance primarily covers four risks, namely:

1. **Launching coverage:** includes launch vehicles, payloads (satellites) and the launch operation. The period for the insurance coverage is from when the engines are ignited until the satellite separates from the launch vehicle.

2. **In-Orbit coverage:** includes In-Orbit failure, improper positioning of the satellite In-Orbit. As of now satellite repair or maintenance is not possible hence the coverage is more like a guarantee.

3. **Third party liabilities:** includes damage caused due to the launch vehicle or the spacecraft.

4. **Pre-launch Insurance coverage:** includes damages caused to satellites and its components during the manufacturing process, in transit to the launch site, etc. until the time the launch engines are ignited.

Based on our analysis both from the research on space insurance and from the interviews conducted we see that the risk coverage for In-orbit related damages may evolve if In-Orbit maintenance becomes a reality. The change might not be immediate but would evolve gradually as In-Orbit maintenance matures both demand wise and technology wise.

As part of the evolution we feel potential partnerships between insurance companies and In-Orbit maintenance providers as a possibility. Apart from having mutual benefits, this partnership could help reduce insurance premiums for satellite operators. The mutual benefit would lie in profit sharing between the two parties.

In addition to the analysis above, the next section through a detailed market analysis will enable us to understand if In-Orbit maintenance is a feasible solution.

VIII. Market analysis

In this section we will focus on the evolution of the satellite industry, the current and future trends in the market, the market for satellite maintenance, challenges and cost/price analysis.

VIII.I. The Space Business: Demand and Supply

Demand and supply are one of the fundamental forces that shape the nature of every business. It is important to understand how these forces interact. A bad estimation of demand and supply by a business will either result in a lot of money in hand (overestimation) or losses (underestimation) which is why companies spend a lot of money in estimating demand and supply.

The formal definition of demand in economics is the consumer's desire and willingness to pay a price for a specific good or service. Holding all other parameters constant, the price of a good or a service increases as the demand decreases and vice versa. Supply on the other hand is the quantity of good or service an individual or a group of individual is prepared to sell for a price.

Very simply put price acts like a yoke of an aircraft which determines the action of buyers and sellers. When price increases, the quantity demanded falls and the quantity supplied rises. When prices fall, the quantity demanded increases and the quantity supplied falls.

Business decisions largely depend on the analysis of supply and demand in the satellite industry.

VIII.I.A. Price elasticity

One of the main parameters that drive the cost is the cost incurred for the launch of satellites. According to a paper written by Hertzfield, Williamson and Peter, although it's from 2005, conclude that the price elasticity of demand of LEO (Low Earth Orbit) satellites is >1.0 ad launches for GEO (GEOsynchronous) satellites have elasticity of <0.5.[24] The price is measured per kilo for a specified orbit.

[24] Hertzfeld, H. R., Williamson, R. A., Peter, N. (2005), Launch Vehicles: An Economic Perspective. Space Policy Institute, The George Washington University. Available at: http://www.gwu.edu/~spi/assets/docs/NASA%20L.Vehicle%20Study%20V-5.pdf [Accessed on 01 04 2016].

It is evident from the current trends of lower launch costs with startup companies such as SpaceX planning to reduce costs by 30% this year and new startups such as Blue Origin who have also successfully tested the reuse of launch vehicles hence cutting costs.

The American aerospace company Rocket Lab offering rocket research and development are working on launch vehicles specifically made for small satellites (nano, cubic and peso satellites).

The 2005 report concludes that the oversupply of the launch vehicle market resulted in significant price drops, in some cases as much as 50%. [25] This price signal would normally cause the demand to increase; however, the demand was stable. One explanation for this lack of “demand response” is the long lead times associated with developing new payloads and building spacecraft. The fact that there is a cheaper launch available doesn’t mean that there will be spacecraft ready for launch. [26]

VIII.I.B. Cost and Price

There is always a distinction between cost and price and understanding this concept is not always that easy in space business. Space projects generally have a long lead time and mostly incur costs overrun, and hence are usually bound by cost-plus contracts. These contracts are reimbursement contracts where the contractor is reimbursed for the costs incurred and are paid a fixed percentage as profit. This lead to cost overruns in space related projects.

A point to be noted in this aspect, commercial players where the first ones to do away with such contracts and put a fixed price bidding process in place. In this case satellite manufacturers assume cost overruns.

The cost and price outlook for private businesses and governments differ. Governments are not concerned about cost overruns and hence subsidize cost intensive projects for other priorities such as social welfare and national security.

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[25] Hertzfeld, H. R., Williamson, R. A., Peter, N. (2005), Launch Vehicles: An Economic Perspective. Washington D.C. Space Policy Institute, The George Washington University. Available at: http://www.gwu. edu/~spi/assets/docs/NASA%20L.Vehicle%20Study%20V-5.pdf [Accessed on 01 04 2016].

[26] Ozgur Gurtuna (2013). Fundamentals of space business and economics, International Space University. Strasbourg: Springer.

VIII.I.C. “Space Value Chain”

In the below figure we have defined a value chain process of the industry. At every phase shown in the below process an additional value is created. At some point of time every actor part of this value chain is dependent on the other. The below value chain identified is for all satellite applications. This gives us a better overview of the market and the various segments of focus in the space business.

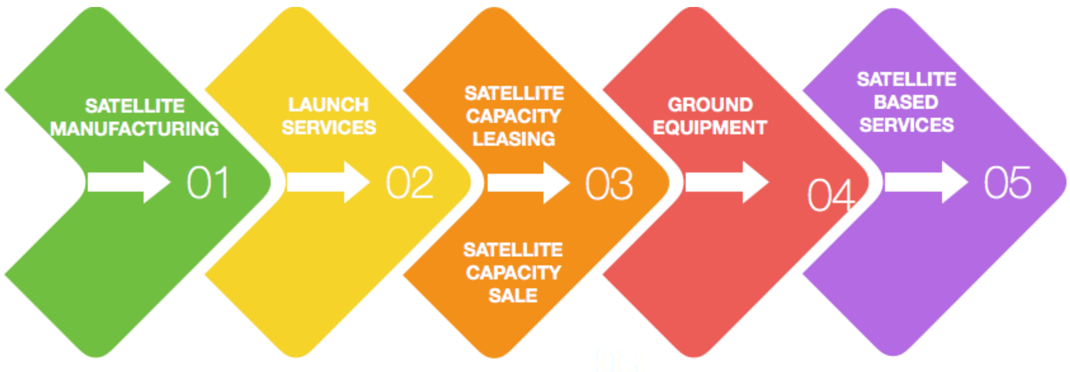

Figure 9 Satellite value chain

VIII.I.C.1. Satellite Manufacturing

Satellite manufacturers build satellites based on the requirements of satellite operators. The satellite program includes from construction to procurement of components from sub – contractors, to assembly, to testing of individual parts to the complete testing of the satellite as a whole. Satellite manufacturing is one of the most complex tasks and takes about 2-3 years to manufacture one satellite. Satellites once launched are supposed to work 24/7 365 days a year. On average a satellites lifetime lasts for around 10-15 years. Hence the complexity in production. Also, satellites are built with the highest redundancy among other products as maintenance of satellites in orbit is not an option (until now). Some of the major satellite manufacturers are Boeing Defence, Space and Security, Lockheed Martin, Airbus Defence and Space, Orbital ATK and Thales Alenia Space.

VIII.I.C.2. Launch Services

Launch companies have two activities, manufacture launch vehicles and launching satellites and other payloads. They start manufacturing once the contracts are signed. Also during the manufacturing process, designs are shared between the satellite manufacturers and the launch company. The launch company’s activities start from manufacturing the launch vehicle to launching the satellite until separation after which the satellite manufacturer takes control. As mentioned earlier, new startups like SpaceX, Rocket Labs and Blue Origin are disrupting the market with low cost launch services. SpaceX launched their Falcon 9 rocket into space on 8th April 2016 and after the first stage delivered the payload, the vehicle descended back to Earth and landed on a drone ship in the Atlantic Ocean. In the next few years with re-useable rockets, the launch process would further go down. Other commercial launch companies are Arianespace, ISRO, Orbital ATK and United launch alliance.

VIII.I.C.3. Satellite capacity sale and lease

Once the satellites are launched successfully and the satellite manufacturers test the satellites and hand over the services to satellite operators, they assign capacity(bandwidth) and coverage to different customers through sale or lease options. Major players in this area are Intelsat and Eutelsat.

VIII.I.C.4. Ground Equipment

Ground equipment are used to relay information to satellites and also act as receivers. Ground equipment companies manufacture specialized equipment such as satellite dishes, mobile terminals, control stations, etc. Ground equipment are also one of the most revenue generating sectors.

VIII.I.C.5. Satellite based services

Satellites are designed for various applications. They provide communication services, location based services to remote sensing. Governments and research institutions use remote sensing based services for earth observation and other related research pertaining to our planet. With the growing number of mobile applications satellite based services have diversified and evolved over the years. One such example of such growth is “One Web’s” plan to launch a build a constellation of satellites covering the whole of earth to provide internet based services to everyone around the world.

VIII.II. Space applications: The Four Gems

Satellite applications have grown significantly in the past decade. Initially we had space telecom, navigation and remote sensing, and now we have a new trend for space application using Big Data. These applications are critical to the value chain as the growth in these areas have a direct impact on the various actors in the value chain. Hence the area of interest.

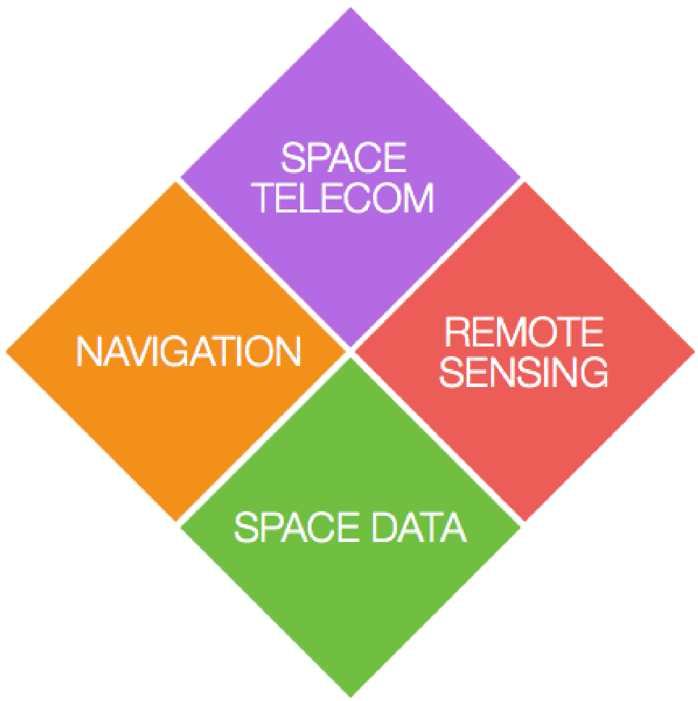

Figure 10 The four gems

VIII.II.A.

The private sector has played a critical and evolving role since the early 1990s. With the dotcom boom, the telecom sector grew in a phenomenal rate. Space telecom has always been innovative and disruptive compared to other sectors. These days everything is connected. Every device has mobile connectivity. As the number of devices embedded with mobile connectivity increases, the space telecom industry's revenue will increase with the amount of demand and opportunity the market has to offer.

VIII.II.A.1. How important is the space telecom sector for Europe?

Communication satellites contribute to more than 50% of the European satellite manufacturing industry revenues. Around 85 % of European satellite manufacturing industries sales ae generated from exports and private customers. As part of the communication satellite value chain a lot of Small Medium Enterprises (SMEs) are active and develop around this value chain. Telecommunications are one of main customers for European launch services. Out of the 64 satellites launched in the past 3 years, 38 of them were for telecommunications and 1 for the European government. Hence the telecom sector plays a vital role in the European satellite industry. [27]

VIII.II.B.

Global Navigation Satellite Systems (GNSS) provide accurate positioning, navigation other related information all over the globe. GNSS are usually a set of constellation of satellites.

We have only two navigation systems which offer global coverage:

- The US Global Positioning System (GPS)
- The Russian GLONASS system

Other countries too have their own set of navigation systems:

- European Galileo
- Indian Regional Navigation Satellite System (IRNSS)
- Japanese Quasi-Zenith Satellite System (QZSS)

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[27] ASD-EUROSPACE. (2015). Telecommunications, Position Paper [online]. Available at: http://eurospace.org/Data/Sites/1/pdf/positionpapers/spacetelecomspositionpaper2015-draftfinal.pdf [Accessed on 15 03 2016]

This technology was initially used by the military and eventually has spread for civil and private applications such as car navigation. With the increase number of smart phones and a huge ecosystem of applications using location based services GNSS plays an important role in the Business to Business and Business to Customer domains.

VIII.II.C.

Remote sensing also known as Earth Observation (EO) is mainly used for monitoring earth and gathering information through imagery and sensors. The data collected is used by both military and government. Private players too have entered the market to provide analysis of the data collected. Moreover, information collected through remote sensing is used by universities and research institutes.

Having earth observation satellites for remote sensing has always been an important strategic objective for every country. This is one of the reasons why a large number of earth observation/ remote sensing satellites are owned by governments (civilian and military).

VIII.II.D.

In the current era data is the next oil in terms of treasure. Just like oil, if not properly refined has no value, data if not processed has no value. Big data is one of the current trends and will continue to trend in the years to come. Moreover, data from space has become an import source of information especially, data from remote sensing satellites

(Earth Observation). Pico bytes of data are transferred from satellites these days and making sense of such large volumes of data is a challenge.

VIII.III. Market Overview for In-Orbit maintenance

VIII.III.A. Market analysis for In-Orbit maintenance

The below analysis is performed using the Union of Concerned Scientists (USC) satellite database as of 31st December 2015[28]. The type of data available in this database spans from mass, power, expected lifetime and orbit of every satellite to the launch date, information on satellite owners, operators and manufacturers.

According to the database there are around 1381 satellites in operation. This does not include spy satellites. Also, it is not easy to get information on Russian and Chinese satellites, the current database does include all of them. The Russian and Chinese satellites part of the UN registry are part of the database.

Where would In-Orbit maintenance fit in the value chain?

Based on the value chain described in section VIII.I.C In-Orbit Maintenance would be part of the "Satellite Service providers" pool. This would be a breakthrough in the value chain.

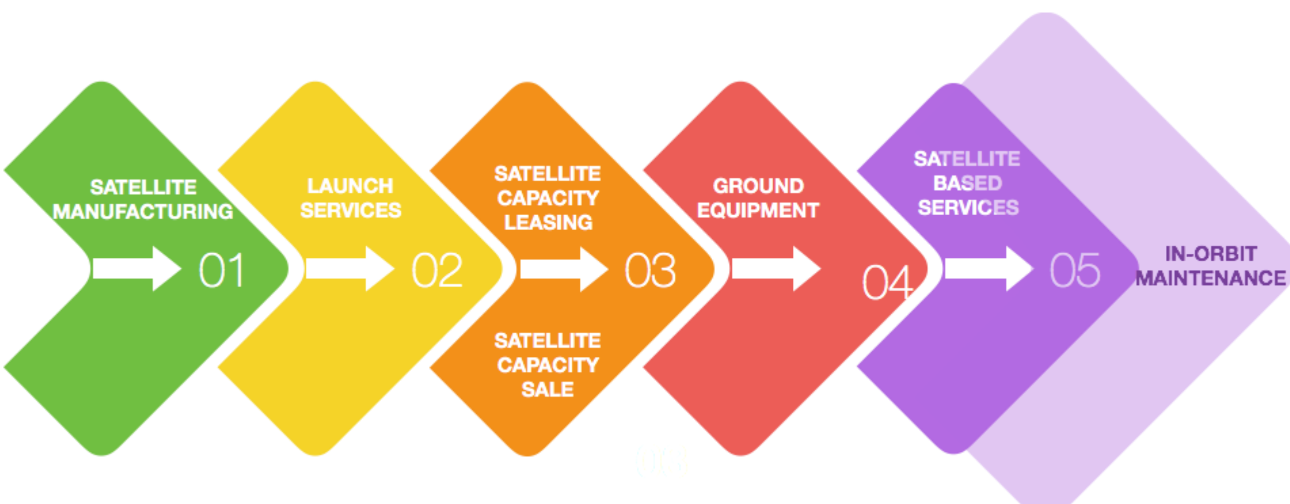

Figure 11 In-Orbit maintenance in the global value chain

[28] USC Satellite Database, Union of Concerned Scientists, Available at: http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.Vw8Uh5N969s [Accessed 15 03 2016]

VIII.III.A.1. Analysis based on USC database

- **Satellite Classification based on sectors**

Commercial satellites dominate the market with a total of 536 satellites in operation. The rest of the market includes military satellites and civil satellites which are 263 and 96 respectively.

Others include satellites which are shared between military/government, government/civil, military/civil, commercial/government and commercial/government/civil.

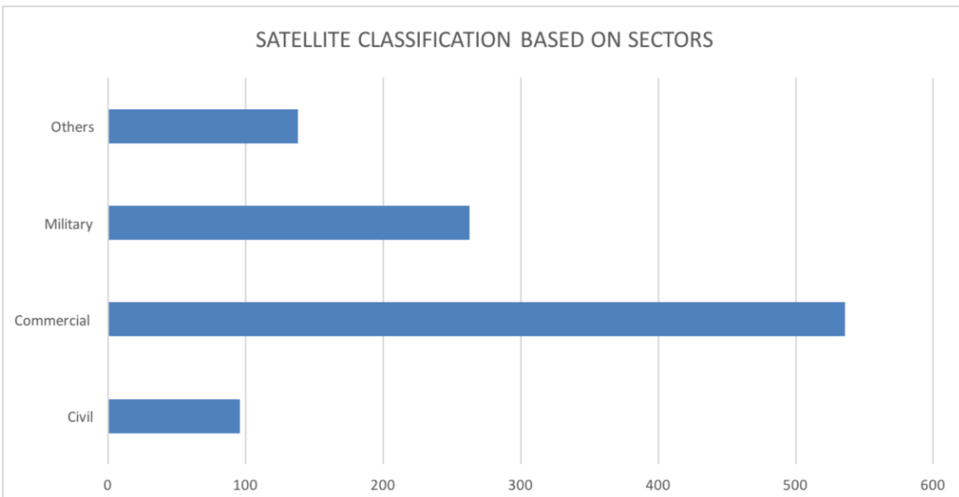

Figure 12 Satellite classification based on sectors (based on USC database)

- **Satellite distribution based on countries**

With the democratization of space and collaboration between countries over the years in the space sector, more than 40 countries are capable of launching satellites. Over the last decade a lot of developing countries have entered the space market. The pie chart below shows the classification of satellites owned by operators based on countries:

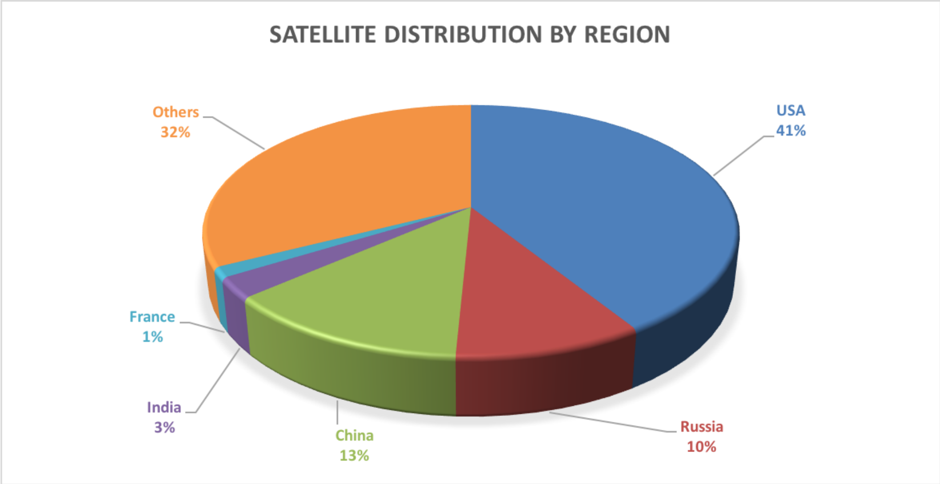

Figure 13 Satellite distribution by region (based on USC database)

- **Satellite Classification based on orbit type**

Based on the orbit type, the number of satellites for LEO, MEO, GEO and Elliptical are as shown below:

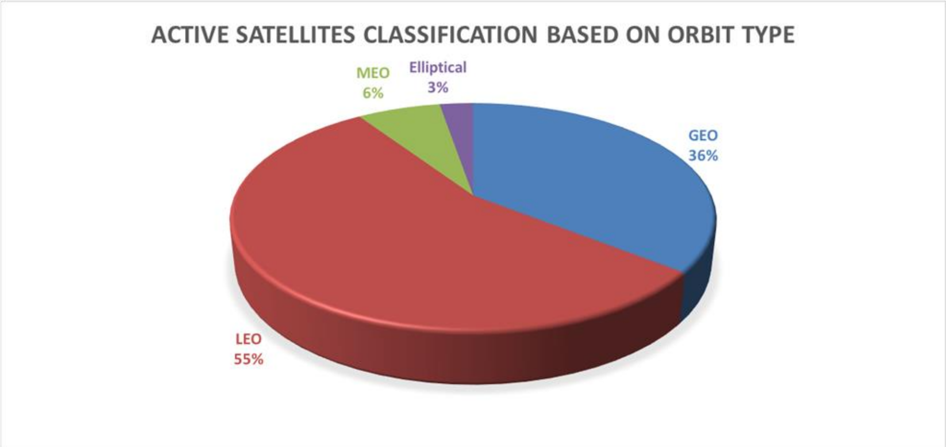

Figure 14 Active satellites classification based on orbit type (based on USC database)

Out of which we have 303 satellites in GEO, 24 in MEO and 206 in LEO that are commercial satellites:

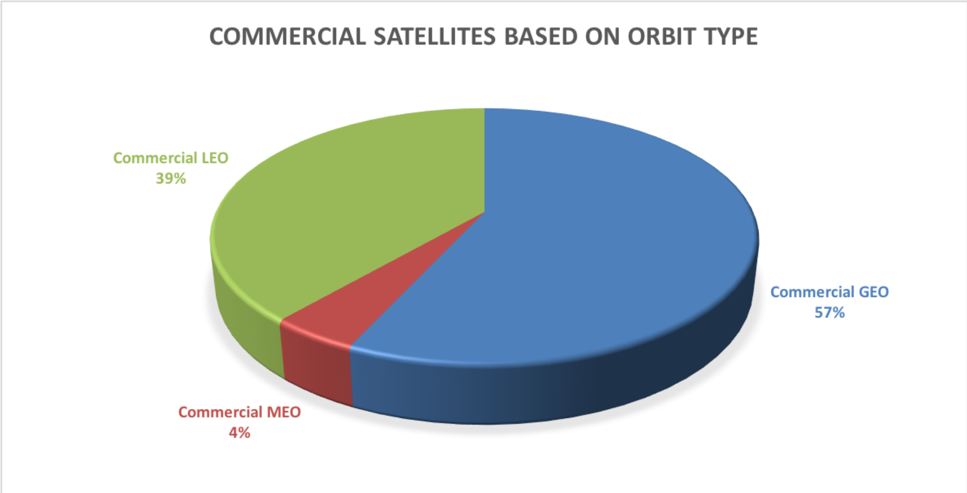

Figure 15 Commercial satellites based on orbit type (based on USC database)

And based on the above numbers, the target market for In-Orbit maintenance would be Communication satellites which are mainly in GEO and LEO orbits, 303 and 112 satellites respectively:

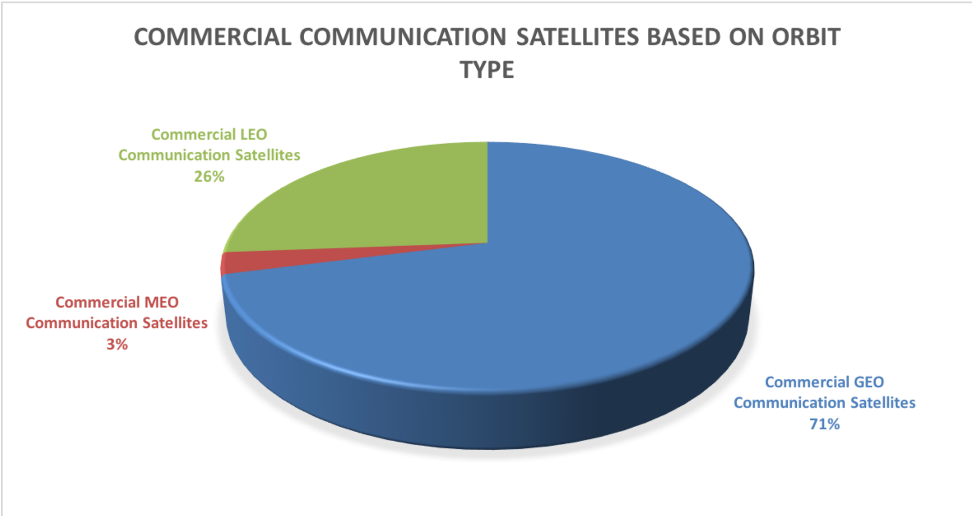

Figure 16 Commercial communication satellites based on orbit type (based on USC database)

VIII.III.A.2. Potential market for In-Orbit Maintenance

Commercial Communication Satellites GEO: Based on the above analysis we can see that there are around 303 commercial communication satellites in GEO orbit. On further analysis from the database, out of 303 satellites we have 86 which are close to end of life or have up to 5 years until end of life which can be serviced and have their life extended. Also, satellites still under operation, which have surpassed their end of life account for 46 satellites. Based on these numbers we have a positive market for In-Orbit maintenance.

Commercial Communication Satellites LEO: Commercial communications satellites in the LEO orbit account for around 112 satellites in total out of which on further analysis, 38 satellites have surpassed their end of life and are still under operation, and 20 of them are close to their end of life.

Government owned Communication Satellites GEO: Servicing government owned satellites is generally not considered as a viable option because budget is not a constraint. But we have a different view on this. Government owned satellites are funded using tax payer's money. Extending the life of government owned satellites by 5 years through In-Orbit maintenance would drastically reduce the capital invested for replacing satellites and hence save tax-payer's money in the process. A public opinion on this factor can be a driver for governments to consider In-Orbit maintenance as a cost effective measure. There are around 400 satellites owned by governments out of which 48 are communication satellites in GEO orbits.

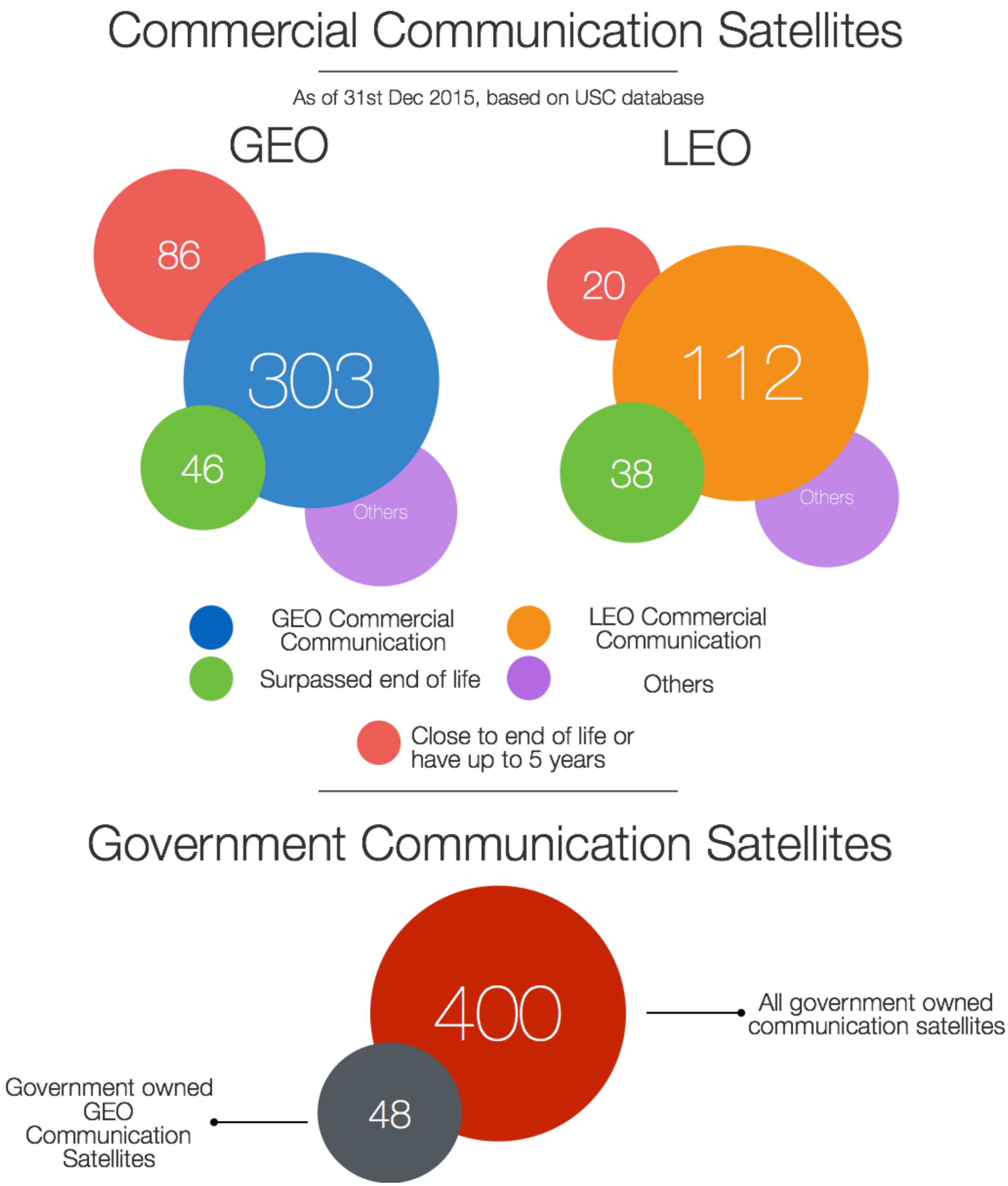

Figure 17 Potential market for In-Orbit maintenance

VIII.III.B. Technology and demand readiness levels analysis

Technology Readiness Levels (TRL) are a type of measurement system used to assess the maturity level of a particular technology. Demand Readiness Levels (DRL) are also a type of measurement from the side of market demand. There are nine levels. Level 1 is the lowest and level 9 is the highest.

We believe these two scales are one of essential factors to judge in which approach, either technology push or market pull[29]. Explaining more precisely, TRL would show us both investment forecast and technology maturing speed through visualizing current technology maturing level. It is said that investment curve which is also connected to technology developing speed is related to progress of TRL. Whereas DRL would show whether the direction of R&D for In-Orbit maintenance need to be corrected. These indicators would answer these following questions. Should R&D of this technology be worth continuing as it is? Should the way of diffusion be just the proposal of solution with continuous R&D result? Or as the consequence of market demand, should R&D of this technology be concentrated on some specific areas or considered collaboration with different ideas from different actors?

VIII.III.B.1. Technology Readiness Level

We tried to rate TRL referring to NASA's criteria. We set our own criteria of TRL for In-Orbit maintenance in addition to NASA's criteria. "Table 4: Criteria of TRL and DRL" shows the definition of TRL and its criteria. According to NASA, TRL is rated only when that criteria is cleared. In other words, that level is not raised during middle of its development. Then, we corrected all information regarding technology of In-Orbit maintenance. Finally, TRL of In-Orbit maintenance is rated.

We believe TLR for In-Orbit maintenance is high, in several reasons although whole service is not demonstrated in space. It is the fact that there are several services for In-Orbit maintenance such as refueling, replacing the broken equipment (repairing). Compared to various services, activity of In-Orbit maintenance is very simple, launching maintaining satellite, rendezvous docking to target satellite, and providing services. Most of individual key technologies have been already adopted to actual spacecraft currently. For example, European automated transfer vehicle to the International Space Station are capable of docking itself onto the International Space Station (ISS). Canadian robotic arm

[29] Florin Paun. (2011). Demand Readiness Level" (DRL), a new tool to hybridize Market Pull and Technology Push approaches, HAL, [online], P.3. Available at: https://halshs.archives-ouvertes.fr/halshs-00565048 [Accessed 15 03 2016].

enables astronauts to build ISS itself or replace equipment. Further to this, according to interviews we conducted for this study, no one expressed the difficulty of technology. The most significant event which had an impact on our analysis was the announcement by Vivisat. This company with Orbital ATK plans to launch first In-Orbit maintenance mission satellite in 2018[30]. This news means Vivisat completed tests by using a prototype and started to manufacture an actual model of maintaining satellite.

Taking these backgrounds into consideration, we conclude TRL of In-Orbit maintenance is rated level 6. Moreover, this level is expected to be raised steadily after first demonstration because each technology is already matured.

VIII.III.B.2. Demand Readiness Level

In terms of DRL, the methodology is the same as TRL. Since DRL is a quite new concept, clear criteria have not been set. Thus we conjectured our own criteria based on definition of DRL (cf. "Table 4: Criteria of TRL and DRL").

We assumed DRL of In-Orbit maintenance is not high whereas conception of this has been discussed for a long time. We figured out from interview that there is no one who did not know about the idea of In-Orbit maintenance. This means the conception widely seeped into space actors. However; only few people insisted on the demand towards In-Orbit maintenance based on their own views, that a lot of compensation against broken satellites has been already well prepared. In fact, satellite operators commonly purchase insurance for satellites. This insurance would perfectly cover another launch fee or cost of manufacturing another satellite when the original satellite is failed. It is also said that numerous redundancy and careful examination of the satellite dramatically decrease the rate of failure in space. According to interview, most of the satellite manufacturing cost is occupied by labor cost for examination. Since satellites cannot be repaired in space, all failures are simulated through various examination on the ground. In addition to this, numerous redundancy reduces the failure completely. These substitutions against In-Orbit maintenance are more general and more practical. The only ray of hope is early adopter's reflection towards this service. In April 2016, annual report for investors of SES, European satellite operator, expressed its intention to invest In-Orbit maintenance[31]. In

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[30] Via satellite. (2016). Access Intelligence, LLC's Official Website, ViviSat Launching First MEV for In-Orbit Servicing in 2018 [online] Available at: http://www.satellitetoday.com/technology/2016/03/24/vivisat-launching-first-mev-for-In-Orbit-servicing-in-2018/ [Accessed 03 04 2016].

[31] Annual Report 2015, (2015). Annual Report / Interim Statement, SES Official Website, [online] P.31. Available at: http://www.ses.com/annual-report [Accessed 03 04 2016].

the same month, Orbital ATK signs Intelsat as first satellite servicing customer[32]. Some companies stated to be aware of effectiveness of In-Orbit maintenance.

Therefore, in conclusion, DRL of In-Orbit maintenance is rated the lowest, level 2. We judged conception of this service is widely spread but no obvious needs exist.

Table 4: Criteria of TRL and DRL

TRL	DESCRIPTION TRL	TRL CRITERIA of In-Orbit maintenance	DRL CRITERIA of In-Orbit maintenance	DESCRIPTION DRL	DRL
9	Market certification and sales authorization	Commercialisation, Marketing, Promotion	Recognition of probability towards In-Orbit maintenance among space actors	Occurrence of a feeling "something is missing"	1
8	Product Industrialization	A industrial prototype is finally conducted and production run	Identification of need towards In-Orbit maintenance	Identification of a specific need	2
7	Industrial Prototype and first flight	The prototype is modified and improved for industrialisation.	Concept of In-Orbit maintenance is infiltrated to space actors.	Identification of the expected functionalities for the new Product/Service	3
6	Field demonstration for the whole system	A prototype of final candidate is demonstrated in the field.	Market starts to recognize that In-Orbit maintenance is better than launching new satellites	Quantification of the expected functionalities	4
5	Technology development	One candidate is selected and tested in relevant environment. At this stage, development is completed.	Demand of In-Orbit maintenance is growing in the market	Identification of the systemic capabilities (including the project leadership)	5
4	Laboratory demonstration	A few candidates are manufactured as breadboard models. They are verified in laboratory environment. Design of software should be done at this stage.	Concept of In-Orbit maintenance is published and market exactly responds to and widely knows the service	Translation of the expected functionalities into needed capabilities to build the response	6
3	Research to prove feasibility	Develop analytical or experimental models or functions for proof of concept. We will make a lot of tries and errors. Through this level, we narrow down candidates to a few. Structural calculation of materials	Securing appropriate resources corresponding to TRL below 6	Definition of the necessary and sufficient competencies and resources	7

[32] Jeff Foust. (2016). Orbital ATK signs Intelsat as first satellite servicing customer. SPACE NEWS, [online], Available at: http://spacenews.com/orbital-atk-signs-intelsat-as-first-satellite-servicing-customer/ [Accessed on 12 04 2016]

		and design of software are managed simultaneously.			
2	Applied research	Concept of the product is designed based on fundamental principles.	Securing appropriate resources for industrialization	Identification of the Experts possessing the competencies	8
1	Fundamental research	Fundamental principles for the product is observed. We keep around 10 ideas at this stage.	In-Orbit maintenance is released to the market	Building the adapted answer to the expressed need on the market	9

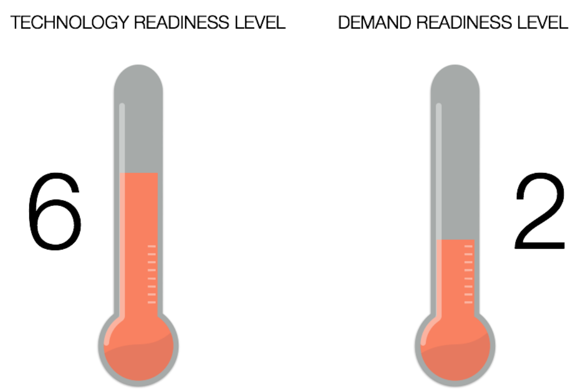

Figure 18 TRL and DRL of satellite maintenance

VIII.III.C. In-Orbit maintenance done in the past

As we explore the events which defined the possibility for maintenance, we came to a conclusion that “the need for maintenance” arose due to mission critical requirements. This was more due to a technology “pull” situation.

ESA started a servicing project in the 1990s through a program called GSV (Geostationary Servicing Vehicle). DARPA launched its own program called RSGS (Robotic Servicing of Geosynchronous Satellites). Both programs have proven the feasibility of such missions and the possible business outcome for satellite maintenance.

One of them was the servicing of the Hubble space telescope. The Hubble space telescope had a total of 4 missions the latest executed in May 2009. These missions involved human interaction in servicing.

The International Space Station (ISS), one of the largest artificial satellites was serviced many times since its inception.

In 2013, Robotic Refueling Mission (RRM) performed the first test on board the ISS. This was done with the help of remotely controlled robots that were able to work through valves and wires and successfully transferred ethanol (the fuel) from a mock servicer to a mock satellite.[33]

VIII.III.D. Future trends

According to the Satellite Today article published on March 18, 2015, ViviSat a joint venture supported by Orbital ATK and US Space signed a contract with one of the key customers for its Mission Extension Vehicles (MEVs). In early 2014, ViviSat had 4 customers who were interested in this mission.[34]

Latest on this was a report from Satellite Today and published in the "Via Satellite" magazine on 13th April 2016, which states that Orbital ATK has signed its first service agreement with Intelsat to extend the life of one of its satellite by 5 years. The MEV 1 satellite manufactured by Orbital ATK will be launched in 2018 and the service mission will begin by 2019.

"*Given the size of our satellite fleet, any technology that enhances our In-Orbit flexibility allows us to be more responsive to our customers, such as extending the life of a healthy satellite so that it can be deployed for a late-breaking opportunity at another orbital location or maintaining service continuity before the arrival of new technology. We have actively supported In-Orbit servicing from its inception, and are proud to pioneer with Orbital ATK on this game-changing innovation*," said Stephen Spengler, CEO of Intelsat.[35]

What is more interesting is another customer SES also a satellite fleet operator has shown willingness to invest in In-Orbit maintenance.[36]

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[33] Nola Redd. (2014). Re-fuelling the Future. SPACE.com, [Online] Available at: http://www.space.com/25259-robotic-satellite-servicing-nasa-technology.html [Accessed 15 03 2016]
[34] Via satellite. (2016). Access Intelligence, LLC's Official Website, New Contracts add fuel to In-orbit servicing advocates. [Online] Available at: http://www.satellitetoday.com/technology/2015/03/18/new-contracts-add-fuel-to-In-Orbit-servicing-advocates/ [Accessed 15 03 2016].
[35] Via satellite. (2016). Access Intelligence, LLC's Official Website, Intelsat announces 5 year In-Orbit servicing agreement with Orbital ATK. [Online] Available at: http://www.satellitetoday.com/technology/2016/04/13/intelsat-announces-five-year-In-Orbit-servicing-agreement-with-orbital-atk/ [Accessed 13 04 2016].
[36] Peter Selding. (2016). SES ready to invest in In-Orbit Servicing and reusable rockets. SPACE NEWS, [Online] Available at: http://spacenews.com/ses-ready-to-invest-in-reusable-rockets-in-orbit-satellite-servicing/ [Accessed 08 04 2016]

VIII.III.E. Customer pull approach

With likes of Orbital ATK and SES showing interest and investing in In-Orbit maintenance, we are already seeing a trend of a market pull or customer pull approach. This customer pull strategy would be the main driver for In-Orbit maintenance.

There are various market drivers which would influence maintenance of satellites, namely:

1. **Price:** With the current trends, we could expect other players entering the market and hence competition would help reduce costs.
2. **Value for money:** The argument between revenue generation against the cost of maintenance for the period of life extension.
3. **Niche Markets:** Services specific to the commercial communication satellites
4. **Diversification:** Future diversification of services such as – space debris management, satellite refurbishment and hence create a secondhand satellite market.
5. **Financing:** Through Public Private Partnerships where space agencies and governments fund the mission and the In-Orbit maintenance company is responsible for operations.

VIII.III.F. Conclusion of market analysis

Based on the analysis performed and the current and future trends, we can see that In-Orbit Maintenance has a positive future. With Intelsat and SES taking the step to accommodate maintenance, we can anticipate more customers (satellite operators) realizing the value In-Orbit maintenance can bring to their business.

As we have seen on the readiness level in terms of technology and demand, TRL is around 6 and DRL is 2 for In-Orbit maintenance. Low level of DRL must be a high obstacle against In-Orbit maintenance. This feature is very similar to A380 case in aviation sector which Airbus is having big difficulty for sales. Everybody believed huge capacity of the fleet and high technology for fulfilling passengers would have to reach customers' heart forecast high demand. However, A380 was not an exact product what customers' wanted. We think that the cause of struggle in Airbus is also this miss match between technological self-satisfaction and market demand. In-Orbit maintenance would not attract much attention from market forever unless any measures in order to raise DRL would be carried out.

To begin with, In-Orbit maintenance companies could begin with refueling and relocation as services. One of the challenges would be standardization of satellite components, but again as observed from SESs intention of providing service friendly components, it is just a matter of time that standardized service friendly satellites are produced.

Further, diversification of In-Orbit services such as space debris management could be one of the future products satellite maintenance has to offer.

IX. Financial analysis

IX.I. Purpose and tools

Satellite Operators should benefit greatly from the ability to perform In-Orbit maintenance. If the typical life of a satellite is now 15 years but refueling or replacement of the attitude control system could be accomplished which would add 5 additional years of life. The purpose of financial analysis for In-Orbit maintenance is to understand how profitable this kind of satellite maintenance would bring and the break-even based on our market analysis and result of our research. This analysis is applied common cost benefit analysis, net present value (NPV).

IX.II. Assumptions

It was very difficult for us to get actual figures through this study because this kind of information is normally classified and the price completely depends on customer specifications. Thus, in order to calculate NPV, we assumed following things taking as much actual number as possible into consideration;

- Cost of targeted satellite and its breakdown;
- Service period;
- Number of maintenance equipment;
- Percentage of serviceable satellites and percentage of worth maintaining satellites;
- Cost of maintaining satellite and its breakdown;
- Margin and service price;
- WACC.

(1) Cost of targeted satellite and its breakdown

Market analysis showed target customers of satellite maintenance would be communication satellite in GEO and LEO. To be simplified this analysis and considering the current trend that most of communication satellites are deployed in GEO and size of these satellites is increasing because of transponders onboard, we decided to focus on only **communication satellite in GEO with big bus system**. These satellites equip 50-60 channels/transponders on it and asset value is very high.

According to the information provided by Satconsult, standard price of the satellite is shown in “Table 5: Cost structure of a standard communication satellite with big bus system”.

Table 5: Cost structure of a standard communication satellite with big bus system

		Percentage to satellite price	Satellites with 50-60 channels
Satellite price (A)=(B)+(C)+(D)+(L)		-	220M$
Breakdown	Design and program management (B)	5%	11M$
	Payload and antennas (C)	40%	88M$
	Satellite bus and platform (D)=(E)+(F)+(G)+(H)+(I)+(J)+(K)	50%	110M$
	Structural subsystem (E)	10%	22M$
	Telemetry Tracking subsystem (F)	3%	6.6M$
	Power subsystem (G)	11%	24.2M$
	Thermal control subsystem (H)	4%	8.8M$
	Attitude and orbit control subsystem (I)	5%	11M$
	Engineering item (J)	12%	26.4M$
	Direct labor cost (K)	5%	11M$
	Ground telemetry tracking and control (L)	5%	11M$
Launch fee (M)		-	90-110M$
Total (N)=(A)+(M)		-	310-330M$

(2) Service period

Service period is determined by technology obsolescence of equipment and customer’s interest. Technology evolves very fast in our present age. After a certain period of time the customer may not be interested anymore in maintaining a satellite whereas he can acquire a more advanced one for a price cheaper than the cost of maintaining the old one.

Normally development and demonstration of new satellite by a space agency takes 7 years (5 years for development + 2 years for demonstration), so we also assumed **7 years** is the period in which the maintenance equipment will be superior to the ones to be maintained.

(3) Percentage of maintainable satellites and percentage of worth maintaining satellites

We estimate that all satellites cannot be maintained because of various reasons such as that equipment is hardly damaged. It is natural that some percentages should be multiplied to calculate the number of orders. Thus, we decided to use 20% as the percentage of maintainable satellites and 40% as the percentage of worth maintaining satellites.

(4) Number of maintenance equipment

This number means how many customers would demand satellite maintenance and which services they demand in 7 years which is assumed in previous point (2). According to failure rate based on insurance claims which is introduced in section **Erreur ! Source du renvoi introuvable.**, as well as our market analysis which 86 satellites are close to end of life, refueling or replacement of attitude control and replacement of power subsystem would have potentially highest demand. Based on this assumption and percentages which is identified previous point (3), number of order would be **9 times for refueling or replacement of attitude control system and once in replacement for power subsystem** in 7 years. Although it is natural to take capacity of launcher into account, we cannot access to the information of equipment weight. Thus we do not consider the weight of satellite in this case.

(5) Cost of maintaining satellite and its breakdown

There must be new elemental technologies to be developed for In-Orbit maintenance. However, again we could not get clues for that unfortunately. Thus, we calculate the cost of maintaining satellite on the presupposition that this satellite consists of following three structures.

- Maintenance satellite itself
  This is calculated by using cost of communication satellite which is mentioned in previous point (1).

- Service equipment
  This is calculated by using both the cost of equipment in communication satellite mentioned in point (1) and the number of equipment for replacement onboard mentioned in point (4)

- Robotic arm

This is one of the critical technology of replacing or removing equipment. We adopted the cost of Japanese small arm which is equipped in Japanese experimental module in ISS because of appropriate size for maintenance[37].

The cost of maintaining satellite is shown in "Table 6: Cost structure of a maintaining satellite".

Table 6: Cost structure of a maintaining satellite

			Cost
Satellite price (A)=(B)+(C)+(K)+(L)+(O)			548.7M$
Breakdown	Design and program management (B)		7.5M$
	Satellite bus and platform (C)=(D)+(E)+(F)+(G)+(H)+(I)+(J)		121M$
		Structural subsystem (D)	22M$
		Telemetry Tracking subsystem (E)	6.6M$
		Power subsystem (F)	24.2M$
		Thermal control subsystem (G)	8.8M$
		Attitude and orbit control subsystem (H)	11M$
		Engineering item (I)	26.4M$
		Direct labor cost (J)	11M$
	Ground telemetry tracking and control (K)		11M$
	Maintenance equipment (L)=(M)+(N)		101.2M$
		Power subsystem * 1 (M)	24.2M$
		Attitude and orbit control subsystem * 7 (N)	77M$
	Development of Robotic arm (O)		308M$
Launch fee (P)			110M$
Total			658.7M$

(6) Margin and service price

We think that constant amount of order would be expected if the price of satellite maintenance is set at least lower than the launching cost of a new satellite in order to replace a broken satellite. Thus, we set the price of refueling or replacement of attitude control system at about half price of current cost for launching a new satellite taking future

[37] The Evaluation Committee on Incorporated Administrative Agencies (2012). P.3. Overview of Japan Aerospace Exploration Agency Financial Report in 2012 [online] 2012 Ministry of Education, Culture, Sports, Science and Technology JAPAN. Available at: http://www.mext.go.jp/b_menu/shingi/dokuritu/005/005j/giji/__icsFiles/afieldfile/2013/10/30/1340906_15.pdf [Accessed 12 04 2016].

cost reduction of launch cost into account. However, satellite maintenance can be set ultimately high margin, 320%, in this case.

(7) Margin and service price

WACC means Weighted Average Cost of Capital and is essential to calculate present value. We use **WACC of Orbital ATK**[38], 2.47%, for calculation.

(8) Tax rate

This service is provided in space where no country cannot declare its territory and which is positioned as an international zone. Thus, we believe provision of this service is not taxed.

IX.III. Net Present Value analysis

Based on NPV analysis, investment to maintaining satellite can be collected within 5 years (See table below).

[38] Orbital ATK Inc, (2016). Bloomberg Official Website. [online] Available at: http://www.bloomberg.com/quote/OA:US [Accessed 20 04 2016].

Table 7: NPV Analysis of satellite maintenance

Year	2017	2018	2019	2020	2021	2022	2023	2024
Time Line	0	1	2	3	4	5	6	7
Number of Demand for power		1.4	1.4	1.4	1.4	1.4	1.4	1.4
Number of Demand for attitude control				1				
Cost for power		24.2	24.2	24.2	24.2	24.2	24.2	24.2
Cost for attitude control	0	11	11	11	11	11	11	11
Margin	0	320%	320%	320%	320%	320%	320%	320%
List Price for power replacement		142.296	142.296	142.296	142.296	142.296	142.296	142.296
List Price for attitude control replacement/r	0	0	0	46.2	0	0	0	0
Revenue/year	0	142.296	142.296	188.496	142.296	142.296	142.296	142.296
Net Income	0.00	142.30	142.30	188.50	142.30	142.30	142.30	142.30
Investment	658.7	0	0	0	0	0	0	0
Capital Expenditure		7.5	7.5	7.5	7.5	7.5	7.5	7.5
Working Capital	658.7	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Cash Flow	-658.70	134.80	134.80	181.00	134.80	134.80	134.80	134.80
Tax rate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net Cash Flow	-658.70	134.80	134.80	181.00	134.80	134.80	134.80	134.80
Discount Rate	2.47%	2.47%	2.47%	2.47%	2.47%	2.47%	2.47%	2.47%
PV	-658.70	131.5467942	128.3759092	168.2204415	122.2615958	119.314527	116.4384961	113.6317909
			NPV	Payback time				
NPV discounted Cash Flow			241.09	4y+11m				

IX.IV. Findings based on financial analysis

Through this analysis, several things should be considered in the future.

First, this result is based on surprisingly high margin rate. If satellite maintenance cannot keep this rate, this business would be failed. Furthermore, technology advances very fast in our present age. A 15-year-old satellite may not be competitive to operate in the face of newer technology even if the life of the satellite is expanded 5 years more. Therefore, it would be necessary to think of another value added service in addition to simple satellite maintenance such as replacement and “improvement of equipment” as if a personal computer is added new memories and improved.

Second, consumer products are essentially not repairable. They are disposable items, since the cost of repair is so much greater than the cost to manufacture a new unit. This is due to the great efficiencies of mass production compared to the low productivity of trouble shooting a single unit.

IX.V. The case of the Hubble space telescope

The single maintenance that has been done in space is related to the repair of the Hubble space telescope. Looking into this example, gives information on how difficult and costly can maintenance can be in space.

The multiple repairs of the Hubble Space Telescope were amazing accomplishments that has brought enormous new knowledge to mankind. However, no one has seriously presented the costs of those repairs. As the Hubble approaches the end of its remarkable life, the numbers are: Total of cost in today's dollars of approximately $10 billion[39] was expended. In addition, NASA indicates the direct costs of the 5 Space Shuttle repair missions was approximately 5 x $450 million[40] = about $2.3 billion without any amortization of the Shuttle development. Although most of the repairs were aimed partially to enhance the capability of the Hubble and scientists in the world appreciated its accuracy of observation, we thought through this study that Space Shuttle could not prove profitability of repairing space objects in space. This is also one of the causes of stopping Space Shuttle program in addition to some failures and loss of great lives.

[39] FINAL REPORT James Webb Space Telescope Independent Comprehensive Review Panel (2010). National Aeronautics and Space Administration's Official Website. Available at: http://www.nasa.gov/pdf/499224main_JWST-ICRP_Report-FINAL.pdf [Accessed on 25 04 2016]
[40] Space Shuttle and International Space Station (2016). National Aeronautics and Space Administration's Official Website. Available at: http://www.nasa.gov/centers/kennedy/about/information/shuttle_faq.html#10 [Accessed on 25 04 2016].

X. Conclusion

Through this academic project we had the chance to focus on an innovative topic, In-Orbit maintenance, that was rarely explored before. The different phases of this project allowed us to provide a constructive answer to the business of satellite maintenance. The project required professional knowledge on the space domain and we acquired this knowledge through research and the set of interviews that were conducted. Though the research of this topic was done in span of a few months and the fact that interviews were sometimes contradictory to the analysis we continued to keep focus on the challenging topic of satellite maintenance. Based on this we have provided findings and recommendations to make satellite maintenance a reality.

Among the interesting findings we discovered new trends given by new players. This provided us a lot of information. Traditional space actors are being challenged by the new entrants, who are changing the rules of the satellite industry. They have different business models, different technologies and innovative ideas that reshape the satellite industry. Furthermore, the mindset of the legacy players related to space operations is being challenged to adapt to new ways of approaching space business. Ultimately we discovered that the way these players approach space is either strongly economically oriented or strongly research oriented due to the fact that the ultimate purpose of these players is different regarding space use.

X.I. Findings

- **Technological barrier**

Technology is one of the cornerstone to break or avoid the barriers related to space access. Technology is progressing rapidly. Improvements in technology are seen to have opposite impact on satellite maintenance, either encouraging it or refraining it. Industrial players have the vision that miniaturization allowed by technology will give the ability to manufacturers to build cheap, small and disposable satellite that do not need any maintenance. On the other side, miniaturization could have a positive impact as it allows to embed for functionalities with less mass on a satellite which is a good argument for satellite maintenance. Having smaller and cheaper devices ease the access to space, which can be called as space democratization. Cubesats or nano-satellites are devices that will compete in the coming years with the previous huge, heavy and costly satellites. The learning curves for these smaller devices is still at its starting point however once mature the technology will enable important market growth. An important finding through this project was related to standardization of technologies embedded in satellites. Currently, no specific standard has been established. So, satellite's physical interfaces are easily interchangeable and maintainable. The legacy satellites are not built to be repairable. They have embedded redundancies to avoid failures. They are designed and manufactured with precise specifications of a single customer. Hence unique.

- **Space debris**

The ultimate goal through satellite maintenance is to reduce the number of debris by having more operational satellites. Space debris are a “dangerous and increasing trend” that can have dramatic impacts on satellite business. Satellite traffic control, which is the final deorbit of a satellite into graveyard orbit, is one of the way to limit the number of debris on a specific orbit. Another way of limiting space debris could be done through space tax. Today, there is no fine for letting passivated satellite on a normal orbit. The operator is only charged for international blame. Setting a fine would make sure all operators move back their satellite into the graveyard orbit. Additionally, licensing of satellites for maintenance purposes is not yet properly defined by the authorities. Those willing to address this market are faced with challenges of licensing. Hence there would be an evolution in providing license dedicated to In-Orbit maintenance satellites. Globally, the legislation tries to secure the sustainability of space activity which can only be achieved by setting proper rules in space.

- **Economical factors**

From an economical perspective, the space sector has a steady growth. This trend is going to continue in the future. Additionally, to this, space maintenance activities may benefit from the growth of global space business. Among the main financial factors impacting the industry is the cost reduction of launches. Moreover, cheaper technology allows to optimize payload and rockets components and this will also benefit the whole satellite industry. Ultimately satellite maintenance will encourage satellite operators to consider the right trade-off between the redundancies embedded in a satellite and its cost. By decreasing the level of redundancy, the satellite becomes cheaper and the result of the tradeoff opens the door to future maintenance activities. This tradeoff would also bare an impact on insurance premium as it is proportional to the cost of the satellite.

- **Potential market for In-Orbit maintenance**

All the aspects described above, make sense only if a potential market exists and allows the expansion of satellite maintenance. Based on the market analysis, we foresee the following three main potential markets are government and commercial satellite in GEO and commercial communication satellite in LEO. Moreover, through our research, some indirect application may trigger potential business for satellite maintenance. We identified four important space applications which are driving the industry. These applications “the four gems” as we call them according to the business value they represent. These four applications indirectly add value to the whole satellite value chain which will also increase the value of satellite maintenance.

X.II. Recommendations

- **Standardization**

Through this research project, we wanted to identify the different actions that could be taken to improve the viability of the business activities related to satellite maintenance. The first requirement that would greatly help this type of business is **standardization**. Standardization, done through an industrial technology push strategy, will enable satellites to be maintained more easily and more efficiently through the usage of common features or interfaces. This technological push can be seen from the satellite operators angle for ex. SES have designed “refueling” connectors for their old satellites to accommodate service friendly equipment for In-Orbit maintenance companies. They are also implementing built it connectors in their future satellites to ensure easy serving.

- **Provision of value added service**

Moreover, in order to keep attracting customers, we also discovered that another value added service should be considered in addition to simple satellite maintenance. For example, improving functionality of equipment would probably give a favorable impression in terms of design scalability and security of radio frequency. Operators can improve their communication capacity/speed while using existing radio frequency and need not negotiate to acquire new one.

- **Creation of a second-hand market**

The other opportunity for In-Orbit maintenance to develop could be related to **the creation of a second-hand market**. Life-extended satellites represent enough value so they can be sold to new customers, to developing countries as an example. A second-hand market would represent additional potential customers for satellite maintenance.

- **Evolution of space regulation**

Finally, **the evolution of the regulation** regarding space activities is a main lever to expand or block business development. On one side, satellite maintenance should be done in accordance to the existing or future space laws. On the other side, space laws may evolve to encourage satellite maintenance.

- **Increasing space awareness**

As **space awareness** increases among the players, space debris management will be the next big initiative. The ultimate goal is to make space a more sustainable environment. In-Orbit maintenance will play an important role in promoting this sustainability. Life extension and refurbishment of satellites will help control space debris over a period of time. Moreover, as part of diversification of In-Orbit maintenance, space debris management would be an opportunity to make space more sustainable for the near future.

What's next?

From the analysis provided in the above report, it is inevitable that In-Orbit maintenance will be a reality in the near future. As seen in other industries, such as aviation, maintenance has evolved into the predictive stage. Predictive maintenance could be the next step for the satellite industry.

XI. Appendix

XI.I. Details of financial analysis

How to estimate the number of maintenance equipment onboard.

Step 1: Calculation of probability of failures based on statistics of insurance claims and USC database

Phase	Failure of subsystem	Cases between 1968-2014	Probability of occurrence*1	Estimated cases in 5 years*2	Estimated number of customers*3
Detail of insurance claims in Launch phase	Failure of launch	47	2%	2,238741993	0,179099359
Detail of insurance claims in Launch phase	Undelivered to the specified orbit	19	1%	0,905023359	0,072401869
Until initial operating test	Power	19	1%	0,905023359	0,072401869
Until initial operating test	Attitude control	14	1%	0,666859317	0,053348745
Until initial operating test	Payload Instrument	12	1%	0,5715937	0,045727496
Until initial operating test	Antenna	7	0%	0,333429659	0,026674373
Until initial operating test	Communication	2	0%	0,095265617	0,007621249
Until initial operating test	Telemetry	2	0%	0,095265617	0,007621249
Until initial operating test	Temperature control	2	0%	0,095265617	0,007621249
Until initial operating test	Others/Unknown	9	0%	0,428695275	0,034295622
Operation phase	Power	42	2%	2,000577951	0,160046236
Operation phase	Attitude control	15	1%	0,714492125	0,05715937
Operation phase	Telemetry	13	1%	0,619226509	0,049538121
Operation phase	Payload Instrument	6	0%	0,28579685	0,022863748
Operation phase	Communication	6	0%	0,28579685	0,022863748
Operation phase	Control processor	4	0%	0,190531233	0,015242499
Operation phase	Antenna	2	0%	0,095265617	0,007621249
Operation phase	Others/Unknown	17	1%	0,809757742	0,064780619
No claims	Attitude control (Fuel exhaustion)	1652	88%	86	6,88

Notes;
*1 Total is not 100% because the data are rounded to integers

*2 Back calculating by using 86 satellites which are close to end of life in 5 years which is identified our market analysis
*3 Multiplying (1)number maintainable=20% and (2)number worth maintaining=40%

Step 2: Calculation of sum of estimated
number of customers in each failure

Failure of subsystem	Total	Step3: The top 2 is equipped.
Attitude control	6,990508115	←Equipped
Power	0,232448105	←Equipped
Failure of launch	0,179099359	←not Equipped
Others/Unknown	0,099076241	←not Equipped
Undelivered to the specified orbit	0,072401869	←not Equipped
Payload Instrument	0,068591244	←not Equipped
Telemetry	0,05715937	←not Equipped
Antenna	0,034295622	←not Equipped
Communication	0,030484997	←not Equipped
Control processor	0,015242499	←not Equipped
Temperature control	0,007621249	←not Equipped

XI.II. Interview key points

Interview key notes

		February 25th	March 2nd	March 2nd	March 4th	March 4th	March 8th	March 8th	March 16th	March 25th
		Cornelius ZUND	Laurent CARELLI	Phillippe LATTES	Lei HUANG	Yusuke MURAKI	Jean-François GENESTE	Delphine MIRAMONT	Sylvain MICHEL	Dominique PONCET
Category	Key notes	SATELLITE 2d	Noveltis	Aerospace Valley	CAST	JAXA	Airbus D&S	Student space law	CNES	Airbus D&S
Traditional trend of satellite market	Cost averse and risk averse market	✓					✓		✓	✓
	Earth observation satellites are not as profitable as Telecommunication satelllites		✓							
	One demonstration is enough to prove feasibility								✓	
Current measures against failures	Insurance gives enough money to launch another	✓		✓						
	A lot of tests to guarantee operation					✓				
	Full redundancy for key devices			✓		✓				
	More robustness			✓		✓				
Emerging trend of satellite market	Business model of NEW SPACE (Reusable launcher & Satellite constellation)	✓				✓			✓	
	Full electric satellites			✓			✓		✓	✓
	Software can be fixed from ground station				✓				✓	
	Big 3(Intelsat, SES, Eutelsat) occupy 80% market share	✓				✓				
	New rules against space debris						✓	✓	✓	✓
Technology	Past trials (Hubbe Space Telescope & Space Shuttles, ISS, DARPA, MDA, ADS, Orbital ATK...)	✓				✓			✓	
	Past trial was demonstrated the necessary technology for satellite maintenance								✓	
	High barrier against standization of equipments					✓			✓	
	Cuurent technology & efficient operation enables maintaining satellites more movable without huge fuel consumption						✓		✓	✓
	Current satellites cannot be a customer because of their customized and incompatible design						✓		✓	✓
	Miniaturization of satellites						✓			
	Democratization of space						✓			✓
Demand	High demand to extention of satellite lifespan	✓	✓	✓	✓	✓			✓	
	Mixture of maintenance services woud be popular	✓	✓		✓	✓			✓	
	High demand to avoid conflict of radio frequency					✓			✓	
	Nano satellites are easily replaceable and do not need maintenance		✓							
	No need of 15 year old satellites because of technology obsolescence					✓				
	Government who own expensive order-made satellites would be interested in maintenance					✓				
Sympathy toward our new idea	Development of second hand Market	✓								
	Method of manufacturing in "space" by using 3D printing	✓								
	Functionality improvement					✓	✓		✓	✓
	Big Data approach for more efficient operation								✓	

XI.III. Interview methodology

The objective of this document is to define how the MCTP group will run interview in order to gather data concerning their MCTP topic. The main idea of the running of the interview is to create and keep a good connection with the interviewed candidate through a professional and comfortable process.

1. Before the interview

a. **Screening email**: a short email will be sent prior to the interview to the targeted individual timeously, so the candidate is informed of the topic, the type of questions that will be asked, and duration of the interview and is given a short context of the project. During the screening process, the MCTP team will be sure to check if the information given by the candidate are confidential and if the candidate agrees to be recorded.
b. The interview may be run by 2 or 3 persons or the entire team at the candidate's request (invitation in the candidate's facilities for example).
c. The questions for the interview are to be prepared in advance. However, the questions can be slightly adapted during the interview to provide a continuous and harmonious discussion.
d. If the candidates agree to be recorded, the recording of the interview has to be acknowledge by the candidate. The candidate has to be fully aware of the way the interviews is going to be recorded (audio only, audio and video).

2. During the interview

a. "**Semi-structured interview**": Running the interview should be done in a positive and comfortable atmosphere, not too formal but well-prepared by the MCTP team.
b. The **FIRST STEP** will consist of introducing the team, the project and its goal.
c. The **SECOND STEP** will consist of defining how the interview will be run: set of questions, duration, confidentiality clauses if any.
d. The **THIRD STEP** will consist of conducting the interview.
   The first set of questions will allow to set a convenient atmosphere for the interview, by asking the candidate to introduce himself.
   Then the actual interview can be run through the define set of questions.
e.
f. The **FOURTH STEP** will consist in thanking the candidate.
   At the end of the interview, the team should ask any potential contact that can be useful in regard of the project.

3. After the interview

a. The candidate should be thanked by an email by the persons that have conducted the interview on the next day.
b. The interview discussion should be transcribed into a word document.
c. The transcript of the interview has to be categorized through the usage of main ideas in regard of a color code (For example, BLUE = satellite related topic, GREEN = In-Orbit maintenance related topic) for the ease of access to information and its processing.
d. After the transcription and categorization of idea, an analysis summary should be done in order to explain:
    - The role of the candidate in the industry,
    - The main ideas and concepts given during the interview,
    - The answers given to the topic question,
    - The information that requires further investigation through another interview or through research.
e. The candidate will be thanked in the final report. If asked, the final report will be provided to him/her.