End-of-Degree Project
Degree in Aerospace Engineering
Specialization in Aerospace Vehicles

Development and implementation of a Project Management Plan for a BEXUS21 experiment

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The comittee judging the Project indicated above is comprised of the following members:

President:

Chair:

Secretary:

They agree to grant this project a grade of:

Sevilla, 2017

Tribunal Secretary

A mis padres, porque son un pilar fundamental en mi vida.

Gracias a su amor y apoyo incondicionales he llegado hasta donde estoy hoy.

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María de la Cruz Sánchez Gómez

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Resumen

Este TFG comprende el desarrollo y seguimiento de un Plan de Gestión para el experimento SPADE (Smartphone Platform for Acquisition of Data Experiment) dentro del programa REXUS/BEXUS. El experimento consistía en una plataforma inalámbrica basada en hardware comercial cuyo objetivo era analizar el rendimiento de la plataforma en condiciones estratosféricas como una primera aproximación a plataformas de sensores inalámbricas embarcadas en misiones de exploración espacial. Finalmente, fue lanzado en octubre de 2015 dentro del globo estratosférico BEXUS 21 con éxito.

Este trabajo engloba la gestión desde la fase de definición hasta el lanzamiento del experimento. Se centra en los siguientes temas:

- El análisis de los requisitos, limitaciones y recursos.
- La planificación del experimento, incluyendo la distribución de carga de trabajo, su distribución a lo largo del tiempo y presupuesto.
- La gestión del experimento junto con la gestión de riestos, logística, gestión de patrocinadores y proveedores y gestión de equipo.
- Otras tareas desarrolladas como documentación, corrección de textos en inglés y divulgación.

Abstract

This TFG concerns the development and implementation of a Project Management Plan for SPADE experiment (Smartphone Platform for Acquisition of Data Experiment) within the REXUS/BEXUS programme. The experiment consisted in a wireless platform based at commercial hardware whose objective was to analyse the performance of the platform in stratospheric conditions as a first step of future wireless sensor network platforms ship in space exploration missions. Finally, the experiment was succesfully launched in October 2015 onboard the stratospheric balloon BEXUS 21.

This work involves the management since the definition phase until the launch of the experiment. It is mainly focused on the following subjects:

- Requirements, constraints and resources analysis.
- Project planning of the experiment, including work-distribution, scheduling and budget.
- Project management of the experiment along with risk management, logistics, sponsors and suppliers' management and team management.
- Other developed tasks like documentation, English proofreading and outreach.

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Abbreviations

AICIA	Asociación de Investigación y Cooperación Industrial de Andalucía, Spain
asap	as soon as posible
BEXUS	Balloon-borne Experiments for University Students
CDR	Critical Design Review
CN	Concentrator Node
CNM	Centro Nacional de Microelectrónica, Spain
COTS	Commercial off-the-shelf
CSIC	Consejo Superior de Investigaciones Científicas, Spain
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAR	Experiment Acceptance Review
ECTS	European Credit Transfer System
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
ETSI	Escuela Técnica Superior de Ingeniería, US Center, Spain
FR	Final Report
GS	Ground Station
H/W	Hardware
IPR	Integration Progress Review
IBM	Instituto de Microelectrónica de Barcelona, Spain
LC	Launch Campaign
Mbps	Mega Bits per second
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
OP	Oberpfaffenhofen, DLR Center
OS	Operating System
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
REXUS	Rocket Experiments for University Students
SD	Smartphone Device
SED	Student Experiment Documentation
SN	Sensor Node
SNSB	Swedish National Space Board
SPADE	Smartphone Plarform for Acquisition of Data Experiment
STW	Students Training Week
S/W	Software
T	Time before and after launch noted with + or -
TAS	Thermal Active System
TBC	To be confirmed

TBD	To be determined
TFG	Trabajo de Fin de Grado (End-of-Degree Thesis in spanish)
US	Universidad de Sevilla, Spain
VTT	Vicerrectorado de Transferencia Tecnológica, US center, Spain
WBS	Work Breakdown Structure
WP	Work Packages
WSN	Wireless Sensor Network
ZARM	Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation

1 INTRODUCTION

THIS Trabajo de Fin de Grado (TFG) concerns the project management of SPADE experiment in all its phases. An overview of this thesis subjects is presented below.

The work done is mainly focused in Project planning and its implementation, as well as the management of the team and the necessary resources. Also, the correct communication with the REXUS/BEXUS programme supervisors, the university, the suppliers and sponsors along with the internal communication of the team is essential. Thus, this project also covers the task developed as a Focal Point among all the project participants. Finally, a substantial amount of the work was focused to documentation production both technical and English proofreading review. Also, scientific and technical background research and outreach was developed.

This TFG is structured as follows:

- Chapter 2 introduces the background which influence this project. The REXUS/BEXUS programme is outlined and within the latter SPADE Project objectives, motivations and experiment concept are described. Also, the result of the scientific and technical background research which justify SPADE is presented.
- Chapter 3 defines the project, its objectives and scope.
- Chapter 4 analyses the requirements and describe the solutions. First, there is an analysis of the requirements, constraints and resources to develop a Project Plan for SPADE. Secondly, the work related to planning, managements and follow-up of SPADE Project is described, as well as risk management and team management. In addition, it defines sponsors and suppliers' management, logistics and material supply, documentation and outreach.
- Chapter 5 presents the results which SPADE project has achieve through this Project Management.
- Finally, chapter 6 presents the conclusions and lessons learned through this thesis.

2 BACKGROUND

THIS chapter provides an overview of REXUS/BEXUS Programme, as well as details about its organisers and schedule. Within the programme, it will focus on BEXUS experiments, explaining its characteristics and a resume of SPADE flight. Within the latter, SPADE was developed which is the framework of this Trabajo de Fin de Grado (TFG).

2.1. REXUS/BEXUS Programme

2.1.1 Definition and Organisers

The REXUS/BEXUS Programme (Rocket/Balloon EXperiments for University Students) is targeted towards university and higher education colleges students in the fields of natural sciences and engineering across Europe. The participants carry out a scientific or technological experiment on stratospheric research balloons (BEXUS) or sounding rockets (REXUS). Each year, two balloons and two sounding rockets are launched, carrying up to twelve and ten experiments respectively. [1]

Figure 2-1: REXUS/BEXUS Programme logo [1]

The programme is realized under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload is available to students from other European countries through a collaboration with the European Space Agency (ESA).

EuroLaunch, a cooperation between the Esrange Space Center of SSC (Swedish Space Corporation) and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. BEXUS and REXUS are launched from SSC, Esrange Space Center, in northern Sweden.

The idea behind REXUS/BEXUS Programme is to provide an experimental space platform for students in the field of aerospace technology and to increase the interest for this sector inside the university environment. Thus, the students experience the full project lifecycle from requirements analysis, design and development, to building and testing, to operation and data analysis. Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. [1]

2.1.2 Schedule

The REXUS/BEXUS programme started in 2007 in its current form and it is implemented in annual cycles. The Call for Proposals marks the beginning of the programme, followed by a condensed typical space project lifecycle. After the selection phase, the key milestones of the cycle include preliminary, critical, integration and acceptance reviews, experiment launch and publication of the final reports. [1]

This TFG was developed during the 8th cycle. The detailed schedule can be found on REXUS/BEXUS Programme official website which was as follows:

REXUS/BEXUS 8th cycle schedule [1]

- 16 June 2014 – Call for Experiment Proposals
- 1 August 2014 – Letter of intent (DLR Only)
- 13 October 2014 – Deadline for Experiment Proposals
- 7 November 2014 – Information about pre-selected Experiments and invitation to the Selection Workshops
- 1-3 December 2014 – DLR Selection Workshop (DLR, Bonn, Germany)
- 2-4 December 2014 – SNSB/ESA Selection Workshop (ESA/ESTEC, Noordwijk, The Netherlands)
- 12 December 2014 – Information about selected Experiments and invitation to the Students Training Week
- 9-13 February 2015 – Student Training Week & Preliminary Design Reviews (PDRs) (DLR Oberpfaffenhofen, Germany)

After the PDR & STW, the BEXUS and REXUS student teams follow different schedules. This work is related with BEXUS part of the programme. Nevertheless, the schedule of REXUS is also shown for informational purpose.

BEXUS schedule (BX 20/21) [1]

- 18-21 May 2015 – BEXUS Critical Design Reviews (CDRs) (ESA/ESTEC, Noordwijk, The Netherlands)
- July 2015 – BEXUS Integration Progress Reviews (IPRs) at student team sites
- September 2015 – BEXUS Experiment Acceptance Reviews (EARs) at student team sites
- 2-12 October 2015 – BEXUS Campaign (10 days) (SSC, Esrange Space Center, Kiruna, Sweden)
- January 2016 – Delivery of the final BEXUS Experiments reports to ESA

REXUS schedule (RX 19/20) [1]

- 22-26 June 2015 – REXUS Critical Design Reviews (CDRs) (DLR, Oberpfaffenhofen, Germany)
- September 2015 – REXUS Integration Progress Reviews (IPRs) at student team sites
- October/November 2015 – REXUS Experiment Acceptance Reviews (EARs) at student team sites
- 23-27 November 2015 – REXUS Integration Week (ZARM-FAB Bremen, Germany)
- 18-22 January 2016 – REXUS Bench Test Week (DLR, Oberpfaffenhofen, Germany)
- 07-19 March 2016 – REXUS Campaign (12 days) (SSC, Esrange Space Center, Kiruna, Sweden)
- June 2016 – Delivery of the final REXUS Experiments reports to ESA

The most important milestones for BEXUS projects in SNSB/ESA payload are described below.

- **SNSB/ESA Experiment Selection Workshop (ESW)**. Once the Experiment Proposal step is ended, the pre-selected teams are invited to a selection meeting called 'Selection Workshop' that involves 17 experts and 14 applicant teams from up to 10 European Member States. [1] During two days, the teams set their proposals out to the panel of experts. The technology and/or scientific part of the experiment is judged in this phase. During the event the participants receive advice and REXUS/BEXUS project information as well as training related to documentation (Student Experiment Document – SED), requirement analysis, schedule, planning and design aspects to consider at the beginning of a project. In addition, first milestones are set and students have, when possible, the opportunity to visit ESTEC facilities.

- **Preliminary Design Review (PDR) & Students Training Week (STW).** PDR is held in parallel with STW in a five-days duration event. The PDR intention is to give the expert board confidence that the team manage all aspects of the project in this phase: technical, organization and planning, safety, financial, outreach... The student teams set the project progress out to the panel of experts and receive feedback of it. The participant teams should demonstrate that their experiment design, including all subsystems, is feasible and reflects the functional, operational and safety requirements.

  Furthermore, the STW is an intensive training in project development. It consists of lectures on relevant scientific and engineering topics as verification of requirements, implementation, design, software or outreach, as well as detailed explanations of the launch vehicles systems. Also, there are "Ask the expert" discussion sessions at which any technical issues can be raised and addressed in a less formal environment. During these week, there are social events that involves tours facilities and cultural activities, which helps to exchange ideas and know more about other teams and their experiments. In addition, the mentoring programme is offered and milestones for CDR are set.

- **Critical Design Review (CDR).** At this stage, the complete detailed design of the experiment must be finished and the design documentation should be of adequate standard to allow the manufacturing and integration of flight hardware as well as experiment testing. The outcome of the CDR is used to judge to readiness of the project to begin the integration and testing phase, although systems testing should have had already begun at that time. [3] During this event, student teams have:
  - Lectures to prepare for the next steps of the programme,
  - Interface discussions for BEXUS,
  - And access to an 'Ask an Expert' session.

  One student from each team, usually the electric/electronic responsible, participates in a Flight Soldering and Harnessing Techniques course.

- **Integration Progress Review (IPR):** The main purpose of IPR is to ensure that the teams are making adequate progress in-line with their project plan and will be able to meet their experiment delivery deadline. By this event, an EuroLaunch representative move at the students' team site to check the progress on the integration phase. At that time, the experiment sub-systems should have reached the stages of development that follows:
  - The experiment design should be frozen and the design documentation should be of adequate standard to allow for the experiment hardware to be manufactured and integrated by a third party.
  - Most hardware should have been manufactured and the main software should be functional.
  - The verification and testing phase should be well underway. [3]

- **Experiment Acceptance Review (EAR):** The EAR is the final review in which an EuroLaunch representative evaluate if the experiment is qualified for flight. It usually takes place at the student team site and the students should present their fully integrated experiment and perform a flight simulation test. Successfully passing EAR implies the hand-over of the completed and fully functional experiment from the experiment team to the launch authorities. [3]

- **Launch Campaign:** The nominal duration of the BEXUS Launch Campaign is about ten days. Campaign and safety information are provided to the students as soon as they arrived to Esrange. The early days are dedicated to the final preparations of the experiments, the flight systems and the vehicles. Functional, interface and system tests are performed in subsequent days, followed by the assembly of the payloads and BEXUS vehicles for two launches. At this point, it is important to ensure that the complete equipment, including experiments and gondola systems, works properly together and per the time planning schedule time frames. Therefore, Interference Test (checking Hardline, E-Net, E-Link and gondola power supply), Flight Compatibility Test (including Radiofrequency Tests) and a flight simulation test are carried out. [2] These last preparations provide the teams a chance to check the communication with their experiment by telemetry as well as to make the final checklists before launch. When the experiments are Ready to Flight, team leaders signed that their experiments are safe and secure in the Pre-flight meeting. During launch, teams should be connected to their Ground Stations, collecting data and status of the experiment. After the launch, the teams should present their preliminary results. Later, if possible, the scientific payload is returned, inspected and dissembled. Finally, the experiment data is stored and the experiments are packed for transport back to the students' team sites. [3]

- **Results Presentation.** Once the Launch Campaign is over, the students should analyze their data, obtain results and draw conclusions. Around three months after, the participant teams should submit the final version of their SED document which acts as the team's final report. This document should be submitted even if the experiment did not function nominally during flight and it should incorporate flight performance information, experiment results and a 'lessons learned' chapter. [3]

2.1.3 BEXUS

One of the main topics in the Selection Workshop is if your experiment really need the vehicle which you are applying for. This means that you need to know what are the needs of your experiment to be success and be aware of the constraints that the vehicle includes in your project.

From the outset, BEXUS projects are determined by the characteristics of the launch vehicle. The total experiment payload mass is between 40 and 100 kg and there are different available configurations depending on the number of the selected experiments and their dimensions and mass. The typical BEXUS configuration consist of a 12.000 m^3 volume balloon filled with Helium gas, a gondola, a parachute and the BEXUS systems, with a total length up to 75 m. Inside the gondola, the payload is modularized to provide flexibility, simple interfaces and independence between experiments. The BEXUS system includes all payload service systems which are necessary for payload control, telecommunication, high speed telemetry and up-link command control of experiments as well as recovery. [3]

The duration of the BEXUS balloon flights is between 2 and 5 hours at 25 to 30 km of altitude, depending on total experiment mass. The balloon position is tracked during flight and the balloon trajectory is predicted in real time, based on GPS trajectory tracking, wind profile and meteorological models. [4] When the gondola has landed, a SSC team moves to its position and recovery occurs using a helicopter or a truck.

BEXUS experiments should be designed for the whole process, which includes the built-up, testing, operations, flight, recovery and programme timeline. Furthermore, safety, vehicle interfaces, radio frequency constraints, environment and loads need to be considered since the early stages of design.

The experiment should be compatible with the environmental conditions, which ranges from temperatures that goes from 20ºC at assembly to near 0ºC on the launch pad and 1atm of pressure, to as low as -70ºC and 6-10mbar during the flight. In addition, there is a very low humidity also called 'dry air'. [5] If the experiment is in direct sunlight during the flight, it is also possible that it can reach temperatures of more than 40ºC. Thus, teams should design a thermal control system (passive and/or active) to ensure that the whole experiment (including electronics and mechanics) is capable to operate in that environment. Also, the team must take it into account in their experiment design related to pressure vessels and possible outgassing of the materials as well as the possible conduction produced by the combination with temperature. Furthermore, when the gondola reaches the stratosphere the experiment is exposed to irradiation. This last condition is especially important for the electronics design and its correct protection.

Regarding the loads, the maximum accelerations are during parachute deployment and at impact with the ground. On the one hand, the ascent velocity is about 5 m/s and the landing velocity is about 8 m/s. On the other hand, it is difficult to predict the shock at impact because it depends on the ground surface. Thus, the payload should be prepared for a wide margin of load combinations. In brief, the experiment must resist 5g in horizontal and 10g vertically as well as to be able to withstand the vibration profile during flight and 3 meters fall. [4]

The power, data and mechanical interfaces should meet the requirements of the gondola systems. Also, the mass of the experiment, its position into the gondola and the power budget during pre-launch preparations and flight should be considered.

Figure 2-2 : BEXUS 21 Balloon just before the launch. Credit: REXUS/BEXUS Programme. [11]

Figure 2-3 : BEXUS 21 Balloon at the time of launching [left]. Credit: REXUS/BEXUS Programme. [11]

Figure 2-4 : BEXUS 21 Balloon after the launch [right]. Credit: REXUS/BEXUS Programme. [11]

On the 7th of October 2015, SPADE experiment was launched on board BEXUS 21 at 9:30 UTC. During the flight, the balloon ascent was nominal and the maximum floating altitude was about 27 km at 11:00 UTC. After about 80 minutes of float time, BEXUS 21 started to descend unexpectedly which were believed to be due to a small hole in the balloon. The decision to cut-down was then made at 12:36 UTC, the parachute released and the gondola touched down in a largely unpopulated area. The total flight time, including ascent and descent, was a slightly higher than 3 hours. Finally, BEXUS 21 just landed about 60 km East of Gällivare in Sweden. The BEXUS 21 gondola was recovered after the BEXUS 20 flight. [11]

2.2 SPADE Experiment

SPADE stands for Smartphone Platform for Acquisition of Data Experiment, which consist of a low-cost real time data acquisition platform for stratospheric exploration missions. It was based on commercial off-the-shelf (COTS) hardware. It was composed of two smartphones and an auxiliary sensor network. The sensor network was composed of sensor nodes, like those being used currently on industrial applications, connected among them by a low powered standard wireless connection (protocol 802.15). [6] It was developed by a team of students in Aerospace, Telecommunication, Industrial and Software Engineering at the Universidad de Sevilla. This experiment was part of the 8th REXUS/BEXUS Programme cycle in BEXUS 21 campaign.

Figure 2-5 : SPADE logo

2.2.1 Scientific and Technical Background

At the beginning of SPADE Project, it was necessary to read up on the state-of-art of space-related wireless networks. Thanks to an agreement with the Universidad de Sevilla (US) and the Institute of Electrical and Electronics Engineers (IEEE), it was possible to use their ‘IEEE Xplore Digital Library’ to do the research. Also, European Space Agency Website has interesting articles which helped with the study. All this information helped to a better understanding of the experiment possibilities which subsequently helped with the objectives and requirements definition. The result was developed through the first versions of the SED and the final version is presented below.

In the space sector, there is a strong interest in forming flying or swarm missions with small satellites, which are expected to have important benefits in terms of low system and deployment costs, distributed sensor capability or high reliability due to redundancy. Up to now, space communication has only addressed static inter-satellite links (ISL), mainly based on proprietary protocols. One idea is to adopt well-known terrestrial communication standards, such as IEEE 802.11. [7] For example, ZigBee, which is based on an IEEE 802.15.4 standard. It has been proven for a wide range of industrial applications and provides the opportunity of developing a smart spacecraft infrastructure. [8]

COTS components are suitable for such protocols with minor changes. Wireless sensor networks (WSNs) are multi-hop self-organizing networks, which include a huge number of nodes integrating measuring, data processing and wireless communications in order to collect and process information. The interest in using space-based wireless sensor networks (SB-WSNs) is increasing. This applies the concept of terrestrial wireless sensor networks to the space. [9] Wireless sensor nodes placed throughout a spacecraft might function as a networked nervous system, yielding a wealth of currently inaccessible structural or environmental data to mission controllers. Similar nodes scattered across a planetary surface would generate a much higher scientific return than a single lander could. [10] WSNs are commercial technology which has the potential of improving data collection and scientific benefits for future space missions by using terrestrial communication standards.

ESA engineers are also working on this direction because they are planning to apply the same wireless system that connect our commercial devices, as mobile phones or laptops, to develop a new generation of networked space hardware. [10]

Finally, smartphones are small and low-cost processing units which include an acceptable number of sensors. These COTS devices may be modified as processing or control units for spacecraft’s infrastructures. They are easy-to-use and the opportunities that they offer, makes it more interesting to have them into account when looking for the creation of a new spacecraft hardware generation. [6]

2.2.2 Motivation

Space agencies earmark very substantial financial and human resources on developing aerospace technology, that is why the space sector is using and adapting commercial technology to space applications with the aim of reducing costs. [6] The main idea behind SPADE was to demonstrate whether commercial technology could replace this specific space technology once they are correctly adapted to space applications. The experiment checked if it was possible to replace them or not in the conditions (BEXUS conditions) that are not exactly outer space conditions, but are quite similar as a first approximation. This would be an interesting result for future experiments such as a satellite platform adaptation. Nevertheless, the extrapolation of SPADE conclusions to other space applications would be too detailed and thus go beyond the scope of this TFG.

2.2.3 Objectives

In space projects the objectives are described in detail as well as clearly and briefly defined. In addition, the common understanding of them by all the mission participants, as the customer, the mission developer and the foreseen mission operator, is necessary.

In accordance with the SED Guidelines [12], the SPADE objectives definition process involved a brainstorming of the team, definition of the most important objectives which should be reached in order to consider the experiment successful (primary experiment objectives), definition of additional objectives which could add some value to the experiment (secondary experiment objectives), consider and define the constraints which need to be considered and distinguish into scientific and technological objectives. The result is developed in detailed though the SED [6] and it is shown below:

Primary Objectives

The experiment includes two main technical goals:

- Obj. 1.1: To study the behavior of the wireless sensors network, which includes the performance of the communications towards/from the central unit in a demanding situation such as the conditions that will be aboard BEXUS (stratospheric environment equals low pressure plus low temperature). Particularly, those conditions that cannot be easily reproduced in ground (radiation).
- Obj. 1.2: To test the performance of commercial components, such as smartphones, sensor nodes and commercial batteries, as the central unit for this type of platform in this harsh environment.

The experiment includes one main scientific goal:

- Obj. 1.3: To measure the flux of cosmic rays' particles (energetic particles) in the stratosphere since they affect electronic devices. The target is to monitor and collect a number of cosmic rays' particles to crosscheck this data with the performance of the platform as a parameter that affects electronics. [6]

Secondary Objectives

Besides, the experiment includes as secondary objectives:

- Obj. 2.1: To prove in the experiment a smartphone application ('CRAYFIS') which is able to catch cosmic rays' particles on land. The idea is to test whether this application would get good results by catching this sort of rays in the stratosphere.
- Obj. 2.2: To prove the protective boxes endurance that covers the devices. [6]

2.2.4 Experiment Concept

The experiment is a real time low-cost data acquisition platform for stratospheric exploration missions. The experiment checked if it is possible to replace space technology with commercial technology. The result is developed in detailed though the SED [6] and it is shown below:

The experiment was formed by the following items:

- Three sensor nodes (SN)
- A concentrator node (CN).

- Two smartphones with internal sensors and cameras (SD1/SD2).
- A router.
- A ground station (GS): a laptop.

With these elements of the experiment there were three functional blocks:

BLOCK 1: consisting on a wireless sensor network, which included the sensor nodes and the concentrator node forming a star set-up.

- The concentrator node store information about the network and send it to the router.
- The sensor nodes were the external measurement unit.

BLOCK 2: consisting on a central unit (CU) composed by two smartphones and the router:

- SD1, SD2 take measurements on their own.
- The router send all the information to E-link.

BLOCK 3: consisting on a ground station (GS) that download data for later analysis and upload commands for any necessary adjustment.

The sensor nodes and the concentrator node was forming a ZigBee communication network, which was connected to the router through an Ethernet connection.

Besides, the smartphones were connected to the router to transmit all the measurements in real time. An microUSB-USB-Ethernet adapter was used to connect it to the router.

In case of failure of one of the smartphones, the other one will be able to assume all the work thanks to the redundancy system.

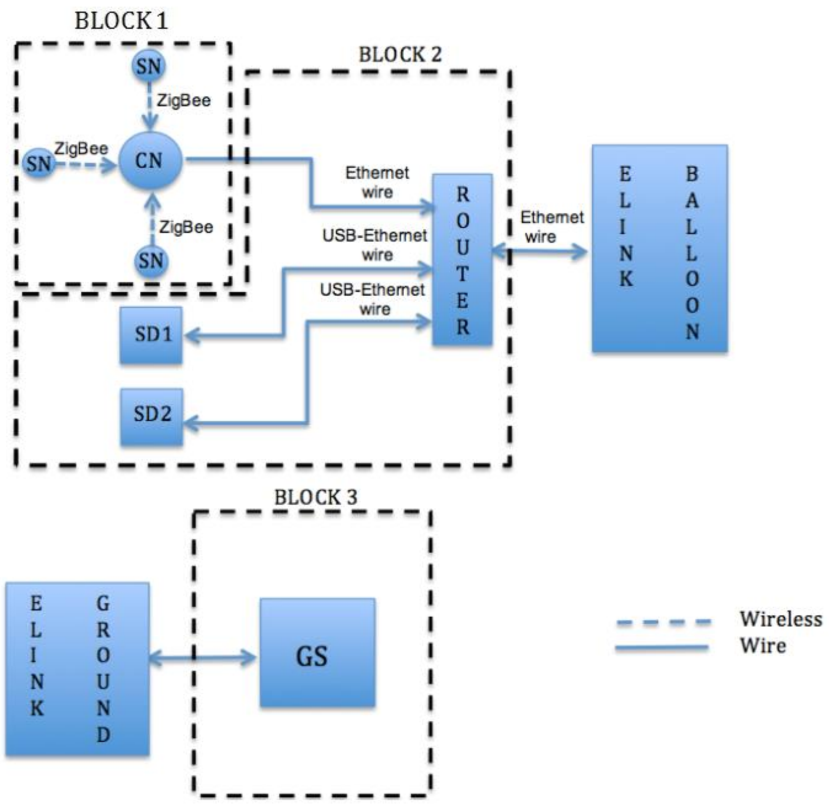


Figure 2-6: SPADE experiment set-up. [6]

3 PROJECT DEFINITION, OBJECTIVES AND SCOPE

PROJECT Planning and its implementation involves all the processes and activities required to plan and execute a project. From the beginning to its completion, all levels and stages of development should be considered in a coordinated, structured and efficient manner. Furthermore, this activity involves close co-operation across the projects domains and its inputs come from all project disciplines [13] In this section, it is defined this TFG, its objectives and scope.

3.1 Project Definition

This final project is mainly focused on the subjects which are outlined below:

- Requirements, constraints and resources analysis.
- Project planning of the experiment, including work-distribution, scheduling and budget.
- Project management of the experiment along with risk management, logistics, sponsors and suppliers' management and team management.
- Other developed tasks like documentation, English proofreading and outreach.

3.2 Objectives and scope

The main objective of this TFG is to develop and follow-up a Project Management Plan, including Risk Management, which involves and manage all the aspects of the project that are necessary for the correct development of SPADE, during all the project life-cycle, in order to achieve the experiment objectives. In addition, other secondary objectives are to develop the Team Leader function, acting as a Focal Point for all project participants (REXUS/BEXUS programme, Universidad de Sevilla, sponsors, suppliers and the team), also to produce and review the required documentation and to develop some support functions like logistics and material supply.

The scope of this project includes all SPADE project life-cycle, from objectives and requirements definition, design, integration and testing phases, to launch and flight. Moreover, the results analysis and conclusions are presented.

4 REQUIREMENTS AND SOLUTIONS ANALYSIS: PROJECT MANAGEMENT

DUE to this project had a duration of more than one year, the proposed Project Plan was changing as the project progressed to adequate it to the reality. This chapter analyses the requirements and describes the followed solutions and its evolutions over time.

As it was said, the main activities were:

- Project planning, management and monitoring of the project, including team and external support management.
- Risk Management.
- Logistics and material supply
- Documentation and proofreading
- Outreach

4.1 Project Planning

At the beginning of SPADE, a Project Plan to organize all the tasks was made. This preliminary plan evolved along the stages of the experiment. This activity follows an iterative process whose objective was to ensure a coherence and complete overview of the whole project as well as guarantee that it was enough detailed to not miss any aspect of the project.

The main subjects of this activity can be summarized as follows:

- **What do we want to achieve?** Define the requirements and constraints of the project in order to achieve the objectives and mission statement of the project.
- **How will it be done?** Analyze the requirements and constraints along with REXUS/BEXUS Programme milestones and other external factors to provide an output with the work packages and define the work breakdown structure.
- **Which are the resources?** Analyze the available resources: manpower, external support and budget.
- **When will it be done?** Define the schedule with phases and milestones which enables the progress of the project to be controlled with respect to cost, schedule and technical objectives.
- **Is the project going as planned?** Monitoring and control of the project.

4.1.1 Requirements and constraints definition and analysis

A space project typically comprises a space segment and a ground segment which are implemented in parallel. They rely on, and have interfaces with the launch service segment. These three segments comprise a space system. [13] SPADE is structured like a typical space system; whose launch service segment is BEXUS. For this reason, BEXUS constraints and requirements (see section 2.1.3) were considered from the beginning in SPADE requirements and constraints definition and analysis.

To achieve the SPADE objectives (see section 2.2.3) the experiment had to have specific functionalities, which needed to be performed during the flight to the desired standard through the good technical design. These functional, performance, design, and operational requirements needed to be determined during the first stages of design, before starting the detailed experiment design.

Requirements may be defined as the practical translation of the objectives and how to achieve them. Moreover, it should consider the whole process, which includes the built-up, testing, operations, flight, recovery and programme timeline. In addition, all the constraints of the project should be reflected to ensure the clear, complete and detailed definition of the experiment.

The process was iterative and started with an experiment objectives analysis, which provides the requirements and constraints. On its drafting, each requirement was sort by a decreasing scale of binding conditions as follows: shall, should or may be done.

The key of design it to follow the 'Keep it simple' rule, which stands for simplify the design as much as possible to avoid problems stemming from the complexity of the design.

Once the several stages of design were finished, the requirements were checked to verify if they were indeed fulfilled. This verifications process was done in the Test phase.

In accordance with the SED Guidelines [12], the requirements are classified as follows:

- Functional Requirements
- Performance Requirements
- Design Requirements
- Operational Requirements

The final requirements list is presented in the sections below.

4.1.1.1 Functional Requirements

Functional requirements define what the product shall perform in order to accomplish with the mission statement. In other words, they define the functionality that the experiment needs to have or the tasks it needs to fulfil in order to achieve the experiment objectives. [12] The experiment functional requirements are presented below, note that F.2 ('F.2: The experiment shall measure the pressure outside the gondola during the whole flight of the balloon by using one sensor node.'), which was defined in a preliminary version, was discarded because it was not necessary for the acomplish of the objectives.

Table 1 : SPADE Functional requirements [6]

F.1:	The experiment shall measure the temperature outside the gondola during the whole flight of the balloon by using one sensor node.
F.3:	The experiment shall measure the CO_2 concentration outside the gondola during the whole flight of the balloon by using one sensor node.
F.4:	The experiment shall measure cosmic ray particles during the whole flight of the balloon.
F.5:	The experiment shall measure the acceleration of the balloon during the whole flight by using two smartphone's accelerometer sensors.
F.6:	The experiment shall measure the angular rotational velocity of the balloon during the whole flight.
F.7:	The experiment shall measure the position of the balloon during the whole flight.

Cosmic ray particles measures were taken by the smartphones' cameras, with CRAYFIS app. [6]

4.1.1.2 Performance Requirements

Performance requirements quantify to what level the functional requirements have been fulfilled. As for measurements, they typically define range, precision and frequency. Moreover, they define how much the functionality had been fulfilled. [12] The experiment performance requirements are linked with the functional requirements and are presented below.

Table 2 : SPADE Performance requirements [6]

Response to F.1	
P.1:	Operational temperature measurement range shall be between -80 and +50 Celsius degrees.
P.2:	The temperature measuring outside the Gondola shall be made with an accuracy of +/- 1 Celsius degree.
Response to F.3	
P.5:	Operational CO_2 concentration measurement range shall be between 400 and 10000 ppm.
P.6:	The CO_2 concentration measuring outside the Gondola shall be made with an accuracy of +/- 3%.
Response to F.1 - F.3	
P.7:	The temperature and CO_2 concentration measurement outside the Gondola shall be made at a rate of 1 measurement every 60 seconds.
Response to F.5	
P.9:	Operational acceleration measurement range shall be between 0 and +/- 20 meters per square seconds.
P.10:	The acceleration measuring shall be made with an accuracy of +/- 2 meters per square seconds.
Response to F.6	
P.11:	The angular rotational velocity measuring range shall be between 0 and 70 degree per second.
P.12:	The angular rotational velocity measuring shall be made with an accuracy of 10 degrees per second.
Response to F.7	
P.13:	The position measuring shall be made with an accuracy of +/- 30 meters.
Response to F.5 - F.7	
P.20:	The smartphone's sensors measurement shall be made at a rate of 1 measurement every 60 seconds.

As the aim was to create a 'real time' data acquisition platform, the team estimated 60 seconds as enough to be considered real time data and avoid to use a big downlink data rate. [6]

4.1.1.3 Design Requirements

Design requirements define all design aspects that the experiment needs to fulfil in order to achieve the experiment objectives. While functional requirements and performance requirements originate from the experiment team, design requirements can come from other sources, such as:

- the flight environment (e.g. the need to withstand mechanical and thermal stress)
- the launch vehicle (e.g. certain components may be forbidden)
- legal limitations (e.g. frequency allocation)
- safety restrictions (e.g. high voltage or ionisation)

An important subset of design requirements are the interface requirements, which determine if the mechanical and electrical interfaces to the launch vehicle are correct. [12]

The following table reports the design requirements that the experiment need to fulfil.

Table 3 : SPADE Design requirements [6]

D.1:	Smartphones shall operate in the temperature profile of the BEXUS balloon.
D.2:	Smartphones batteries shall be qualified for their use on a BEXUS balloon.
D.3:	Smartphones batteries shall be either rechargeable or shall have sufficient capacity to run the experiment during pre-flight tests, flight preparation and flight.
D.4:	Smartphones batteries shall be accessible from the outside within 1 minute, once the experiment is in the Gondola.
D.5:	Smartphones shall operate in the pressure profile of the BEXUS balloon.
D.6:	Smartphones shall be well fixed to the Central Unit Box.
D.7:	The Wireless Sensor Network (WSN) components shall operate in the temperature profile of the BEXUS balloon.
D.8:	The batteries of the WSN components shall be qualified for use on a BEXUS balloon.
D.9:	The batteries of the WSN components shall be either rechargeable or shall have sufficient capacity to run the experiment during pre-flight tests, flight preparation and flight.
D.10:	The batteries of the WSN components shall be accessible from the outside within 1 minute, once the experiment is in the Gondola.
D.11:	The WSN's components shall operate in the pressure profile of the BEXUS balloon.
D.12:	The WSN's components shall not transmit in 2.4GHz
D.13:	The WSN's enclosure boxes shall be well fixed to Gondola.
D.14:	Experiment boxes shall resist the vibration profile of BEXUS balloon.
D.15:	Experiment boxes shall resist 3 meters fall.
D.16:	Experiment boxes shall not harm or disturb the Gondola.
D.17:	Experiment boxes shall be well fixed to the Gondola
D.19:	The router shall operate in the pressure profile of the BEXUS balloon.
D.20:	The router shall operate in the temperature profile of the BEXUS balloon.

D.21:	The router shall be well fixed to the experiment box.
D.22	Smartphone's cameras shall have a clear view up. (Response to F.4)

4.1.1.4 Operational Requirements

Operational requirements define what should the experiment fulfil to be handled and operated safely and reliably. With ‘operation’ we do not just cover the processes ocurring during the flight, but also those occurring prior and post flight. Some of the operational requirements are related to experiment safety. [12]

The operational requirements of SPADE experiment are shown in the following table.

Table 4 : SPADE Operational Requirements [6]

O.1:	The experiment shall be able to switch the smartphone to any mode by receiving a signal from the ground station.
O.2:	The experiment shall be able to store all the data in an internal memory.
O.3:	The experiment shall be able to turn on/off the camera during the flight.
O.4:	The experiment shall be able to restart devices from the ground station in case that any of them hangs.
O.5:	The experiment shall stop taking measurements after landing.
O.6:	The experiment shall be able to keep sending measurements even if any sensor is not working.

4.1.1.5 Constraints

Constraints are conditions which limit the design and should be considered throughout the design process. Related to SPADE experiment, the main constraints are cost, availability of the team members and some specific technical issues. The experiment constraints are listed below.

Table 5 : SPADE Constraints [6]

C.1:	The cost of the experiment shall not exceed 7000 €
C.3:	The experiment COTS components usually work in a temperature range higher than in BEXUS conditions.
C.4:	Sensor nodes must take measurements every 60 seconds to optimize the taking data network.
C.5:	The amount of time that each member can put into the project is limited due to all team members are students.
C.6:	The holes for the smartphones' cameras must be placed in the top of the Central Unit box.

Nevertheless, there are some ‘constraints’ that are not listed above but were taken into consideration during the management of the project. These additional constraints are the inexperience of some team members, whose learning curve had an impact on the planning, and the bureaucracy of the activities that need to be carried out through the university caused by its status as a public institution, which increased the time frames.

4.1.2 Work Breakdown Structure (WBS)

The WBS is a structure which divides the project into manageable work packages (WP) organized by the nature of the work by breaking down the total work into increasing levels of detail. A WP can be any element of the WBS down to the lowest level that can be measured and managed for planning, monitoring, and control. [13]

This structure could be used as a reference system for the project management to:

- Identify the tasks and responsibilities of each actor;
- Facilitate the coherence between all activities of the whole project;
- Perform scheduling and costing activities. [13]

At first, the initial workload distribution was focused on its technical aspect. This decision was taken because the idea was to adapt COTS and it was easier to identify the workload using the blocks that composed the experiment: Wireless Sensor Network (WSN), Smartphones Devices (SD), router and ‘hardware adaptation & testing’. The latest including the designing of the protective enclosures that covered the systems and the proper testing.

After that, new needs such as project planning and documentation arose. Furthermore, REXUS/BEXUS programme requested to control the experiment using a Ground Station during flight and an outreach plan. For these reasons, four new WP were created: Project Management, Documentation, Ground Station and Outreach. Also, the ‘Hardware adaptation & Testing’ WP was split in two: ‘Hardware set-up and adaptation’ and ‘Endurance testing’. This last decision was taken to have a better control of the tasks due to an increase of the original WP tasks.

The WBS was reviewed through the several phases. During this process, some of the tasks were created, modified or deleted by project needs, mainly caused by an increasing detail in the design and changes in the manpower. At the end, the overall work was split into 9 WP and each WP had several tasks which are described below. Note that Task 6.4-2 is not in the list, as it was deleted during the design phase caused by a modification.

Table 6 : Work packages of SPADE Experiment [6]

SPADE Experiment
WP1. Project management
Task1.1 Organization: defining Work Breakdown Structure
Task1.2 Planning: defining Project Schedule
Task1.3 Resources
Task1.3-1 Manpower
Task1.3-2 Budget
Task1.3-3 Financial and Technical Support
Task1.4 Risk management
Task 1.5 Team coordination
Task 1.6 Shipping preparations
WP2. Documentation
Task2.1 Proposal
Task 2.1-1 Proposal v1

Task 2.1-2 Proposal v2

Task 2.2 Experiment Defense (Selection Workshop)

Task 2.3 Prepare SED for PDR

Task 2.4 Prepare SED for CDR

Task 2.5 Prepare SED for IPR

Task 2.6 Prepare SED for EAR

Task 2.7 Prepare SED for Final Report

Task 2.8 Documentation management

Task 2.9 Revision of the SED before review

Task 2.10 Proofreading

WP3. Wireless Sensor Network (WSN)

Task 3.1 Sensor Nodes (SN) and concentrator node (CN) settings

Task 3.2 Configure and prove wireless connection (ZigBee) between SN and Concentrator Node

Task 3.3 Configure connection between Concentrator Node and Router

WP4. Smartphone Devices' (SD)Sensors data collection

Task 4.1 Program a SD's sensors data collection and storage app

Task 4.2 Configure connection between SD and Router

Task 4.3 Check the continuous transmission between SD and Ground Station (GS): configure balises

Task 4.4 Configuration of a cosmic ray particles app

WP5. Router Communications

Task 5.1 Configure router settings

Task 5.2 Configure connection between router and E-Link

WP6. Hardware set-up and adaptation

WP6.1 Preview design COTS testing

Task 6.1-1 Thermal test

Task 6.1-2 Pressure test

Task 6.1-3 Power test

Task 6.1-4 Thermal and Pressure test

Task 6.1-5 Vibration and Fall resistant test

Task 6.1-6 Batteries suitability test

WP6.2 Protective enclosure design

Task 6.2-1 Preliminary design

Task 6.2-2 Assembly

Task 6.2-3 Integration

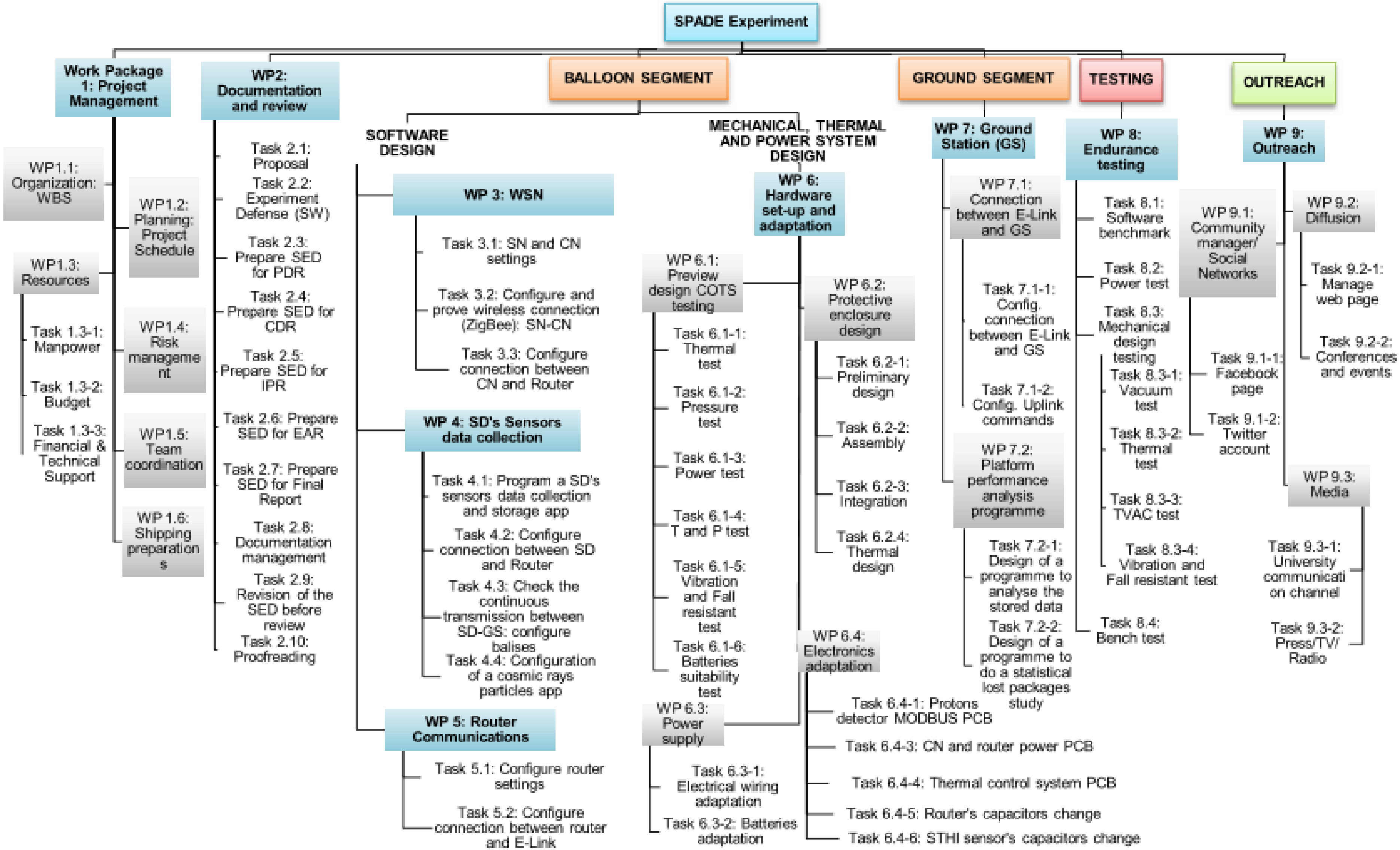
Task 6.2-4 Thermal design

WP6.3 Power supply	
Task 6.3-1 Electrical wiring adaptation	
Task 6.3-2 Batteries adaptation	
WP6.4 Electronics adaptation	
Task 6.4-1 Protons detector MODBUS PCB	
*Task 6.4-3 Concentrator node and router power PCB	
Task 6.4-4 Thermal control system PCB	
Task 6.4-5 Router's capacitors change	
Task 6.4-6 STHI sensors' capacitors change	
WP7 Ground Station (GS)	
WP7.1 Connection between E-Link and GS	
Task 7.1-1 Configure connection between E-Link and GS	
Task 7.1-2 Configure Uplink commands	
WP7.2: Platform performance analysis programme	
Task 7.2-1: Design of a programme to analyse the stored data	
Task 7.2-2: Design of a programme to do a statistical lost packages study	
WP 8: Endurance testing	
Task 8.1 Software benchmark	
Task 8.2 Power test	
Task 8.3 Mechanical design testing	
Task 8.3-1: Vacuum test	
Task 8.3-2: Thermal test	
Task 8.3-3: Vacuum and Thermal (TVAC) test	
Task 8.3-4: Vibration and Fall resistant test	
Task 8.4: Bench test	
WP 9: Outreach	
WP 9.1: Community manager/ Social Networks	
Task 9.1-1: Facebook profile	
Task 9.1-2: Twitter account	
WP 9.2: Diffusion	
Task 9.2-1: Manage web page	

Task 9.2-2: Conferences and events
WP 9.3: Media
Task 9.3-1: University communication channel
Task 9.3-2: Press/ TV/ Radio

In the next page, every WP is associated with the total work of the project in the final version of the WBS:

Figure 4-1: Final Work Breakdown Structure [6]



4.1.3 Resources analysis

4.1.3.1 Manpower

The human resources of SPADE team have been changing along the project phases. At the beginning, the team was composed by five Engineering Degree students and one Journalism Degree student. The lattest being responsible of the Outreach programme.

After that, the complexity of the software increased substantially and owing to this additional support was needed on this area. Due to this reason, a Software Master student joined the team. Also, a Translation of Software and New Technologies Master student joined the team to help with the English translation and proofreading of the documentation.

For unrelated reasons, the Journalism Degree student and the Translation Master student left the team at different times. Therefore, their workload was redistributed and assigned as part of the Team Leader's function as well as the documentation WP.

Nevertheless, most of the time the team was composed of six students:

- **A**: Aerospace Engineering Degree student specialized in Aerospace Vehicles
- **B**: Aerospace Engineering Degree student specialized in Aerial Navigation
- **C**: Telecommunications Engineering Degree student
- **D**: Industrial Engineering Degree students not specialized yet
- **E**: Industrial Engineering Degree students not specialized yet
- **F**: Master Student with a Software Engineering Bachelor

The detailed availability of each team members was considered and updated periodically in the SED [6]. In the following table, it is shown an overview of the availability of the SPADE team members during the year 2015 and January 2016:

Table 7: SPADE team members' availability [6]

Team member	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**
A													
B													
C													
D													
E													
F													

% of time per week	**100%**	**>75%**	**50-75%**	**25-50%**	**<25%**	
Estimated hours	**16h**	**>12h**	**8-12h**	**4-8h**	**<4h**	

As said, manpower was changing along the project and the tasks were redistributed and reviewed consequently. However, the possibility of changes in the human resources were considered since the very beginning. For this reason, when the workload distribution was planned, every member of the team was assigned several tasks and 'pre-assigned' tasks of other members of the team in case of need. The decision of which tasks were designated for each person was made depending on their skills, their technical background and their availability. Moreover, one person per WP is chosen as responsible who reports back for progress reports.

The final workload distribution was detailed in the SED [6] and it is shown below. Note that team member 'A' does not appear as 'Backup responsible' since 'A' took over the workload and roles from the said ex-member that left the team.

Table 8: Summary of SPADE workload distribution

SPADE Experiment	**WP/Task Responsible**	**Backup Responsible**
WP1. Project management	**A**	All team
Task1.1 Organization: defining Work Breakdown Structure	A	All team
Task1.2 Planning: defining Project Schedule	A	All team
Task1.3 Resources	A	B
Task1.3-1 Manpower	A	B
Task1.3-2 Budget	A	B
Task1.3-3 Financial and Technical Support	A	B
Task1.4 Risk management	A	D
Task 1.5 Team coordination	A	All team
Task 1.6 Shipping preparations	A	All team
WP2. Documentation	**A**	All team
Task2.1 Proposal	All team	All team
Task 2.1-1 Proposal v1	All team	All team
Task 2.1-2 Proposal v2	All team	All team
Task 2.2 Experiment Defense (Selection Workshop)	All team	All team
Task 2.3 Prepare SED for PDR	All team	All team
Task 2.4 Prepare SED for CDR	All team	All team
Task 2.5 Prepare SED for IPR	All team	All team
Task 2.6 Prepare SED for EAR	All team	All team
Task 2.7 Prepare SED for Final Report	All team	All team
Task 2.8 Documentation management	A	All team
Task 2.9 Revision of the SED before review	A	All team
Task 2.10 Proofreading	A	All team
WP3. Wireless Sensor Network (WSN)	**B**	**F**
Task 3.1 Sensor Nodes (SN) and concentrator node (CN) settings	B	F
Task 3.2 Configure and prove wireless connection (ZigBee) between SN and Concentrator Node	B	F

Task 3.3 Configure connection between Concentrator Node and Router	B, F	F
WP4. Smartphone Devices' (SD)Sensors data collection	**F**	**B**
Task 4.1 Program a SD's sensors data collection and storage app	F	B
Task 4.2 Configure connection between SD and Router	F	B
Task 4.3 Check the continuous transmission between SD and Ground Station (GS): configure balises	F	C
Task 4.4 Configuration of a cosmic ray particles app	F	D
WP5. Router Communications	**F**	**C**
Task 5.1 Configure router settings	F, C	C
Task 5.2 Configure connection between router and E-Link	F, C	C
WP6. Hardware set-up and adaptation	**E**	**D**
WP6.1 Preview design COTS testing	D, E	D
Task 6.1-1 Thermal test	D, E	D
Task 6.1-2 Pressure test	D, E	D
Task 6.1-3 Power test	D, B, E, A	D
Task 6.1-4 Thermal and Pressure test	D, E, A	D
Task 6.1-5 Vibration and Fall resistant test	D, E	D
Task 6.1-6 Batteries suitability test	D, A	D
WP6.2 Protective enclosure design	E	D
Task 6.2-1 Preliminary design	E	D
Task 6.2-2 Assembly	E	D
Task 6.2-3 Integration	E	D
Task 6.2-4 Thermal design	D	E
WP6.3 Power supply	B	E
Task 6.3-1 Electrical wiring adaptation	E, D	E
Task 6.3-2 Batteries adaptation	B	E
WP6.4 Electronics adaptation	B	C
Task 6.4-1 Protons detector MODBUS PCB	B	C
Task 6.4-3 Concentrator node and router power PCB	B	C
Task 6.4-4 Thermal control system PCB	B	C
Task 6.4-5 Router's capacitors change	B	C
Task 6.4-6 STHI sensors' capacitors change	B	C

WP7 Ground Station (GS)	**C**	**F**
WP7.1 Connection between E-Link and GS	C	F
Task 7.1-1 Configure connection between E-Link and GS	C	F
Task 7.1-2 Configure Uplink commands	C	F
WP7.2: Platform performance analysis programme	C	F
Task 7.2-1: Design of a programme to analyse the stored data	C	F
Task 7.2-2: Design of a programme to do a statistical lost packages study	C	F
WP 8: Endurance testing	**D**	**E**
Task 8.1 Software benchmark	F, C	E
Task 8.2 Power test	D	E
Task 8.3 Mechanical design testing	D	E
Task 8.3-1: Vacuum test	D	E
Task 8.3-2: Thermal test	D	E
Task 8.3-3: Vacuum and Thermal (TVAC) test	D	E
Task 8.3-4: Vibration and Fall resistant test	D	E
Task 8.4: Bench test	D	E
WP 9: Outreach	**A**	**All team**
WP 9.1: Community manager/ Social Networks	A	All team
Task 9.1-1: Facebook profile	A	All team
Task 9.1-2: Twitter account	A	All team
WP 9.2: Diffusion	A	All team
Task 9.2-1: Manage web page	A	All team
Task 9.2-2: Conferences and events	A	All team
WP 9.3: Media	A	All team
Task 9.3-1: University communication channel	A	All team
Task 9.3-2: Press/ TV/ Radio	A	All team

4.1.3.2 External support

The external support was achived along the development of the experiment. Thus, planning the needs of the project in every stage was an iterative process. Moreover, the economic resources available were provided by the public institutional bodies and private sponsors. The external support which was achived is described below as well as in SED [6].

SPADE was born as a project of students within an educational programe. Because of this, the project had the support of Universidad de Sevilla (US) and its school of engineering, Escuela Técnica Superior de Ingeniería (ETSI), both based in Seville (Andalusia, Spain). In addition, part of the experiment was financially supported by an Airbus Chair at Universidad de Sevilla. [6]

The main technical and scientific support was the Electronics Engineering Department, ETSI and US. This activity was supervised by professors from the Electronic Engineering Group. Especially, by Dr. Miguel A. Aguirre, Dr. Hipólito Guzman, Dr. Fernando Muñoz and Dr. Rogelio Palomo. [6]

The sponsorship from a microelectronics company called Adevice Solutions, based in Seville (http://www.adevice.es/en/), was obtained. They provided the wireless sensors nodes.

Also, the sponsorship from Alter Technology (Tüv Nord Group) was gotten, which provided the facilities to perform the tests to prove the experiment before flight. Furthermore, Alter sponsored the transport of the experiment to Kiruna (Sweden) for the Launch Campaign. Also, they provided the shipping of the experiment back to Seville from the Launch Campaign. [6]

Furthermore, a collaboration with Barcelona Microelectronics Institute (IBM) – Spanish National Centre of Microelectronics (CNM) – Spanish National Scientific Research Council (CSIC) was achieved. They provided a Proton Sensor for the Wireless Sensor Network. [6]

Besides an in-kind sponsorship of SAFT Baterías, the Spanish section of SAFT Groupe, was achieved. They supplied the batteries to SPADE experiment. [6]

Finally, the sponsorship of MCM Ingeniería y Mecanizados Aeronáuticos was gotten. s an Andalusian company dedicated to design, manufacture and machine components for the aeronautical sector. They had provided the material and manufacturing costs of the clamps and the 3D components. [6]

4.1.3.3 Budget

The analysis of economic resources and a correct distribution of the cost during the different stages of the progress was essential for the full development of the project. A preliminar estimation of the cost was made and it was modified through the time.

The economic resources available included the funding provided by the sponsors, both public and private (see section 4.1.3.2). A preliminar estimation of the experiment included the basic materials and the team travel costs. More specific needs were added as the design progressed. To maintain a control of the cost from the several sources, a budget chart was made. The final version of budget [6] and the keys for funding and status used during the project are presented above.

Key for funding:

- US (Universidad de Sevilla) means the financial support provided by Universidad de Sevilla and its partners: ETSI (Escuela Técnica Superior de Ingenieros) and VTT (Vice-chancellorship of Technology Transfer).
- AICIA (Association of Investigation and Industrial Cooperation of Andalusia).
- Airbus Chair for Aeronautical Engineering studies of the Universidad de Sevilla.
- Alter Technology (Tüv Nord Group).
- Barcelona Microelectronics Institute (IBM) – Spanish National Centre of Microelectronics (CNM) – Spanish National Scientific Research Council (CSIC).
- SAFT Baterías (SAFT Group).
- MCM Ingeniería y Mecanizados Aeronáuticos (Aeronautical Engineering and Machining). [6]

Key for the statuses of the elements:

- TBD (To Be Determined) meant that the element to purchase was not decided yet.
- Ordered meant that the element was already ordered but the team was waiting for its delivery or its purchase.
- Ready meant that the component was already with the team.
- NA (Not Applicable) meant that the sponsor covered the costs. [6]

Table 9 : Budget [6]

Component	Units	Cost (€/unit)	Partial Cost (€)	Funding	Current status
Adevice: "One Go" Sensor Node (3+3spare)	6	140 €	840 €	Adevice Sponsorship	Ready
Adevice: "One Go" Concentrator Node (1+1spare)	2	285 €	570 €	Adevice Sponsorship	Ready
Outdoor antenna for Sensor Nodes (3+2spare)	5	10 € (*)	50 € (*)	Adevice Sponsorship	Ready
STHI: Temperature sensor MODBUS	1	90,75 €	90,75 €	US (VTT)	Ready
STHI: CO_2 IR sensor MODBUS	1	221,43 €	221,43 €	US (VTT)	Ready
STHI: Temperature, CO_2 IR and humidity sensor MODBUS (spare)	1	251,68 €	251,68 €	US (VTT)	Ready
Protons sensor (1+spare)	2	NA	NA	IBM-CNM-CSIC	Ready
Samsung: Galaxy S5 (1+1 Spare)	2	469 €	938 €	US (VTT)	Ready
LG G3 D855 (1+1 Spare)	2	499 €	998 €	US (VTT)	Ready
Edimax: USB - Ethernet wire (2)	2	38,06 €	76,12 €	US	Ready
Hirose: USB-Micro USB adapter (1 spare)	1	12 €	12 €	US	Ready
Arduino: Micro USB Male to USB A Female Adapter (2)	2	3,44 €	6,88 €	US	Ready
D-Link: Router DSR-250N	1	272,69 €	272,69€	Airbus Chair	Ready
Rotronic: Cat6 Ethernet Cable Assembly S/FTP	4	1,14 €	4,56 €	US	Ready
METCASE: Box M5505110 (Unicase 5)	1	127,45 €	127,45 €	US	Ready
METCASE: Box M5504110 (Unicase 4)	3	105,19 €	315,57 €	US	Ready
Aluminum plates	10	11,69 €	116,89 €	US	Ready
RS: Separating bolt M6 30 mm	16	0,756 €	37,81 € (50 units)	US	Ready

RS: Separating bolt M6 40 mm	16	0,932 €	46,59 € (50 units)	US	Ready
RS: Distance bolt M5 10 mm	48	0,375 €	18,76 € (50 units)	US	Ready
RS: Washer M60	16	0,056 €	5,6 € (100 units)	US	Ready
RS: Autoblock nut M6	16	0,079 €	7,88 € (100 units)	US	Ready
RS: Distance bolt PCB M3	64	0,672 €	67,16 € (100 units)	US	Ready
RS: Bolt PCB M3	64	0,033 €	3,29 € (100 units)	US	Ready
RS: Nut PCB M3	64	0,05 €	12,55 € (250 units)	US	Ready
RS: Washer PCB M3	64	0,019 €	4,67€ (250 units)	US	Ready
RS: Insulating Washer M6	16	0,06 €	14,86 € (250 units)	US	Ready
Panduit: Nylon 66 Clamp, 6,3mm Bundle diameter	24	0,143 €	14,27 € (100 units)	US	Ready
Loctite: pipe & thread sealant liquid for thread locking	2	57,63 €	115,26 €	US	Ready
RS: Washer M5 10mm	12	0,06 €	5,98 € (100 units)	US	Ready
Paulstra: Rubber bumper M6 only male (12+2spare)	14	4,041 €	56,58 €	US	Ready
Paulstra: Rubber bumper M6 male/male	6	5,02 €	30,13 €	US	Ready
Bosch Rexroth: Profile 30*30 (380 mm)	2 (0,38m)	22,42 € (1 m)	22,42 € (1 m)	US	Ready
Bosch Rexroth: Strut profile angle bracket 8mm (7+3spare)	10	8,1 €	80,95 €	US	Ready
Bosch Rexroth: T-bolt with nut M8 (8+2spare)	10	2,076 €	20,76 €	US	Ready
Bosch Rexroth: T-nut (6+4spare)	10	1,33 €	13,27 €	US	Ready
RS: Polyethylene Rubber Sheet (1m*2m*10mm)	3	91,85 €	275,55 €	US	Ready
Steel safety cable (3+7spare)	10	3,74 €	42,35 €	US	Ready
Transceiver MAXIM 3460ESD + (Protons sensor-MODBUS PCB adaptation)	1	0 €	0 €	Free sample	Ready
TRACOPOWER: Isolated DC-DC Converter Vout 5V TEN 15-2411	1	43,93 €	43,93 €	US	Ready
TRACOPOWER: Isolated DC-DC Converter Vout 12V TEN 30-2412WIN	1	68,37 €	68,37 €	US	Ready

Texas Instrument: Launchpad Texas instrument	1	---	---	US	Ready
Alpha & Omega: MOSFET AOD 514	1	0,46 € (*)	0,46 € (*)	US	Ready
3-Terminal Adjustable Regulator LM317	2	---	---	US	Ready
Tantalum Capacitor	24	---	---	US	Ready
Resistor	11	---	---	US	Ready
Zener diode	2	---	---	US	Ready
Board	5	---	---	US	Ready
TE Connectivity: Ethernet cable	1	14,96 €	14,96 €	US	Ready
Arcolectric: Toggle switch SPST, ON-OFF (6+2spare)	8	4,44 €	35,53 €	US	Ready
Arcolectric: Toggle switch protector serie 3900 (6+2spare)	8	6,33 €	50,64 €	US	Ready
SAFT: LSH20 (3,6 V) battery (3+5 spare)	8	11,42 €	91,36 €	SAFT	Ready
SAFT: LS 9V battery (4+4 spare)	8	17,05 €	136,4 €	SAFT	Ready
Laptop	1	300 € (*)	300 € (*)	Provided by US	Ready
Shipping of the experiment	1	NA	NA	Alter Sponsorship	Ready
Clamps (6+2spare)	8	NA	NA	Provided by MCM Sponsorship	Ready
3D components (2+2spare)	4	NA	NA	MCM/US	Ready
Total Experiment Cost:				**6530,4 €**	

(*) Estimated value

To have a global overview of the contribution of each sponsor, the programme suggested to make a table. It was really usefull to control the total budget of the experiment and where the funding came from. The result is presented below:

Table 10 : Sponsorship contribution [6]

Sponsor	Sponsorship	Amount spent (€)/Total amount sponsored (€)	In-kind donations (€)
US: ETSI	-Team members' travels (SW, STW & PDR, CDR)	1277,01 €/ 1277,01 €	---
	-Team members' travels for 5 (LC)	4415,93 €/ 4415,93 €	---
	-Hotel costs at Esrange (LC) for 1	700 €/ 700 €	---
	-Extra night during travel (LC) for the team	211,8 €/ 211,8 €	---
	-Material	1000,39 € / 1500,39 €	500 € (*) / 1500,39 €
	-Laptop (in-kind donation)	---	300 € (*)
US: VTT	-Material	1500 €/ 3433,91 €	---
	-Team equipment	350,72 €/ 3433,91 €	---
	-Team member travel (LC) for 1	883,19 €/ 3433,91 €	---
	-Hotel costs at Esrange (LC) for 1	700 €/ 3433,91 €	---
AICIA	Team members travels	166,65 € / 166,65 €	---
Airbus Chair of US	Material	1000 € / 1000 €	---
Adevice	Material: WSN	---	1440 €
IBM-CNM-CSIC	Material: protons sensor	---	NA
Alter	Shipping and test facilities	---	NA
SAFT	Material: batteries	---	227,8 €
MCM	-Material and manufacturing: clamps -Manufacturing: 3D components	---	NA
ESA	-Team members' travels (SW, STW & PDR, CDR)	2863,28 € / 4305,58 €	---

(*) Estimated value

4.1.4 Schedule

The schedule was planned after the identification of the tasks and creation of the WBS, the assignment to manpower and the analysis of the available resources.

The most important aspects to consider were:

- Project milestones: both external (from REXUS/BEXUS Programme) and internal (critical points during the development of the experiment). The internal milestones for the experiment were set according to the external ones. The external milestones for SPADE (see section 2.1.2) were:
  - Preliminary Design Review (PDR) on Feb. 9-13, 2015
  - Critical Design Review (CDR) on May 18-21, 2015
  - Integration Progress Review (IPR) on Jul. 27, 2015
  - Experiment Acceptance Review (EAR) on Sept. 4, 2015 [6]
  - Shipping of the Experiment on Sept. 14-17, 2015
  - Launch Campaign (LC) on Oct. 2-11, 2015
  - Final Report (FR) on Feb. 10, 2016
- Deadlines which were imposed by milestones, material supply deliveries and human resources availability.
- Available resources: material, human resources or facilities.

A preliminary schedule was defined and it was updated periodically. Before the milestones, the responsible of each WP should update their associated tasks in a common file. Also, to follow the schedule progress in a visual way a Gantt Chart were created that included the project milestones deadlines (figure 4-2).

The following table provided information about the final status of all work packages (WP) and the estimated start and end dates of each task.

Table 11: SPADE Schedule

SPADE Experiment	**Start**	**End**	**Status**
WP1. Project management	**13/10/2014**	**10/02/2016**	**Done**
Task1.1 Organization: defining WBS	04/12/2014	08/03/2015	Done
Task1.2 Planning: defining Project Schedule	04/12/2014	10/02/2016	Done
Task1.3 Resources	17/11/2014	10/02/2016	Done
Task1.3-1 Manpower	13/10/2014	10/02/2016	Done
Task1.3-2 Budget	17/11/2014	10/02/2016	Done
Task1.3-3 Financial and Technical Support	04/12/2014	10/02/2016	Done
Task1.4 Risk management	04/12/2014	10/02/2016	Done
Task 1.5 Team coordination	13/10/2014	10/02/2016	Done
Task 1.6 Shipping preparations	25/01/2015	20/10/2015	Done
WP2. Documentation	**13/10/2014**	**10/02/2016**	**Done**
Task2.1 Proposal	13/10/2014	17/10/2014	Done
Task 2.1-1 Proposal v1	13/10/2014	13/10/2014	Done
Task 2.1-2 Proposal v2	17/11/2014	17/11/2014	Done
Task 2.2 Experiment Defense (Selection Workshop)	02/12/2014	04/12/2014	Done
Task 2.3 Prepare SED for PDR	04/12/2014	25/01/2015	Done
Task 2.4 Prepare SED for CDR	25/01/2015	17/05/2015	Done

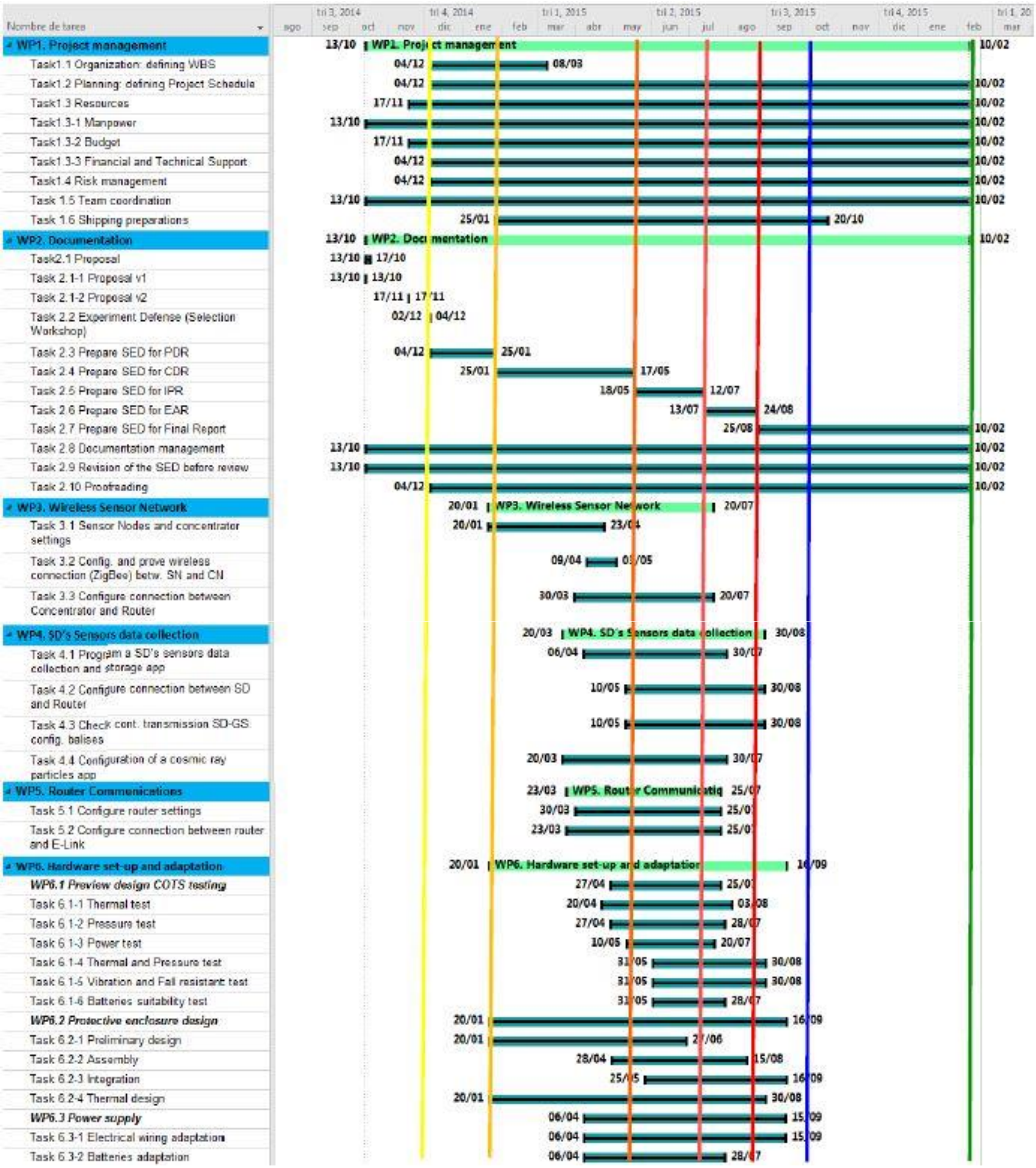
Task 2.5 Prepare SED for IPR	18/05/2015	12/07/2015	Done
Task 2.6 Prepare SED for EAR	13/07/2015	24/10/2015	Done
Task 2.7 Prepare SED for Final Report	25/10/2015	10/02/2016	Done
Task 2.8 Documentation management	13/10/2014	10/02/2016	Done
Task 2.9 Revision of the SED before review	13/10/2014	10/02/2016	Done
Task 2.10 Proofreading	04/12/2014	10/02/2016	Done
WP3. Wireless Sensor Network (WSN)	**20/01/2015**	**20/07/2015**	**Done**
Task 3.1 Sensor Nodes (SN) and concentrator node (CN) settings	20/01/2015	23/04/2015	Done
Task 3.2 Configure and prove wireless connection (ZigBee) between SN and Concentrator Node	09/04/2015	03/05/2015	Done
Task 3.3 Configure connection between CN and Router	30/03/2015	20/07/2015	Done
WP4. SD's Sensors data collection	**06/04/2015**	**30/08/2015**	**Done**
Task 4.1 Program a SD's sensors data collection and storage app	06/04/2015	30/07/2015	Done
Task 4.2 Configure connection between SD and Router	10/05/2015	30/08/2015	Done
Task 4.3 Check the continuous transmission between SD and GS: configure balises	10/05/2015	30/08/2015	Done
Task 4.4 Configuration of a cosmic ray particles app	20/03/2015	30/07/2015	Done
WP5. Router Communications	**23/03/2015**	**25/07/2015**	Done
Task 5.1 Configure router settings	30/03/2015	25/07/2015	Done
Task 5.2 Configure connection between router and E-Link	23/03/2015	25/07/2015	Done
WP6. Hardware set-up and adaptation	**20/01/2015**	**16/09/2015**	Done
WP6.1 Preview design COTS testing	27/04/2015	25/07/2015	Done
Task 6.1-1 Thermal test	20/04/2015	03/08/2015	Done
Task 6.1-2 Pressure test	27/04/2015	28/07/2015	Done
Task 6.1-3 Power test	10/05/2015	20/07/2015	Done
Task 6.1-4 Thermal and Pressure test	31/05/2015	30/08/2015	Done
Task 6.1-5 Vibration and Fall resistant test	31/05/2015	30/08/2015	Done
Task 6.1-6 Batteries suitability test	31/05/2015	28/07/2015	Done
WP6.2 Protective enclosure design	20/01/2015	16/09/2015	Done
Task 6.2-1 Preliminary design	20/01/2015	27/06/2015	Done
Task 6.2-2 Assembly	28/04/2015	15/08/2015	Done
Task 6.2-3 Integration	25/05/2015	16/09/2015	Done
Task 6.2-4 Thermal design	20/01/2015	30/08/2015	Done
WP6.3 Power supply	06/04/2015	15/09/2015	Done

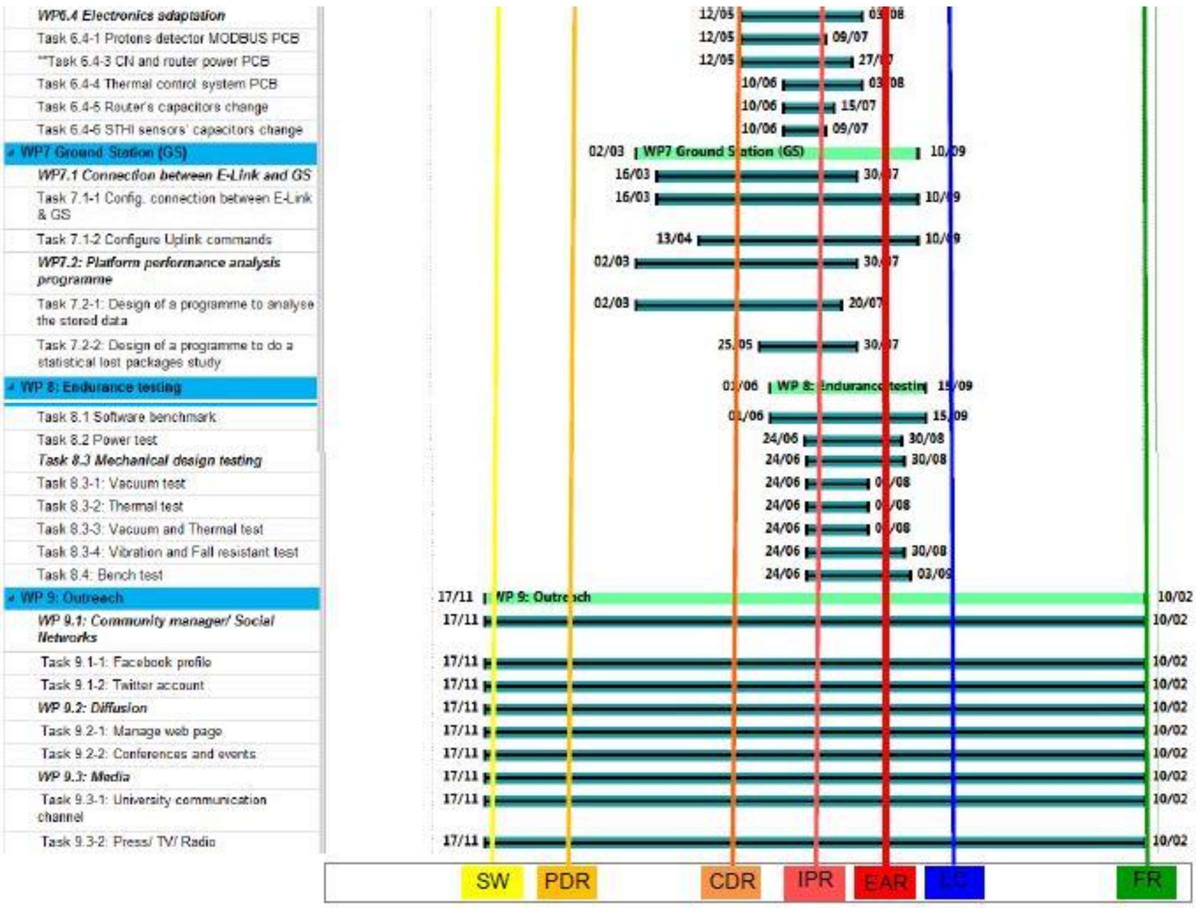
Task 6.3-1 Electrical wiring adaptation	06/04/2015	15/09/2015	Done
Task 6.3-2 Batteries adaptation	06/04/2015	28/07/2015	Done
WP6.4 Electronics adaptation	12/05/2015	03/08/2015	Done
Task 6.4-1 Protons detector MODBUS PCB	12/05/2015	09/07/2015	Done
**Task 6.4-3 CN and router power PCB	12/05/2015	27/07/2015	Done
Task 6.4-4 Thermal control system PCB	10/06/2015	03/08/2015	Done
Task 6.4-5 Router's capacitors change	10/06/2015	15/07/2015	Done
Task 6.4-6 STHI sensors' capacitors change	10/06/2015	09/07/2015	Done
WP7 Ground Station (GS)	**02/03/2015**	**10/09/2015**	Done
WP7.1 Connection between E-Link and GS	16/03/2015	30/07/2015	Done
Task 7.1-1 Config. connection between E-Link & GS	16/03/2015	10/09/2015	Done
Task 7.1-2 Configure Uplink commands	13/04/2015	10/09/2015	Done
WP7.2: Platform performance analysis programme	02/03/2015	30/07/2015	Done
Task 7.2-1: Design of a programme to analyse the stored data	02/03/2015	20/07/2015	Done
Task 7.2-2: Design of a programme to do a statistical lost packages study	25/05/2015	30/07/2015	Done
WP 8: Endurance testing	**18/05/2015**	**15/09/2015**	Done
Task 8.1 Software benchmark	01/06/2015	15/09/2015	Done
Task 8.2 Power test	24/06/2015	30/08/2015	Done
Task 8.3 Mechanical design testing	24/06/2015	30/08/2015	Done
Task 8.3-1: Vacuum test	24/06/2015	05/08/2015	Done
Task 8.3-2: Thermal test	24/06/2015	05/08/2015	Done
Task 8.3-3: Vacuum and Thermal (TVAC) test	24/06/2015	05/08/2015	Done
Task 8.3-4: Vibration and Fall resistant test	24/06/2015	30/08/2015	Done
Task 8.4: Bench test	24/06/2015	03/09/2015	Done
WP 9: Outreach	**17/11/2014**	**10/02/2016**	Done
WP 9.1: Community manager/ Social Networks	17/11/2014	10/02/2016	Done
Task 9.1-1: Facebook profile	17/11/2014	10/02/2016	Done
Task 9.1-2: Twitter account	17/11/2014	10/02/2016	Done
WP 9.2: Diffusion	17/11/2014	10/02/2016	Done
Task 9.2-1: Manage web page	17/11/2014	10/02/2016	Done
Task 9.2-2: Conferences and events	17/11/2014	10/02/2016	Done
WP 9.3: Media	17/11/2014	10/02/2016	Done

Task 9.3-1: University communication channel	17/11/2014	10/02/2016	Done
Task 9.3-2: Press/ TV/ Radio	17/11/2014	10/02/2016	Done

During the project, some delays impacted in the planning, especially in mechanical part, that produced delayed tasks through the whole work. On one hand, the critical path was estimated with enough contingency time and it could reduce part of the delay. On the other hand, in the forecast of the material supply, it was considered extra elements which were used to balance out the needs produced by the delays. Nevertheless, thanks to these considerations, the tasks were finished on time for the Launch Campaign.

Figure 4-2: Gantt Chart overview





4.1.5 Sponsors and external support management

The project had three types of external support: technical and scientific, public and private. Regarding to the public and private ones, the way to get support was different.

In public institutions time frames were higher and needed more documentation but the procedures were standard. For that reason, planning beforehand the needs of the project which needed to be covered for the public sponsors became more critical.

In private institutions, the approach was different because the procedure should be personalized. First, a preliminar study was made:

- Which companies could be interested in the project?
- What could they offer to us?
- What could we offer to them?

Then, information about the project and contact details were sent to the selected companies. If the company was interested, the conditions of the agreement was stablished. Sometines, a face-to-face meeting was held before closing the deal.

Due to the project was without financial gain, it offered to the companies:

- Publicity and visibility in the space sector thanks to REXUS/BEXUS programme events.
- Scientific or technical results. A few companies supplied their own products with in-kind donations. In this way, part of the results of the experiment could be extrapolated to their components.

Finally, it was important to maintain a fluid communication during and after the sponsorship to solve in an efficient manner any issue that may arrose.

4.1.6 Monitoring and control of the project.

The control of the project was developed using the milestones (see section 4.1.4) as points of control. Before every milestone, the work progress of each WP was sent by the responsibles to the Team Leader. This inputs updated the Management Plan and reflected the overall vision of the project status. In addition, the Risk Management Plan was updated in every stage.

When an unforeseen event occurred, it was necessary to align the team to minimise the impact on the development of the experiment. In these cases, the Team Leader should act as a Focal Point, coordinating the available resources, to facilitate an appropiate solution.

Most of the time, the team was composed by 6 members from different Degrees with the result that everyone in the team has different University schedules. This way, the team was not working together all the time and it was necessary to stablish several communication channels, without forgetting to talk face-to-face.

- Before and after every milestone, there was a face-to-face meeting to prepare the next steps.
- A group chat to comment the everyday issues that need to consider all the team.
- An online shared folder, in which every member should upload the progress and the files.
- Weekly emails with the project status: the achieved points and a reminder with the ongoing or new ones.

Finally, the decisions where taken all along the project, but the way that were taken changed too. At first, decisions were taken with all the team members. As the project progressed, the responsible of each WP took decision which affected mainly its WP and should communicate it to the rest of the team.

4.1.7 Team management

Team management has been the most challenging subject in this work and probably the most difficult one. Team communication is the key of success in every project and consider it in a Project Management Plan es essential since the beginning but it could be a difficult issue to deal with.

As this project was composed by students, it had particularties which affected to the whole planning and are defined above:

- Availability and schedule compatibility, specialy during exam periods because it was an important reduction of the the available time.
- Communication problems
- Longer development times due to the learning curve impact.
- The quality of the work depends on the team member’s motivation.
- Lack of expertise

These subjects were considered when the plan was made in order to mitigate its effect. The proposed solutions are outlined below.

- Stablish communication channels and used them as well as face-to-face meetings, specially when there is less availability of the members.
- Increase the contingency time when the scheduled task is new.
- Try to motivate the team and be proud of the work done.
- Focus on supply the inexperience with skills training

4.2 Risk Management

The identification and evaluation of the risk is an essential activity which need to be done since the early stages of the Project. For this reason, along with the Project Management Plan, a Risk Management Plan was stablished and controlled. The sooner the risk has been identified, the less it cost.

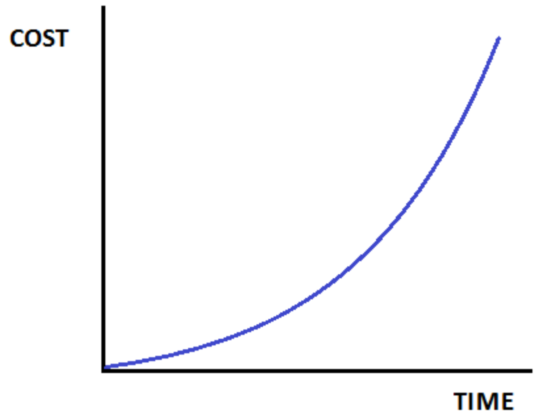


Figure 4-3: Cost vs Time Risk Graphic

Firstly, it was necessary to answer the question: What are the risks? The identification of the risk started once the objectives and the preliminary project plan, including WBS, resources and schedule, was set. Then a brainstorm of the possible common risk sources was made. The analysis went in an increasing scale of detail in an iterative process. Then, the risks need to be classified in certain relevant categories.

As per SED Guidelines [12], the main risk sources considered in this work can be classified as follows:

Risk ID

TC – technical/implementation

MS – mission (operational performance)

SF – safety

VE – vehicle

PE – personnel

EN – environmental

PM – project management and logistics

Then, it was necessary to quantify the risk: What is the probability of failure? and How would it be its severity? Probability and severity can be estimated according to the following criteria [12]:

Probability (P)

A. Minimum – Almost impossible to occur

B. Low – Small chance to occur

C. Medium – Reasonable chance to occur

D. High – Quite likely to occur

E. Maximum – Certain to occur, maybe more than once

Severity (S)

1. Negligible – Minimal or no impact

2. Significant – Leads to reduced experiment performance

3. Major – Leads to failure of subsystem or loss of flight data

4. Critical – Leads to experiment failure or creates minor health hazards

5. Catastrophic – Leads to termination of the REXUS and/or BEXUS programme, damage to the vehicle or injury to personnel

After, the ranking of probability (P) and severity (S) were combined in the risk index (P x S) to assess the overal risk classification. Risk index ranges from very low to very high, with

Figure 4-4: Example of Risk index and magnitude scheme. Figure credit: EuroLaunch [12]

Probability (P)					
E	low	medium	high	very high	very high
D	low	low	medium	high	very high
C	very low	low	low	medium	high
B	very low	very low	low	low	medium
A	very low	very low	very low	very low	low
	1	2	3	4	5
			Severity (S)		

Then, it is necessary to propose actions to mitigate or remove the risk either reduce them to an acceptable level.

Finally, to unify and manage all the risks of the project along with their severity and probability, the risk register was created and it is shown below.

Table 12 : Risk Register [6]

ID	Risk (& consequence if not obvious)	P	S	P x S	Action
TC.10	Smartphone device do not run the software properly due to hardware problems.	B	3	Low	Early tests to detect possible failures and change the device.
TC.20	Sensor nodes do not send the data to concentrator node.	B	3	Low	Early tests to detect possible failures
TC.30	Concentrator does not send data to router.	B	3	Low	Early tests to detect possible failures Acceptable risk, data is also stored locally.
TC.40	Router does not communicate with E-Link.	B	3	Low	Early tests to detect possible failures. Acceptable risk, data is also stored locally.
TC.41	Router does not communicate with concentrator node and/or smartphones.	B	2	Very Low	Early tests to detect possible failures. Acceptable risk, data is also stored locally.
TC.50	OS Android fails during tests	C	3	Medium	Test the experiment for several days. Program malfunction detect systems to know the

					possible reasons.
TC.60	A critical component (SD, SN, concentrator or router) is destroyed during testing	B	3	Low	Order spare components and keep them available
TC.70	A critical component does not arrive in time	B	2	Very low	Order components in time
TC.80	Reduction in smartphones or concentrator batteries capacity due to intensive testing	B	3	Low	Design the power system to adapt it to these needs. In extreme cases: change batteries.
MS.10	OS Android fails during flight	C	4	Medium	Looking for a solution (app that reboot the system even with the phone off). We need to accept the risk.
MS.11	On-board software failure of one smartphone during flight	C	2	Low	Since redundancy of the system it is an acceptable risk.
MS.12	On-board software failure of two smartphones during flight	B	3	Low	Test the experiment for several days. Looking for a solution. We need to accept the risk.
MS.20	Batteries fail to recharge before flight, limiting the experiment lifetime	A	2	Very low	Keep spare batteries charged and available
MS.30	Wireless connection between SN and concentrator fails during flight	C	3	Medium	Intensive testing before launch
MS.40	Short time power loss will shut down the whole experiment temporally	A	3	Very low	Same as MS10: looking for a solution. The system should be able to reboot and continue from the last saved time, (for doing so we will use remarks). We need to accept the risk.
MS.50	Experiment lands in water, which can cause electronic disruptions and short-circuits. This might affect the whole experiment or only parts of it.	B	2	Very low	Acceptable risk: data will be sent and stored in both SD and GS
MS.60	Router fails during flight	B	4	Low	Intensive testing before launch
MS.70	Loss of connectivity via E-Link	B	1	Very Low	Acceptable risk. Experiment is designed to operate autonomously. Data is also stored locally.
MS.80	Smartphones shift and they are not able to see through the rubber cones.	B	2	Very Low	Enhance smartphones' clamps. Early vibration tests.
MS.90	Some component of the gondola or some component of other experiment shields some camera hole.	B	2	Very Low	Acceptable risk.
SF.10	Sensor nodes falls from balloon gondola over a populated area during flight	B	5	Medium	-Attached nodes with safety cables to gondola. Improve design of clamps. -Vibration tests.

PE.10	Somebody cannot work for some reason during a long period	C	2	Low	-Other team member takes over tasks (for more details see chapter 3.3.1). -Increase number of team members when necessary.
PE.20	Bad working environment	B	3	Low	Talk with the interested parts and try to resolve the problem between them.
PE.40	Personnel not available unexpectedly at launch campaign	B	3	Low	-Increase the number of team members who know the launch procedure of each subsystem. -Make setup easy to operate and maintain.
PM.10 (previously PE.30)	Cannot raise enough founding for the experiment	B	2	Very low	Apply for scholarships in our university and our country or use personal funding.
PM.20	Sponsoring cancelled	A	1	Very low	Since each sponsor is financially independent, we would use another sponsor or search a new one.
PM.30	Whole experiment or part of the experiment delivery not on time in Kiruna	B	4	Low	-Shipping as early as possible. -Including extra time for shipping.
PM.40	Some components broke during shipment to Kiruna	B	4	Low	-Mark storage container as FRAGILE. -Bring spare components and tools to repair if necessary.
PM.50	Construction is delayed	C	4	Medium	-Carry out the necessary work in time and frequent reviews of progress. -Schedule a contingency time.
VE.10	BEXUS batteries fail	A	4	Very Low	Single point of failure, we need to rely on the BEXUS team.

Finally, related to MS.10, MS.12 and MS.40 the risks were accepted because the team was not able to find a suitable solution that works.

4.3 Logistics and material supply

The main developed activities related to logistics were travel management, dispatch the experiment to and from Kiruna and to search and buy material as well as inventory management to ensure that the experiment had the necessary material in time.

Travel management was partially sponsored by the European Space Agency (ESA) and the management went through Escuela Técnica Superior de Ingenieros (ETSI). The process began with a request, then a travel budget as well as the details should be submitted. After studing the request, the manager of ETSI propose a deal and it is time to made the travel arragements. Finally, after the travel the receipts of all ESA sponsored students should be sent to be reimboursed. An example of the documentation that need to be submitted to ETSI is shown below.

Figure 4-5: Example of Budget and travel details

Budget SPADE Experiment

	WORK-RELATED TRAVELS	TOTAL COST	Detalles	Devolución a ETSI	Pago ETSI
LOGISTICS	**Selection Workshop. ESA/ESTEC Noordwijk (The Netherlands), 1-5 December 2014**	1.263,28 €	3 vuelos: 417,76 €+2*422,76€	1.263,28 €	0,00 €
	Air Travel (economy fare) Seville (Spain) - Amsterdam (The Netherlands)				
	Students Training Week. DLR Oberpfaffenhofen (Germany), 9-13 February 2015	1.957,40 €	4 vuelos: 3*496,85€ +466,85€	1.600,00 €	357,40 €
	Train travel (economy fare) Seville (Spain) - Madrid (Spain)				
	Air Travel (economy fare) Madrid (Spain) - Munich (Germany)				
	Air Travel (economy fare) Munich (Germany) - Barcelona (Spain) - Seville (Spain)				
	BEXUS Critical Design Reviews (CDRs). ESA/ESTEC Noordwijk (The Netherlands), 18-21 May 2	1.365,71 €	4 vuelos: 3*253,11€ +606,38€	Pendiente**	
	Air Travel (economy fare) Seville (Spain) - Amsterdam (The Netherlands)				
	Subtotal	**4.586,39 €**		**2.863,28 €**	**357,40 €**

* Se detallan los vuelos que se han adelantado y las devoluciones a la Escuela

** Al ser el valor menor a 1600 €, se espera la devolución íntegra de todos los vuelos.

Regarding to the material supply, the process began with the needs of design when the technical caracteristics need to be defined. After a search, the material was bought or requested through in-kind donation depending of its caracteristics and cost. A register of all the material was shown in the bugdet analysis (see section 4.1.3.3).

4.4 Documentation and proofreading

There were two types of documentation during the project: the administrative one and the technical one (SED).

- The administrative documentation could have several purposes: sponsorship, control and monitoring, outreach, etc. It was created and modified during the project.
- The technical documentation was centralized in the Student Experiment Document (SED). Before every key milestone deadline, every team member updated his sections in a copy of the last version of the SED and uploaded it to the common online shared folder. Then every document was technically review and the translation to English were proofread and corrected. Finally, all the documents merge into the SED. This task took a lot of time every time but also avoid mistakes.

4.5 Outreach

The objective of Outreach was to reach the largest audience possible. The outline of the outreach programme was:

- Using the website and social media to provide the highlights broadcasting activities: share the news, the sponsors and REXUS/BEXUS programme details and a brief information about the project reviews, using a non-technical language. Also, it was used to contact with other selected teams that previously participated in the program as well as with other people and scientists interested in our project. The information was provided both in english and spanish.
- Using the contact in different engineering associations and local radio to spread the project.
- Introduce the project to the University environment and secondary school to awake the interest of young people for the engineering and the space sector.

Besides the website and the social media, some lectures in seminars and conferences were made. The activities related to this work were:

- “SPADE en el programa REXUS/BEXUS” conference at Avionics Seminar SINASA 2015, Escuela Técnica Superior de Ingenieros (ETSI), Universidad de Sevilla (US), Seville 15th April 2015.
- “SPADE en el programa REXUS/BEXUS” conference within the framework of the round tables cycle of Singularity University, San Francisco de Paula school, Seville 22th October 2015.
- “Oportunidades en el sector espacial: proyecto SPADE” conference at Escuela Técnica Superior de Ingenieros (ETSI), Universidad de Sevilla (US), Seville 18th February 2016. The results were presented as well as the experience inside REXUS/BEXUS programme, also it was talked about other ESA related educational programmes.

5 RESULTS

As was said before in the text, the main objective was to develop and control a Project and Risk Management Plan which involved and managed all the aspects of the project in order to achieve the experiment goals.

Once SPADE experiment completed the flight, it was time to analyse the outcome, check the level of success and discuss the results. In addition, a review of all the process was done to obtain lessons learned which could help in further projects.

5.1 SPADE mission success

The experiment aim was to check if it was possible to replace space technology with suitably adapted COTS, by studying the performance of the platform and the accuracy of the obtained data. In case of failure, the experiment would have record enough data to prove when and in which conditions it had happened. Thus, either high or low performance ratings imply getting important results since both would give a start point to improve the design of a future wireless sensor platform for space missions.

5.1.1 Total system success

Because of some problems during the project, the flight version of SPADE was a slightly amended version of the designed one. Therefore, the success of the experiment was studied from two points of view: related to functioning of the flight version and concerning the objectives of the experiment.

In the following table is detailed the percentage of success of each component as per the 'System Success Verification List' included in the final version of the SED [6]. According to the configuration of the experiment, the global success of the flight version was 79.5 %.

Table 13 : Flight version – System success [6]

Subsystem		Level of success (%)
WSN	Sensor nodes	15
	Sensors: SN1+SN2+SN3	5+3+0
	Concentrator	15
Total of the WSN		38
Router		10
Smartphones: SD1 + SD2		10+0
Power system		4
Thermal system		5

Mechanical system	7.5
Ground station	5
Total:	**79.5**

As it is described in table above, the success of the project related to the objectives of the experiment was 77.5 % (see section 2.2.3). The primary objective 1.3 could not be achieved because the protons sensor had to be removed from the flight version. Although 'CRAYFIS' app was tested (objective 2.1), the app did not get any measurement of the flux of cosmic ray's particles. [6]

Table 14: Objectives of the experiment – system success [6]

Objective	Contribution of the total success (%)	Level of success (%)
1.1 Study the behaviour of the WSN.	40	40
1.2 Check the performance of the COTS.	30	30
1.3 Measure the flux of cosmic rays' particles to crosscheck with the performance of the system.	20	0
2.1 Prove the CRAYFIS app (SD1 + SD2) on nearly space environment.	2.5+2.5	2.5+0
2.2 Check the endurance of the adaptation of the experiment.	5	5
	Total:	**77.5**

5.2 Project Management success

With the results of SPADE presented above, the presented planning has fullfilled its function because:

- The experiment has achieved the primary objectives and a considerable amount of the secondary ones.
- The Planning has been fulfilled from the beginning to its completion. Also, it helped to solve and mitigate difficulties which were presented along the project.
- The documentation was centralized and reviewed in time.
- The Team Leader function was also completed, acting as a Focal Point for all the resources, REXUS/BEXUS programme and Universidad de Sevilla.

6 CONCLUSIONS

IN Project Management, every project has challenges to deal with. Many things went well and others might have gone better. In any case, the experience gained is highly positive and lessons could be drawn. In this section, the conclusions and lessons learned of this TFG are presented.

6.1 Lessons Learned

From the point of view of the management, it could be pretty complicated to develop a project successfully with an inexperienced team. Everything is new for everyone and there is a lot of methodologies and techniques to implement. However, there are some advices that can be useful to consider: [6]

- Internal communication is the key for a good work environment. All the team members must know what is doing the rest of the team in order to improve the communication in the team and avoid compatibility problems on the different parts of the experiment.
- It is important to schedule a contingency time for the critical path. Delays is something very usual in projects and it is important to manage them or the project can be in risk. Some external delays are out of your control, that's why it is important that everyone try to not delay their tasks on the project because that the only ones you could manage.
- It is good to have meetings face to face each one or two weeks to track the work done and to solve technical and team problems. These meetings are always better than communication though other medias.
- Documentation will consume a lot of time. That why, it is a good idea to have more than one member doing it.
- Using file hosting services is a good way to keep all the SEDs and documents updated and it makes the team work easier.
- If the team works in several OS for the documentation, it highly probable that it produces compatibility problems with the 'SED MSWord template'. Try to find an alternative to have the same editor no matter which OS you use.
- Outreach is very important. It is good to have people working on that.
- A good marketing is a good way to obtain economical support and it will consume a lot of time as well.

6.2 Final conclusions

In a near-space project, the requirements and constraints are severe with a harsh environment. Also, the launches are much more expensive and are restricted by dates and availability of technicians and launch bases. For these reasons, risk analysis and mitigation plans were required and a good Management Plan is very important.

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