Study of a preliminary value-cost model of Earth Observation (EO) satellites operating in Very Low Earth Orbit (VLEO) and Low Earth Orbit (LEO) for a Non-Governmental Organization (NGO)

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Abstract

This thesis is about a preliminary study of a value-cost model of an Earth Observation satellite operating in a Low Earth Orbit and a Very Low Earth Orbit for an NGO. In this thesis, the Non-Governmental Organisation needs detected are from humanitarian, medical and rescue aid. The thesis relate some parameters, like the weight, resolution and swath with the cost. Furthermore, it is described the mission to cover *Médecin Sens Frontières* needs and the cost to develop the project and the operation of the mission. To conclude, it is evaluated the possible *Médecin Sens Frontières* partners to make up and pay the project.

DEDICATION AND ACKNOWLEDGEMENTS

I dedicate this thesis to my family; Maria, Raul and Luisa. They helped me in numerous occasions, more than I can remember. They have supported my decisions, not always agreeing or sharing them. I would also like to mention the rest of my family, especially, my little goddaughter, that always helped me with no need of asking for it. Thank you for all this time spent with me.

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Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: .... DATE: ....

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Chapter 1

Introduction

1.1 Aim of the thesis

The objective of this thesis is a preliminary study of a cost-value model for the Earth Observation (EO) satellites' application for a Non-Governmental Organisation (NGO). During the development of this project, we are going to establish the price that the client would be willing to pay in relation to the needs and covered by Low Earth Orbit (LEO) and Very Low Earth Orbit (VLEO) commercial satellites. Finally, a preliminary equation that modelise the relationship between the cost and the value will be developed, as well as an environmental study with the risks and implications of this project.

1.2 Scope

This final degree thesis is split up into the following parts:

1. State of the Art of commercial satellite applications in EO on NGO market.
2. Identify the values and needs of the NGO market in relation to the EO market with interviews and internet searches.
3. Estimate the price that the market would be willing to pay (depending on the customer value) with industry experts interviews .
4. Relate the values and/or needs with the potential applications / technologies of commercial satellites in VLEO.
5. Prioritise the values and/or needs of the market versus the viability of the applications with current technology or improvement of it.

6. Disaggregate the utility in different levels according to the needs covered by the market and/or the market Willingness-to-Pay.

7. Identify the associated costs and price about developing this application in relation to the established categories according with industry experts interviews.

8. Relate the categories with the costs and establish a first equation model that relates the value-cost.

9. Further make a market study of applications in other markets.

10. Application environmental study, implications and risks.

1.3 Requirements

Analysing the scope, some common requirements are extracted:

- In order to understand how EO is developed, I am going to look for what kind of use have cubeSats.
- Determine if a VLEO and LEO cubesat accomplish need from NGO.
- Otherwise, look for support technologies to accomplish all the needs.
- Search if other markets that need some of the NGO's requirements.
- Modelise a cost-value for a NGO.

CHAPTER 2

State of the Art

The first steps to conquer space, and the new world of possibilities that it offered, was in 1957 with Sputnik-1. Since then, the great nations have competed to innovate and improve their technology, making our today's life dependent of all the infrastructure that resides in space (GPS, Earth Observation, Telecommunications ...).[1][2]

EO started a few decades before this first launch. With the invention of photography during the nineteenth century [3] and the aerostatic balloon, it began to devise what would later become EO. With this mixture, the first aerial photographs of the Earth's surface were taken. Although at the beginning, they were merely for an artistic purpose and very far from current use, they were the first steps for what would later be known as remote sensing. Of course, the war marked the development of these ideas, from the use of pigeons (Fig.2.1a) with cameras to spy from Sputnik (Fig.2.1b) were developed by this conjuncture. The wars were nourished by these observations, for control of the arsenal or for recognition of the war zone for instance.[1][2]

(a) Julius Neubronne Pigeons[4]

(b) Sputnik-1[5]

Figure 2.1: Evolution of the remote sensing to Earth Observation

As it has already mentioned, the first satellite considered for Earth Observation was Sputnik-1, which for a short period of weeks provided atmospheric density data [5]. Years later, in 1960, the first meteorological satellite, Tiros-1, was launched, which in just over 11 weeks showed that the new space technology could be used for forecasting weather [6]. The great age of the satellites began (ATS, EROS, ERTS, BOMEX), and with them a different vision was given of how the different phenomena on Earth looked [1][2].

2.1 Small satellites

With the new millennium, appears a new idea called New Space. Since the Sputnik-1, the satellites were getting bigger and more expensive, so they had many disadvantages when it came to setting up private projects. The New Space companies focus on space at a low-cost to allow the use of new technology for a consumer that does not belong to the large customers as governments or space agencies. This revolution was accompanied by the small satellites orbiting at Very Low Earth Orbit and the lower parts of Low Earth Orbit, which are all satellites under 500kg that are categorised as:

Table 2.1: Type of small-satellites [7]

Satellite	Characteristics
Mini-satellites	Between 100kg -500kg
Micro-satellites	Between 10kg -100kg
Nano-satellites	Between 1kg -10kg
Cubesat (1u)	Nano-satellite, Around 1kg Cube form with 10cm edge. They can work several at the same time together
Pico-satellites	Between 0.1kg -1kg
Femto-satellites	Between 0.01kg -0.1kg

One of the greatest problems of large satellites are the technological obsolescence that leads to their development. These take years to be designed, built and launched, and they have to operate for a long time to be viable. With the appearance of the small-satellites, this problem is partially solved. By having these characteristics, their development time is shorter and their cost is also lower. They usually orbit in LEO and VLEO so their life-time is between 1 and 7 years. This allows a faster evolution of the technology because the constellations require a continuous supply of new satellites. This supply also involves a big problem,the launching of these satellites. Although the technological cost is gradually decreasing, access to space does not decrease in a similar way. The growing demand for EO data along with the appearance of small-satellites seems to allow new companies to make the New Space viable. The sector grows annually and investors seem interested in investing in new start-ups [7][8][9].

Although for our final degree thesis, the interesting applications of the small satellites focus on the EO, Telecommunications seems to be another great field of exploration for the New Space enterprise as machine-to-machine, internet of things or computer security linked to quantum phenomena [7].

2.2 NGO projects

For this final degree thesis, it is going to search non-governmental organisations needs and look into what technology can supply the present market. Determine if technology cover all the needs, otherwise propose improvements on cubesats or small-satellites technology and look for some alternatives to cover the needs that present technology cannot achieve in the following years.

For focus on this bachelor's degree final thesis, it has to be decided what kind of NGO project will be sought to provide a solution with EO. There is a wide spectrum of NGO's with different projects, the vast majority are discarded because they have no possibility of using EO technology. Broadly speaking, the main projects with EO technology solutions are:

- EO for natural catastrophe projects (Red Cross)
- EO for people rescue in the Mediterranean (Open Arms)
- EO for detection and control of the evolution of diseases (*Médecins Sans Frontières*-MSF)

2.2.1 Natural Catastrophe projects

Several NGO's are dedicated to humanitarian assistance in areas with natural catastrophes occurs such as earthquakes, hurricanes or floods. These projects are financed by governments, international institutions and individuals, usually in financial support to carry out food, medicine and other needs. However, there are also other projects related to the logistics of these project.

For instance, it was recently implemented a project with drones after hurricane Harvey which devastated southern parts of USA. American Red Cross with the support of UPS, deploy a drone with a camera to recognise the devastated area and determine which areas need immediate intervention [10]. These devices are also helpful in countries of the third world to map remote areas that do not have maps or are not updated. According to Amaury Gregoire, MSF's head of mission in Malawi *"Although Google Maps is gaining strength, we continue to work in very remote or politically charged areas that are often not mapped. Requesting satellite images during an emergency is often a very slow process, very expensive or offers rather rigid information"*, this gives us an idea of the perception that some NGO have on EO satellites uses [11].

Another project more related to the EO satellites is the Disaster Monitoring Constellation (DMC), this project is an international consortium formed by England, Nigeria, China, Turkey and Algeria. This consortium has several nano-satellites that allow to have an image of any part of the world once a day [12][13][14]. The purpose of this project is to provide images for humanitarian actions in catastrophes. To finance this humanitarian projects, the use of the images also has a commercial purpose. Other companies, such as Planet Labs, offer the data of their constellations to the **International Charter Space and Major Disasters**, an international consortium that provides satellite data to humanitarian organisations that require it [15].

2.2.2 People rescue projects

Another type of NGO is dedicated to the rescue of people in maritime zones. The support of the state and private organisations for this case is usually economic and basic resources of medical assistance. This type of NGOs born mainly with the war in Syria and the displacement of millions of people trying to reach Europe. Therefore, there are no active projects, however, some projects are being developed to logistically assist this type of NGOs.

The **FREEDA** project aims to support the NGO Activa Open-Arms in order to cover more area. It is about 2 autonomous drones that will allow a control of the zones where the ships are not and to warn the boats capsized . With this information, they would allow more rescue actions and be alert of possible cases that cannot be rescued. These cases, which cannot be rescued, often go unnoticed, because if they are not documented, they do not exist, says Sergi Tres, project coordinator[16].

Another related project, in this case with the European Global Navigation Satellite System (EGNSS), is Search and Rescue Aid and Surveillance (SARA). This project belongs to H-2020, like the mother project of this final degree thesis. The aim of the project is to provide a technological contribution to support vessels to detect people lost in the sea, especially during the hours of darkness. SARA is conceived to support Search and Rescue operations based on a deployable Remotely Piloted Aircraft System (RPAS) which is tightly coupled with a ship architecture through a cable (tethered flight): as soon as its function is needed, the aircraft flies from its home (a dedicated hangar on the top of the ship), and becomes "virtual pylon" which elevates to VIS-TIR sensor (Visual Spectrum and Thermal Infrared); captured images are made in real time by a local computer. Both RPAS and hangar are equipped with 2 high accuracy EGNSS receivers (i.e. Galileo ready) in order to provide the relative positioning between the hangar and the RPAS hovering on the target[17].

2.2.3 Diseases outbreaks and evolution control

The NGOs related to the control and detection of diseases, as well as their treatment, are one of the most numerous. Many companies and countries support this type of NGO, either with economic or medical resources.

There are projects with drones that help this type of NGOs. Several of them allow access to remote areas, this is the case of *Médecins Sens Frontière* drones in Malawi. This project allows to map areas to see the best way to reach affected areas. The drones were also used to identify the habitat vectors of the mosquitoes that cause malaria in Zanzibar [18].

In certain cases, such as the outbreak of cholera in Bangladesh, predictive models were used to see the effect of this disease. This was achieved due to the EO imagery. Also through this method they could trace the evolution of malaria or hantavirus pulmonary syndrome in Africa [19]. On South-Africa, Swaziland and Mozambique, the program **MALAREO** was used to cover land mapping and support their malaria control program. This program was carried out due to EO data from multiple EO satellites [20]. Some Brazilian researchers look for the feasibility from Remote sensing data to survey endemic diseases in Brazil [21].

Table 2.2: NGOs activities related projects

NGOs activities related projects			
Project Name	**Project Type**	**Operator**	**Activity related**
Hurricane Harvey dron	Dron	Red Cross/UPS	Humanitirian aid
Disaster Monitoring Constellation	EO satellites	International Consortium	Humanitarian aid
International Charter Space and Major Disasters,	EO satellites	non-binding charter	Humanitarian aid
FREEDA	Dron	Open Arms	Rescue aid
SARA	Dron	H-2020 consortium	Rescue aid
MALAREO	EO satellites	Cordis (EU)	Medical aid
Brazilian diseases	EO satellites	Brazilian university	Medical aid
Malawi drones	Dron	MSF	Humanitarian and Medical aid

CHAPTER 3

VALUES AND NECESSITIES

3.1 Necessities of NGO market

As it has explained in the previous chapter, it is seen that some needs are common in the different types of NGOs activities. This can allow to cover more than one of these initiatives so that there are enough common needs. It has been looked for all the activities carried about NGOs to determine all the needs that they have.

It is seen that the common need for this three types of NGO is the cost of this data, it is mainly because they are non-profit organisations, so they do not obtain income as a company. Many of these NGOs obtain income from grants and donations so they would allocate the greater percentage of these to their activities, whether they are buying vaccines, life jackets, non-perishable food ...

Especially in an organisation dedicated to the rescue, and with a limited budget, the resolution of images, optical and thermal, is of the utmost importance. This happens due to the limited resources they must be sure that it is a rescue situation and not any other type of incident.

Another need for these NGOs are the amount of information about a specific area. This varies according to what type of action they have, from a desire for images in real-time in the case of rescues to daily NGOs information with humanitarian actions. This need is the most difficult to cover, although this will be discussed later , but it will be one of the key factors that would increase the cost to impede it in some cases.

The last need is for the medical case, where the optical and thermal images may not be enough to estimate the disease vectors. Although much information can be extracted from these images indirectly, it will not be enough to obtain the necessary characteristics to detect and control some specific diseases.

3.2 Satellites values nowadays for NGOs

In order to establish the market values, information has been collected of the small satellites dedicated to the EO of the last 20 years, these are tabulated in the annex A.1. In this annex, different categories are distinguished and certain patterns are appreciated that will be analysed below.

Within the small satellites, the larger ones are the ones that have the biggest lifetime, so it can be appreciated more their evolution than the smaller once which not have a wide catalogue. Among its main features, the increase of the resolution that has lasted over the years starting from 30m (table 3.1) to 2m in visible-NIR (table 3.3) and less than 1m in PAN (table 3.2). This technical improvement has also led to an increase in weight due to size. For example, it can be seen in the evolution from the first generation (table 3.1) to the third of DMC (table 3.2), the satellites class change from micro-satellite to mini-satellites.

Table 3.1: NigerianSat-1 [22]

NigerianSat-1	
Operated by	NASRDAR
Operation time	2003-2012
Satellite type	Micro-satellite
Orbit altitude	686 km
Orbit type	Sun-Synchronous
Technology	
SLIM6 MS (G,R,NIR) **Green** 520-620 nm **Red** 630-690 nm **Near Infra-Red** 760-900 nm GSD: 32m SW:620 km Nadir	

Table 3.2: TripleSat (DMC-3) [23]

TripleSat (DMC-3)	
Operated by	DMC
Operation time	2015-Now
Satellite type	Mini-satellite
Orbit altitude	651 km
Orbit type	Sun-Synchronous
Technology	
MS (B,G,R,NIR) **Blue** 440-510 nm **Green** 510-590 nm **Red** 630-690 nm **Near Infra-Red** 760-910 nm GSD: <4m SW:23 km PAN 450-650 GSD: <1m SW: 23km	

Table 3.3: SkySat [24][25]

SkySat	
Operated by	Planet Lab
Operation time	2014-Now
Satellite type	Micro-satellite
Orbit altitude	450 km
Orbit type	Constellation
Technology	
MS(B,G,R,NIR) **Blue** 450-515 nm **Green** 515-595 nm **Red** 605-695 nm **Near Infra-Red** 740-900 nm GSD: 2m SW: 8km PAN 450-900 nm GSD: 0.9 m SW: 8 km	

Table 3.4: NigerianSat-X [26]

NigerianSat-X	
Operated by	NASRDAR
Operation time	2011-Now
Satellite type	Micro-satellite
Orbit altitude	686 km
Orbit type	Sun-Synchronous
Technology	
SLIM6 MS (G,R,NIR) **Green** 520-620 nm **Red** 630-690 nm **Near Infra-Red** 760-900 nm GSD: 22m SW:600 km	

In the case of the cubesats and nano-satellites, the technology is not yet as developed as the larger satellites. The catalogue of the commercial nano-satellites is much smaller. The vast majority of these are experimental satellites launched by universities and small start-ups, so there is not a large commercial catalogue [27]. There is a great disparity in relation to its resolution, they vary between 20m (table 3.5) and 4m (table 3.6). It is appreciated that this resolution improves according to the renovation of these satellites, as it happened with the small satellites of greater size previously commented.

Table 3.5: Perseus-O [28]

Perseus-O	
Operated by	Dauria Aerospace
Operation time	2018-Now
Satellite type	CubeSat (6u)
Orbit altitude	650 km
Orbit type	Sun-Sync Const.
Technology	
MS(B,G,R,NIR) GSD: 22m	

Table 3.6: Flock-1 [29]

Flock-1	
Operated by	Planet Lab
Operation time	2014-Now
Satellite type	CubeSat (3u)
Orbit altitude	420 (475) km
Orbit type	ISS Const (Sun-Syn Const)
Technology	
MS(B,G,R) **Blue** 420-530 nm **Green** 500-590 nm **Red** 610-700 nm GSD: 2.7(3.7) m SW: 21.8 (24.6) km	

With the technology of radio-ocultation using the Global Navigation Satellite Systems (GNSS), they allow the smaller small satellites (table 3.7) to obtain weather data with the support of the main GNSS satellites. This technology allows the determination of climatic variables of temperature or humidity of certain zones.

Table 3.7: Lemur-2 [30][31]

Lemur-2	
Operated by	Spire Global
Operation time	2015-Now
Satellite type	CubeSat (3u)
Orbit altitude	400-600 km
Orbit type	Cubesat Const.
Technology	
STRATOS Determine atmosphere temperature, humidity and pressure by GPS radio occultation **SENSE** Monitoring of vessels movements	

A general characteristic of all small satellites is their revisit period. Due to its sun-synchronous orbit they allow to have images of any place on the planet at least once a day. Even multiple times, if that deals with a constellation of hundreds of cubesats. Another feature common to most of these satellites data is the free use of images for humanitarian purposes, for example DMC, and the private sector usually give them to International Charter 'Space and Major Disasters' or publish it themselves as PlanetIQ.

3.3 Technological feasibility in the different NGOs

With the values offered by the market, detected from the previous section,summarised on the following table, they have to be related to the needs mentioned in the section 3.1.

Table 3.8: Needs of NGOs

	Disaster	Rescue	Sanitary
Optical high resolution		X	
Thermal high resolution		X	
Optical imagery	X	X	X
Thermal imagery		X	X
Other type of information			X
Near real-time information		X	
Daily information	X		X
Low or free cost	X	X	X

The application of satellites in maritime rescues of organisations like Activa Open-Arms seems impossible to be achieved because the current technology resolution (low thermal resolution), revisit time and limited NGO resources does not seem to be a NGO project in which it can be focus this thesis.

Then, it is necessary to discern whether to choose between the humanitarian action carried out by the Red Cross or the humanitarian action on a smaller scale of MSF together with its medical action. The existing technology today, with a wide range of resolutions and different technologies, seems to satisfy both cases. It does not require the a priori use of high resolution thermal imaging as in the case of rescue NGOs. In contrast, the optical resolution has a large catalogue from lower resolutions for smaller satellites to higher resolutions for larger ones within the framework of small satellites. There are also small satellites that can provide climatological data in an area. This satellites have daily revisit time, which allows to have all the technical requirements established in the table 3.8

It seems that the best choice is the Red Cross, because it has a greater number of active projects at humanitarian aid frame. It is the largest organisation so in principle it should be easier to contact them to corroborate what their needs are. In addition, the number of projects with which they count seems to be much higher than MSF, so it will be possible to detect more specific needs.

However, due to time constraints, the final choice was to focus on the case of MSF. It was the only NGO which an interview (annex A.2) could be established to make sure that the estimated needs are correct. On the other hand, although the number of projects is smaller, MSF also performs humanitarian tasks such as help in camps for displaced persons or refugees, whether due to disasters or wars, as well as projects, as mentioned above, for the detection and control of diseases for your treatment. Despite the smaller number of these projects, the other side of the organisation could be interesting to investigate if the current technology can perform these tasks of detection and control.

CHAPTER 4

Médesins Sens Frontières

For this chapter, we will focus specifically on the NGO of Médecins Sens Frontières as it has been previously mentioned that it is the NGO that allowed us to have a meeting with them. This NGO was founded as a result of the war conflict in Biafra as a split of a group of French doctors belonging to the Red Cross who, faced with the impossibility of carrying out their work, decided to create a movement to do it. This medical-humanitarian movement will be converted into MSF (1971), which, independent of geopolitical interests, will give aid wherever it is required [32].

4.1 MSF projects

MSF has participated throughout these almost 50 years on all continents. His medical-humanitarian actions are summarised in the table 4.1.

Table 4.1: MSF activities [33]

MSF projects		
Paediatric health	Chikungunya	Sexual health
Surgery	Distribution of first needs articles	Vaccination
Mental health	Sleeping sickness	Tuberculosis
Water and sanitation	Dengue	Cholera
Ebola	Diarrhea	Chagas
Kala Azar	Yellow fever	Malnutrition
Malaria	Pneumonia	Meningitis
VIH	Measles	

Later, the different actions with the possible uses of satellites will be related but first we must see the origin of these actions. It is also necessary to analyse which projects are used to cover the different needs, and, in the case which the project could not cover them, use this projects to support the EO satellite project.

Many of these actions are related to armed conflicts and migratory movements caused by wars or political instability. War conflicts such as Syrian or political instability in regions such as the Central African Republic have caused thousands of people to leave their homes. In the case of the Central African Republic, political instability due to multiple coups d'état and weak governments has caused, in eastern parts of the country, 850,000 people move to other areas or leave the country in favour of other areas with greater stability[34]. In the case of the Syrian war, the number now stands at 6.5 million displaced people and 5.6 million refugees, this being one of the many conflicts around the world [35].

While earlier it has been said that MSF's actions are essentially related to wars and massive displacements, it is not entirely true. To a lesser extent, its medical action is also focused on areas with endemic diseases, such as Kala Azar or Malaria, or areas with few economic resources where access to certain treatments is non-existent. The possible use of EO satellites would also be useful for this facet of the NGO.

Evidence that EO satellites cannot directly help migratory movements or health aid. However, indirectly, if it is possible to provide assistance, although not to all the activities of the NGO. The EO satellites cannot help the following MSF tasks:

Table 4.2: Non-available use of EO satellites

MSF projects without help of EO application		
Pediatric health	VIH	Sexual health
Surgery	Mental health	Pneumonia

Then the use of satellites can indirectly support the coordination of the rest of the activities carried out by MSF. We can distinguish 2 categories for the application of EO technology.

Table 4.3: Categorised activities of MSF

MSF projects with help of EO application		
Humanitarian activities	**Medical activities**	
Vaccination	Ebola	Sleeping sickness
Distribution of first aid articles	Kala Azar	Diarrhea
Water and sanitation	Meningitis	Yellow
	Chikungunya	Cholera
	Chagas	Dengue

4.2 MSF needs

During the development of the thesis, it has had the pleasure of having an interview with Juan Jose Arévalo who holds a position of management of logistics information, knowledge and content of logistics department in MSF [36]. From this interview (A.2), general needs of this NGO are inferred, besides what are its obstacles and priorities to cover.

The first relevant data of the interview is the fact that they know the existence of the EO data that can be obtained from satellite, since they already use satellite images when they coordinate their actions in countries where they are required or at least have a knowledge of what happens in areas that cannot be accessed for some reason.

One of the main needs for this NGO is the cost related to obtaining the data from the satellites, mainly the EO images that they are using right now. According to the interlocutor, the cost of archive images are usually around a couple of hundred euros, and sometimes these do not exist so they have to be required, so the price increases between 1,500€ and 9,000€. This cost represents a large outlay, although in cases of need they pay their cost because the information that it provides them is useful.

Another need is related to the resolution of these images. In the case of optical images, they have a high resolution, allowing them to detect roofs in cases of migratory movements. This detecting roofs give them the possibility to determine how many people are living in that area. It also enable them to detect even through later analysis how long they have been there according to the materials and information of the area. The problem with these images is when clouds appear, denying them from seeing all or part of the information they need. In the case that the partially covered images,they draw upon to previous images to complete the information or even thermal images. When the clouds totally deny these optical images, they use thermal images, which are more difficult to interpret and with a lower resolution. As commented, even with the little information that can be obtained from the thermal images, they prefer to work with some information.

The last need detected in this interview was how often these images are required. Access to this type of information must be practically immediate because it allows them to quickly focus their resources and start their logistics. For example, during the movement of the Rohingya people to Bangladesh, it was detected that the island where the Bangladeshi government intended to send these refugees was potentially flooded due to the continuous typhoons that harry the area during the monsoon season. This was done through an analysis of the satellite images, which caused the project to be reconsidered [37]. In addition to have a fast access, they also require a periodic renewal of these images to detect changes in patterns of movement, if the arrival of refugees decreases or increases, if they are concentrated in other areas,etc. This would allow them to redirect resources from some areas to others according to the needs.

Both for the information gathered and for the interview with Mr. Arévalo, the potential of the use of images for coordination and knowledge of the situation was revealed. In the words of the MSF worker "Having the image on the table within a few hours is happening, it makes us advance weeks in the planning of an emergency intervention". He also reaffirmed our inquiries about how useful these images currently are "From how many people are there to what the trend is and how are they moving, what are the first needs, what kind of constructions are they using, what is the humanitarian situation and the situation of precariousness. There is water or there is no water, the road network state to get there. "

On the other hand, he was asked if in the case of his medical help it would be interesting to use these resources provided by satellites in some way, because, by radio-occultation technology, it is possible to determine environmental variables that affected the proliferation of certain diseases. His answer was that it could be interesting if some way of analysing these images could be developed but that their resources are limited and the part that is really interesting is the emergency action part. In addition, he added there are other factors that reveal these diseases so it is not so necessary. Therefore, it could be an interesting case to investigate to what extent it can be used for diseases mentioned in the table 4.3 but it is not a priority for MSF.

Another important question asked to Mr. Arévalo was the utility of drones to do the mentioned activities. They can use them but they have a lot of problems to get authority permissions and they also have problems with the misinformation of people. They think that this kind of technology may hurt them and they refuse to accept the usefully advantages that give to MSF coordination.

4.3 Value required for MSF

In summary, the needs of this NGO are:

Table 4.4: Necessities detected in the Interview with MSF

Necessities related to values of small satellites
Optical high resolution camera
Panchromatic camera
Near infrared and short wave infrared camera
Fast access to images
Two-three days revisit time
Atmospheric data
Low-cost project or private partners

As it is seen on the previous table 4.4, a huge part of them are related to technological limitations, only the cost of the project is not a technical limitation and it will be not use to create the value-cost model. This necessity will be focused on the section 6.3.

With the values, the satellite that MSF will require is, in the case of emergency action, a micro or mini satellite ($\sim 100kg$) due to, as seen in the annex A.1, this weight satellites have a high RGB resolution with NIR band and panchromatic camera. Panchromatic camera provides the satellite the possibility to do not require a very high resolution (1-2m) and use a high resolution

(4-5m) because it allows to use a panchromatic sharpening (PAN-S). This method allows to fuses a higher panchromatic resolution with a lower optical resolution giving a better resolution to the optical image, as it is seen in the figure 4.1. There are multiple types of PAN-S like Esri, IHS, Simple mean, Gram-Schmidt or Brovey methods, this thesis will not analyse which is the best of them to use in the data provided by the MSF satellites but if this thesis is continued by other students it is recommended to look Esri and IHS methods due to they can use the near infrared band to give a more accurate image.

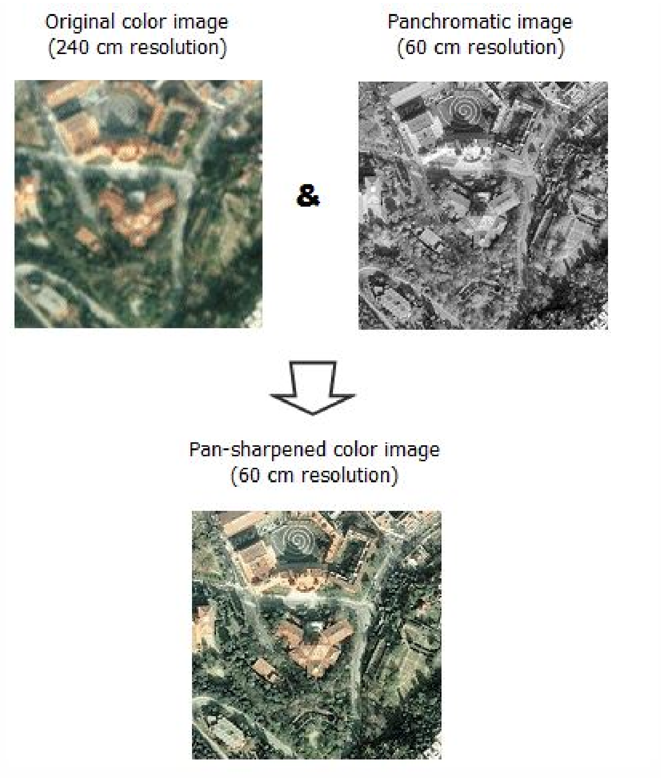


Figure 4.1: Panchromatic sharpening [38]

After determining the payload required for the emergency MSF action, it is necessary to determine the altitude, orbit type and how many satellites will be required. As seen on our analysis of the present satellites, MSF satellite will be in the sun synchronous orbit (SSO). These orbits allows a satellite to pass over a section of the Earth at the same time of day, that solve the daily revisit time need of MSF. This orbit with that especial characteristic give some advantage in the phase of download satellite data and with some ground station in specific places, MSF could access to that data hours after require this information. This thesis will make the cost of the mission, considering 2 satellites in SSO. As it will be seen in the next chapter , the economic cost of this satellites will be enough to limit to two the satellites due to MSF has to look for some partners to develop this project.

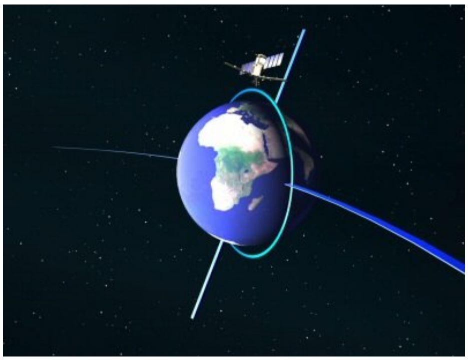


Figure 4.2: SSO Dawn-Dusk orbit [39]

In the case of the medical actions, MSF will not require satellites due to the cost, and MSF limited budget, and the interview with Mr.Arévalo who does not see a priority to develop this kind of algorithm to detect and control some diseases. As well, although it is not a priority for MSF, the NGO is able to acquire this atmospherical data from the **Lemur-2** (table 3.7) or **PanetiQ** (table A.17) cubesat constellation and develop this algorithm.

CHAPTER

5

VALUE-COST MODEL

In this chapter, it is about finding a value-cost model for the case of the NGO MSF. To achieve it, costs of the different satellites were sought to estimate the best option for the NGO. However, it is not found this cost from satellites summarised in the annex A.1. The only information available to modelise this value-cost is from the *OpenCosmos* interview and an excel from *Spacemic* and his guidance [40][41]. This thesis will only focus the value-cost model for the emergency case and not on the medical one because the priority of MSF to acquire the EO data from satellites is focused on the first one. Medical detection and control necessities are solved by other standards which do not require EO data. General characteristics of the MSF mission is:

Table 5.1: Characteristics of MSF satellites

MSF Satellites
2 Satellites
Sun-Synchronous orbits
High-resolution multi-spectral camera (RGB-NIR)
High-resolution panchromatic camera
100kg weight per satellite
LEO (between 500 and 800km)
5-10 years lifetime

In the table 5.1, the red parameters are the ones which are not determined by the necessities of MSF but the information obtained from similar satellites like NigerianSat-2 (table A.8) or DubaiSat-1 (table A.4).

However, an other type of constellations could be develop to solve the MSF needs. This one is a cubesat constellation like the one describe in the table A.16. This type of constellation will not be considered to the MSF estimation due to:

- The information that can be obtained from this satellites is little because a huge part of cubesats develop are experimental or from Universities.
- A single cubesat could not take a RGB and PAN cameras so it should be develop two types of cubesat.
- Technological more complex that the one explained on the table 5.1.
- Developing this project requires a knowledge than MSF, and partners, could not have.
- This type of constellation requires a continuous replacement of the cubesats, MSF objective is humanitarian and medical aid and not technological improvement.

In the case that MSF could find a partner who can afford the limitations and the cost of this type of project, they will get some benefits from using this type of constellation. The benefits are:

- Faster access to the data due to the revisit time of the cubesats constellations. It always depends from the amount of cubesats orbiting.
- Possibility of a continuous evolution of the technology.
- This satellites could have radio-ocultation technology (table A.13) to measure atmospheric data and allow MSF diseases break down and control.

5.1 OpenCosmos interview

For this thesis part, Florian Deconinck [42] from `OpenCosmos` gives some advises and help in a skype teleconference. In his opinion, to create a new mission,the phases are:

Figure 5.1: Mission Development

The first part, squared in green, detect the needs and search main characteristics it has already been done in the previous chapters. Their cost is the less important of this project due to is a information research. Purple square is the mission cost which includes the payload (cameras), the satellite to support payload and the satellite launch. The third square in red is the operational cost of the mission which include the data processing and the maintenance of the ground station and facilities. When the interview take place, the satellite main characteristics (table 5.1) were found so it was asked directly his opinion about the cost of the mission. In his opinion camera cost with a multi-spectral 5m resolution would be of two million dollar and the whole 100kg satellite around twenty million dollar and the launch cost will be around four million dollars. The operational part could not being determinate by him because the cost depends from a lot of variables such as number of satellites and mission lifetime.

Table 5.2: Deconinck Value-cost

Deconinck Value-Cost	
High-resolution RGB-NIR camera	2M $
Total satellite cost	20M $
Launch cost	3-4M $

5.2 Dependencies Value-cost

In the interview, Mr. Deconinck said that the resolution improve makes the cost of the payload increase. The payloads cost is not a available on the internet and Mr Deconinck oriented about this, as well an excel with a cost model (annex A.3) was found with reasonable values in accordance with the data of Mr. Deconinck.

Table 5.3: Resolution-cost (Annex A.3)

Resolution-Cost	
Low-resolution (20-50m)	0.2M $
Medium-resolution (5-10m)	1M $
High-resolution (1-2.5m)	2M $

As it is seen in the table 5.3, the cost of the payload technology increase with the resolution upgrade. The technology price is not as accurate as the thesis should require to conform value-cost model but this general data allows to determine a preliminary qualitative model and first approximation to the value-cost equation where the value is the optical resolution. The figure 5.2 graph the data from Spacemic excel and Deconinck and include the first step of the equation from optical resolution-cost.

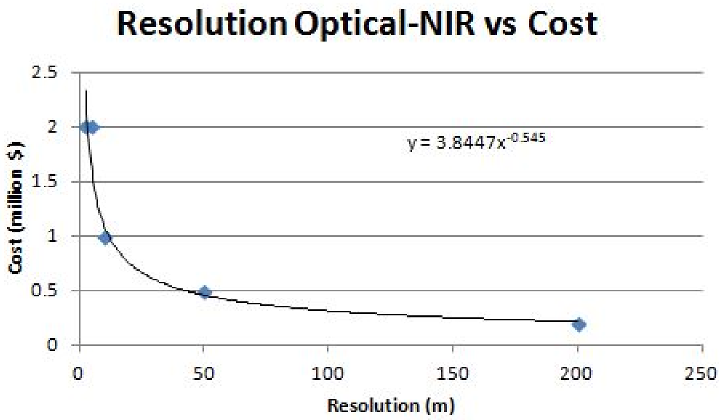
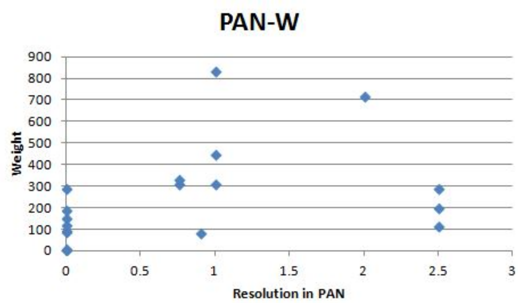


Figure 5.2: Optical resolution- cost equation

Another important point related to the payload is this own size and weight. To improve the resolution, it requires in the most of cases a bigger payload. A bigger payload requires a bigger satellite to support and the cost of launch increases as well. Mr Deconinck inform the cost per kilo launched is between 30,000 and 40,000 dollars so the total cost of the launch with the prevision of 100kg is between 3 and 4 million dollars. The figure 5.3 resumes the resolution from the satellites related to the weight and, therefore, the launch cost:

(a) Multi-spectral resolution related with the weight



(b) PAN resolution related with the weight

Figure 5.3: Resolution vs Weight

As it is seen, there is a consonance between the multi-spectral (MS) resolution improve and total weight increase but some cases are unusual due to their swath width, either the quick evolution of the technology could affect to that figure 5.3a. PAN resolution has not a relation with weight because all the satellite have not a PAN camera(PAN resolution is 0 in this cases) and it depends more with multi-spectral resolution as it is said. Swath width is the last important value to NGO project. Larger is the SW, less altitude and number of satellite will be required to have a daily revisit time.

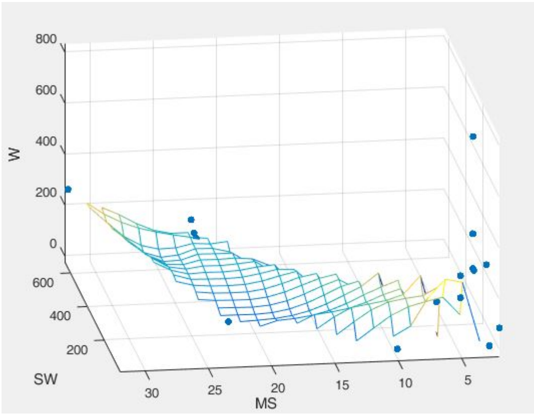


Figure 5.4: Weight and Multi-spectral resolution related with Swath width

As much MS resolution increase, SW decrease and weight increase significantly. So the NGO satellite project will require the largest SW in order to not request multiple satellites or at least a minimum amount of these. As it is said in the last chapter, due to a budget limitation the total constellation will be 2 satellites in order to achieve the daily revisit time need from the NGO. With the 2 satellites, it is able to cover the daily revisit if they do 15 orbits around Earth, the orbit altitude is LEO, between 500 and 700 km [43]. In this thesis, it is estimated both units cost is the same, but it is known that produce more than 1 unit reduce the cost of the following due to the learning curve.. It is not taking account because the estimation is preliminary and it is not necessary to do an accurate total cost to ensure that NGO, and partners, could assume other unforeseen.

Last value which affects to the project cost is the operational cost. As the cost of the camera, the only way to assume the yearly cost of the satellites operation is with the excel (Annex A.3). With that data about the yearly cost per ground station, it is only require to know lifetime mission and the total ground station to acquire the data from EO satellites.To reduce the cost, it will be necessary at least 1 ground stations with a high-download data system. The lifetime of the mission, as the similar ones (annex A.1), should be of 5 year, prolongable to more, but it will be assume 7 year of operation time. This assumption is because most of the satellites that data has been obtained, life time was around 7-8 years. It is important to assume a longer life time to ensure that the NGO and partners could afford a longer operational time. The costs of this operational part are:

Table 5.4: Operational Cost (Annex A.3)

Operational Costs	
Ground Station Development:	1M $
Maintenance of the Ground Station:	0.5M $/y
Analysis of the data of remote sensing:	1M $/y
Total 7 years operation:	11.5M $

Another solution to this operational cost is the KSAT or SSC ground station network. This enterprises rent a multi-mission ground station network for small satellites [44][45]. Their services allows to do not need to build up the self ground station network.The use of their ground station requires a fee that it is estimate about 0,75M $. The cost is higher than the one make for a unique mission but it allows to have multiple station to download data for get it faster than the other way.

The table 5.5 resume the total estimate cost of the mission for MSF:

Table 5.5: Total estimate cost of the MSF project

MSF Mission Costs estimation			
Satellite Cost	20M $/unit	*Ground Station Development*	1M $
Total	40M $	Total	1M $
Launch Cost	0.04M $/Kg*unit	*Maintenance Ground Station*	0.5M $/y
Total	8M $	Total	3.5M $
Ground Station Rental	0.75M $/y	*Analysis data*	1M $/y
Total	5.25M $	Total	7M $

Total (with GS rental)	60.25M $
Total (with GS development)	59.5M $

The figure 5.1 explained the development of this type of projects and the cost from table 5.5 of the purple and red squares.In the purple one, satellite cost includes the payload and all the subsystems require to the correct operation of it. Launch cost represent the total estimated cost to launch the two satellites as secondary payloads coordinated orbits. In the red square, analysis data represents the data processing estimated cost. Maintenance is represented by two ways to achieve it. First way is the development and maintenance of a ground station estimated by the Ground Station Development and Maintenance Ground Station costs. The other way is the Ground Station Rental estimated cost to do not build and maintain a ground station.

To end this chapter, with all the information obtained to the develop of the MSF, it is possible to explain qualitatively a value-cost model. From the figure 5.2, it is able to determine that one of the main value that determine this value-cost model is the optical resolution cameras. Nonetheless, the other main values is the SW and the dependence from it has from the camera resolution. When resolution increase, it makes the SW decrease. Decrease the SW affects on the area able to be pictured. This is a problem due to it is needed more satellites to get a daily revisit or other types of constellation configurations. This cost are not detailed on the information obtained to this thesis but it an important value to determine the final cost.

The table 5.6 summarise the values-cost dependence or equation in the case that it exist.

Table 5.6: Value-cost model

Value-Cost model		
Value	**Equation (M $)**	**Dependence**
Optical resolution (m)	$3.8447 * (X)^{-0.545}$	-
Swath width	-	From the camera resolution and the size

CHAPTER 6

MARKET STUDY AND EXTRAPOLATION

MSF project belongs to the disaster monitoring market, 1 of the 11 markets of Earth Observation (fig.6.1). In this chapter, it will be explain how the market is evolving and the application of the technology in the other markets. This extrapolation will allow the project carried out because the resources of an NGO, like MSF, do not permit develop this project.

Earth observation markets	
Defense	Telecommunication and utilities
Living resources	Transport and logistics
Disaster management	Insurance
Mining	Agriculture
Energy	Weather
LBS (located-based services)	

Table 6.1: Earth Observation market categories[46]

6.1 Disaster monitoring market

The design of this project is oriented to the MSF necessities, that can be include in the disaster monitoring market. Nowadays, the EO market is increasing his value and many reports detail the evolution of the small satellites technology as result of this increased value [47]. In the figure 6.1, Euroconsult report estimate the EO market value-added service (VAS) grouped only in 9 categories.

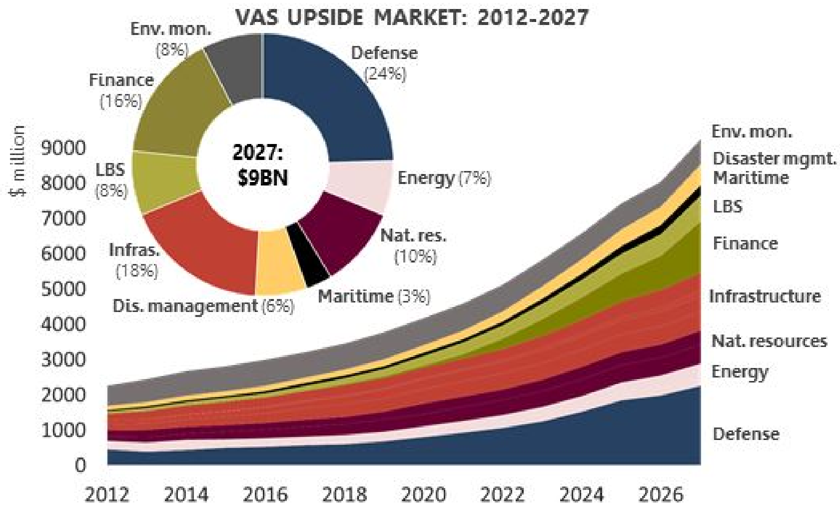


Figure 6.1: Euroconsult VAS estimation [47]

Previous data reflects an increase of the market value in all the categories, even in the disaster management category. On the Euroconsult anual report, they estimate 2.4 billion dollar data market, reaching 5.3 billions dollars in VAS market However, in the upside case VAS value could reach 9 billions dollars due to the fast-changing environment, this is provoked by more and more enterprises enter to create their own constellations. According to Euroconsult 20 enterprise will develop their constellation launching up to 1,500 small satellite in the next decade [47] [48] [49].

This market part, as mentioned in the chapter 3, is important for the NGO works. Due to the information that EO satellites can provide to this NGO, their work can be done easily or with most effective way. The small satellites technological part develops, like the big satellites decades ago, reaching better resolution and better download system. The real issue that affects the development of this market is the access to that data. NGOs can not afford the cost of satellite project, even most of them could not afford the cost of the data.

6.2 Extrapolation of the technology for other EO markets

As mentioned on the previous section, the EO market value increase yearly in all markets but the NGOs could not afford the cost so the best way to solve this problem is find the other EO markets that could use the same technology than NGOs necessities.

During the progress of this thesis, many of the necessities were named and the solution with the EO satellites data. Most of the solution is an optical and thermal imagery, and main EO market is defense who requires the same high-resolution and can afford the projects cost. This should be the main market which NGO should band together, also they requires the weather data that medical action referred on the section 4.4 needs. Defense projects covers from the border control to the weather change detection,his extended coverage permits to any EO project to be usefully for defense projects.

Secondary markets like living resources, mining, energy or agriculture are the other ones where optical and, especially, thermal imagery are usefully. One of the problems from living resources is the growth of the cities. How to control this development is the same idea as the NGO control human migration due to the wars or crisis. The other 3 markets requires this imagery to control the development of this economical strategic areas. Also, the agriculture market needs weather data to make easier the containment plans.

The rest of the markets do not use the same technology than NGO requirements but with this the fast-evolving EO market it is necessary keep an eye on it in the case that their technology requires some support. However, it is possible to design a satellite that could support both markets, including a camera and some global positioning services devices.

6.3 Assumption of the MSF project cost

During the writing of this thesis, it is mentioned the limitation of budget that a NGO has. MSF, as any other, could not afford a 60 million dollars project described on the table 5.5. So an important part of this thesis, addressed especially to the MSF, is how to achieve this project with some partners or national or international economic aids.

As it is said in the previous section, the EO markets will increases his value and huge percentage is related with the defense market. Their application are numerous and diverse so it is possible to merge the NGO project with other catalogued on the defense market. The problem with that partners are the difference between their aims. It is possible that, even if are the best project partners, border control projects or other military project aims can not be mixed due to insurmountable differences. Eventually, they are great partners with their huge budgets and the support of governments and international entities so it is necessary to take them in mind.

In the previous section, other markets projects use similar technology so entities or enterprises that will appear in the EO market in the following years, more than 20 as mentioned by Euroconsult [48]. It is said too that more and more small satellites will be launch in the following years as part of new constellation, this increase in the number give more opportunities to look for a partner.

The final question is who can be this partner and why they will accept a NGO, like MSF, as partner. First, and maybe one of the most available partners, could be the European Union. Through consortium in a project, like the one shelters this thesis (H-2020), that some universities and companies could develop with the economical support of EU. With the estimation done by Euroconsult, with the new companies entering in this space market the NGOs have a lot of opportunities to become part of this EO projects. Moreover, spatial agency like ESA or NASA could help to develop this projects with they knowledge and resources.

This is not only an opportunity to the NGOs, companies who held this partners can have some benefits from the commercial use of the satellite. Moreover, having a partnership with a NGO is positive to a company due to a big amount of them have a social aim than can be accomplished by the NGO. For this companies, it is a beneficial market where invest resources, might be for their own use of the data collected or to sell this data to third parties. The EO imagery market as mentioned before in this thesis, it is also growing so more and more companies require this information to detail their business plan.

MSF Spain incomes are over 180 millions dollars nonetheless, MSF total incomes are 1500 millions dollars [33]. With this incomes, they need some help to afford this project economically. Do not forget, they are a NGO and their main mission is medical and humanitarian aid and a great part of their incomes have to be spend for that purpose. Furthermore, their knowledge about Satellites or spatial mission is not enough to work up the project, so they require technological companies or agencies to a successful mission.

CHAPTER 7

Environmental, implications and risks studies

For this chapter, it is bound to have some aspects in consideration due to UPC final thesis degree regulations. This aspects are 3 an environmental, implication and risk studies. All studies are discussed from two points of view, the thesis itself and the project to take into consideration everything that this thesis implies.

7.1 Environmental study

As a part of an UPC thesis, it is obligatory to consider environmental consequences of the project. In this case, the MSF project has an important impact on the environment. The construction of a satellite requires a lot of resources and this have an impact on the Earth and the launch and the operative part too. As a NGO, they will focus on have the less impact on the environment due to they social help. This impact is due to people work, build of the satellite or transport.

Another point is the use of this project to help to the environment. With the imagery obtained by this satellite constellation, it is able to control deforestation or ice sheet mass on the poles. As well most of the imagery, could help to mentalise the popular opinion about how the human activities affects to the Earth. Furthermore, the develop of the project should take in account the space debris that the satellites become when the lifetime ends.

7.2 Project implications and risks

It is mandatory to comment that being a cost estimation of the mission, the risk as well as the implications of this thesis are insignificant.

In the case of this thesis starts a project with MSF, or a similar NGO, the cost is high (around 60 millions) so the economical risk is high too. Also, the risk related to a spatial mission in the case of failure exists. The technology aboard the satellite could do not work as it is expected or the launch failure are risks that the project should keep in mind. To reduce these risks, the consortium, where the NGO will take part, has to control all this risk and make a plan to do not end the project due to them.

Financially, as this thesis is only a mission estimation cost, these costs are only indicative so there is a possibility of extra cost, however the cost are estimated upward so the total 60M $ cost could be higher than the final cost. Before the project start is recommended to make a pre-design of the mission to have a correct knowledge of the cost. On the technological risk, ensure that technology will work in spatial conditions talking to experts and testing this technology in extreme conditions. Last risk is related to a launch failure, both undesired orbit launched or a destructive one. The first one should be analysed in situ when this happens. For the second case, an insurance should be the best way to reduce this risk.

The implications of the project are a cheaper access to the space for an important NGO like MSF, or other one with similar needs. As Mr. Arévalo mentioned in the interview (annex A.2) the future of their work is related to imagery obtained by satellite. The information provided by this imagery is so usefully for them that even with the high cost of this images they acquire them.

Table 7.1: Risk and implications of the development of the project

Risk and Implications related to the development of this project

Risk	**Possible solutions**
Economical	Ensure availability of the cost estimation described in this thesis
Correct operation of the satellite	Test the technology in spatial conditions and ask expert opinion
Non-destructive launch failure	Depends on the case. Look for viability work in the orbit. Orbit modification...
Destructive launch failure	Insurance to reduce the economical risk of this issue

Implication
Access to the EO data for a NGO
Specialisated project to NGOs like MSF

CHAPTER 8

CONCLUSIONS

To conclude this thesis, this chapter will resume the contents written during it. First of all, the possibilities, that brings to a NGO the EO imagery are incalculable. The information obtained by EO satellites allows a quick knowledge about situations in regions with no information like Syrian war refugees.

As it is mentioned, this final project try to look for necessities of the NGOs. In this case, it is made a list of necessities of the 3 main NGO in Spain that focus on rescue, humanitarian and medical aid (table 3.8). As it is mentioned, the information are contrasted only in the case of MSF which provides humanitarian and medical help however the information collected is enough to ensure the needs of them. The lack of information makes impossible to develop an equation which can relate value and cost, however a preliminary equation has been expose (figure 5.2) and a preliminary qualitative model has been obtained which is presented and analysed to the develop of MSF project.

This thesis provides a preliminary estimation of the MSF EO satellites constellation that will be able to cover this NGO needs. Nonetheless, it is only considered only a 2 satellite constellation orbiting in a LEO orbit. Other type of mission, like a constellation of cubesats could realise the same function but the technology and logistics to make this project is more complicated. It is high recommended to research on this option if the partners are able to assume the renew annually to the satellite constellation. The medical aid, that MSF give, could be helped with the radio-ocultation that cubesats can take.

As expected, the cost of the estimation is high enough to do not allow a NGO to pay it. The cost estimation is around 60 millions dollars but, before start the project, this estimation should be revised asking for more detailed information. As well, it can be said that the total cost is estimated above due to the lack of information obtained from the sector.

Finally, this thesis is a start from other thesis which can develop future application to NGOs. Mr Arévalo and MSF should be a good way to develop these thesis. They work with universities to develop better ways to use the information received by EO satellites, so, in the case that a consortium could make up the project, I recommend to take them in consideration as a partner.

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