EXECUTIVE SUMMARY REPORT

Equatorial Satellite Constellation Derisking
EQSATCONDR

Code: EQSATCONDR-DES-TEC-MEM01
Issue: 1.0
Approval Date: 14/12/2022
Confidentiality Level: Restricted

Approval Signature:

Prepared by: EQSATCONDR Team
Reviewed by: B.Delmas / Technical Lead
Approved by: S.Campo / Head of Systems Eng. Division

P.A. Beatriz Delmas
Digitally signed by Beatriz Delmas
Date: 2022.12.19 16:47:55 +01'00'

This page intentionally left blank

Document Status Log

Issue	Section	Change Description	Date
1.0	All	First issue for the Final Review (FR) milestone	14/12/2022

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

1.1. Project Overview

The EQSATCONDR project aims at assessing and demonstrating the business and technical feasibility of a dual high-throughput satellites (HTS) telecommunications (telecom) and Earth Observation (EO) service (Figure 1) over the Equatorial region provided by a constellation of homogenous small satellites flying in Equatorial Low Earth Orbits (LEO).

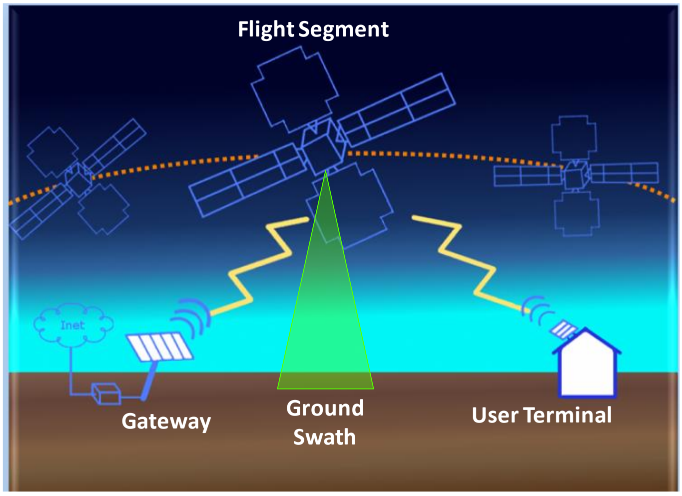

Figure 1: EQSATCONDR concept of an equatorial constellation of small satellites offering dual HTS communications and Earth Observation services

Being a new and disruptive service concept, it is necessary to assess the feasibility and performance of the proposed constellation, and demonstrate its viability from a use-case perspective, considering schedule and cost, and the market status and evolution. It is also necessary to develop the specifications on the system, and consider the payloads and operations that underpin the envisaged services. The EqSatConDR project will tackle this objective, to develop the system concepts, the specifications, the satellite and payload architectures, all from a multidisciplinary perspective, to demonstrate the soundness of the satellite and equatorial services from a technical point of view, and thus to be able to demonstrate to potential customers and end users the capability of the proposed equatorial constellation.

Hence, the objective of the activity is to assess and demonstrate the business and technical feasibility of this dual regional service of HTS telecommunications and Earth observation (HR, MR), through an initial study exploiting and building on the existing capabilities and heritage of the consortium. This study will focus on the critical aspects of the constellation and satellite, to remove the principal risks. This will result in a system concept and architecture, a preliminary business case, development schedule, and an assessment of critical aspects, such as the satellite architecture, payloads and their accommodation, the combined service quality (communications and EO), the spectrum feasibility and potential interferences with existing assets (e.g., GEO satellites). The feasibility of the proposed product will be proven by a simulation/analysis campaign. This will further facilitate the impact of this concept and service, to establish a basis for inversion in the satellite and constellation development.

The product, in the small satellite, will be of direct use in the equatorial constellation concept, enabling an innovative and disruptive HTS communications and Earth observation service. It is to this use case that the present activity responds principally.

1.2. Purpose and Scope of the Document

The present document contains the Executive Summary Report for the EQSATCONDR Study.

The Executive Summary Report is the deliverable of the WP6000 ("Management and Reporting") of the contract (No. 4000135220/21/NL/GLC/va) between the European Space Agency (ESA) and DEIMOS Engineering and Systems S.L.U. (DES), in the frame of the EQSATCONDR Study.

This version of the Executive Summary Report (1.0) has been prepared for delivery at Final Review (FR) and Contract Closure of the EQSATCONDR Study.

1.3. Acronyms and Abbreviations

The acronyms and abbreviations used in this document are the following ones:

Acronym	Description
AD	Applicable Document
AR	Acceptance Review
BFN	Beamforming Network
CDR	Critical Design Review
COTS	Commercial Off-The-Shelf
DES	Deimos Engineering and Systems
DP	Development Plan
ECSS	European Cooperation for Space Standardization
EFM	Electrical and Functional Model
EM	Engineering Model
EO	Earth Observation
EPS	Electrical Power Subsystem
EQM	Engineering Qualification Model
EQSATCONDR	Equatorial Satellite Constellation Derisking
FM	Flight Model
FoR	Field of Regard
FR	Final Review
GEO	Geostationary Orbit
GS	Ground Station
GSD	Ground Sample Distance
HR	High Resolution
HTS	High Throughput Satellite
ITU	International Telecommunication Union
KO	Kick-Off
LEO	Low Earth Orbit
LWIR	Long-Wavelength Infrared
MAR	Mission Architecture and Analysis Report

Acronym	Description
MCC	Mission Control Centre
MMIC	Monolithic Microwave Integrated Circuits
MR	Medium Resolution
MSR	Mission and System Requirements
NIR	Near Infrared
NPV	Net Present Value
ORR	Operational Readiness Review
PDR	Preliminary Design Review
PFM	Proto-Flight Model
PL	Payload
PRR	Preliminary Requirements Review
QR	Qualification Review
RD	Reference Document
RD	Requirements Document
ROM	Rough Order of Magnitude
S/C	Spacecraft
SEP	System Engineering and Exploitation Plan
SM	Structural Model
SRR	System Requirements Review
STQM	Structural and Thermal Qualification Model
TIR	Thermal Infrared
TRL	Technology Readiness Level
URD	User Requirements Document
UT	User Terminal
VSAT	Very Small Aperture Terminal
WP	Work Package

2. RELATED DOCUMENTS

2.1. Applicable Documents

The following table specifies the applicable documents that shall be complied with during project development.

Table 1: Applicable documents

ID	Code	Title	Issue	Date
[AD1]	4000135220/21/NL/GLC/va	ESA Contract No. 4000135220/21/NL/GLC/va with DEIMOS Engineering and Systems S.L.U.	-	July 2021
[AD2]	EQSATCONDR-DES-COM-MEM01	Minutes of the EQSATCONDR Negotiation Meeting with ESA	1.1	28/06/2021

2.2. Reference Documents

The following table specifies the reference documents that shall be taken into account during project development.

Table 2: Reference documents

ID	Code	Title	Issue	Date
[RD1]	EQSATCONDR-DES-COM-PRS01-E	"Equatorial Satellite Constellation Derisking" FULL-PROPOSAL for ESA	1.0	23/04/2021
[RD2]	EQSATCONDR-DES-PMD-MOM-KOM	Minutes of the EQSATCONDR Kick-Off Meeting with ESA	1.0	08/10/2021
[RD3]	EQSATCONDR-DES-TEC-URD01	EQSATCONDR - URD-1 User Requirements	1.1	21/03/2022
[RD4]	EQSATCONDR-DES-TEC-SRD01	EQSATCONDR - MSR-1 Mission and System Requirements	1.2	22/07/2022
[RD5]	EQSATCONDR-DES-TEC-TNO01	EQSATCONDR - SYS-1 System Concept Definition	1.1	21/03/2022
[RD6]	EQSATCONDR-DES-TEC-TNO02	EQSATCONDR - MAR-1 Mission Architecture and Analysis Report	1.1	25/04/2022
[RD7]	EQSATCONDR-DES-TEC-TNO03	EQSATCONDR - SYS-2 Preliminary System Operations Concept Report	1.1	25/04/2022
[RD8]	EQSATCONDR-DES-TEC-SRD02	EQSATCONDR – RD-1 Preliminary Platform Requirements	1.1	22/07/2022
[RD9]	EQSATCONDR-DES-TEC-SRD03	EQSATCONDR – RD-2 Preliminary Payload Requirements	1.1	22/07/2022
[RD10]	EQSATCONDR-DES-TEC-TNO04	EQSATCONDR - SYS-3 Platform Analysis and Definition	1.1	22/07/2022
[RD11]	EQSATCONDR-DES-TEC-TNO05	EQSATCONDR – SYS-4 Payload Analysis and Definition	1.1	22/07/2022
[RD12]	EQSATCONDR-DES-TEC-TNO06	EQSATCONDR – DP-1 Preliminary Technology Development Plan	1.1	02/12/2022
[RD24]	EQSATCONDR-DES-TEC-TNO07	EQSATCONDR – SYS-5 Communication and EO Service Analysis	1.1	02/12/2022
[RD24]	EQSATCONDR-DES-TEC-TNO08	EQSATCONDR – SYS-6 System Budgets and Cost Estimates	1.1	02/12/2022
[RD13]	EQSATCONDR-DES-TEC-TNO09	EQSATCONDR – SEP-1 System Engineering and Exploitation Plan	1.1	02/12/2022

3. MISSION ARCHITECTURE DESIGN

Selection of satellite orbit and constellation configuration is paramount, with significant impact on system cost and performance. Following aspects has been considered for preliminary orbit selection and constellation design: for the EO payload, Swath width and Resolution (GSD); for the comms payload, the System latency, the Link Budget, or the Power Required; Delta-V and Fuel Budget (also related with the manoeuvre frequency and the mission lifetime); Coverage and Revisit time; and Eclipse duration.

After an assessment of different configurations, the selected orbit and mission architecture for the EQSATCONDR mission have been **60 satellites placed in 4 orbital planes at 1100 km altitude and 15º inclination guaranteeing continuous coverage in the ±20º latitude band.**

It should be noted that, although it was initially intended to cover +/-30º latitude band, too many satellites and orbital planes would be needed for that purpose. From a market analysis point of view, a latitude band of +/-20º is still interesting, not significantly reducing the number of possible users of the proposed service.

3.1. Coverage, Revisit Time & Duty Cycle for EO Payload

The selected orbit and constellation architecture have been taken to assess the coverage and duty cycle performance. Instrument acquisition (Long-Wave IR) can be performed during both day and night without constraints on Sun illumination. Given the coverage band of the comms service, **the threshold value of ±20º latitude band will be also considered for the EO service**, meeting the requirement expected for the mission.

Given the selected orbit inclination of 15º, a payload Field of Regard (FoR) of ±25º is required to cover up to 20º latitude. This FoR can be achieved either by the instrument Field of View, or by platform agility.

For the average revisit time for the entire constellation, apart from a very tiny band around 20º where the revisit time is around 45 min, **the average revisit time is below 15 minutes**. This value is fully compliant with the 30 min goal requirement.

With regard to the duty cycle, notice that it will be defined by the actual users of the service and their operational needs. Taking into account that it is a value that has high impact on the S/C design (e.g., power subsystem sizing or data volume management), **an average duty cycle of 15% has been considered as reference.**

3.2. Ground Segment Visibility Analysis

The mission architecture design ensures that **each gateway is capable of communicating with up to three satellites at once** and acquiring a communication link down to 20° elevation. Furthermore, other of the conclusions obtained during the visibility analysis is that the gateways should be placed away from the equator, extending to a region of +/- 13º, meaning that they could take advantage of lower atmospheric attenuation, leading to decreased likelihood of satellites being unable to maintain a link with a gateway.

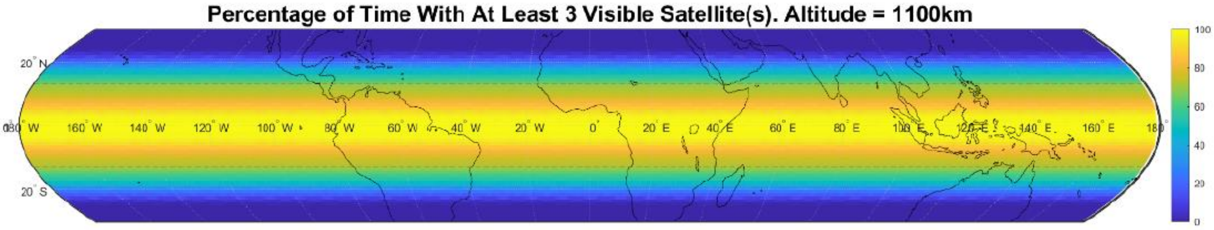

Figure 2: Three satellite visibility map for a 4×15 orbital configuration at 1100km

With regard to the user terminal visibility for the selected orbit and constellation architecture, the entire region up to approximately 20° either side of the equator is covered for 100% of the time. This implies that **at least one satellite would be visible per any user terminal located in the region**.

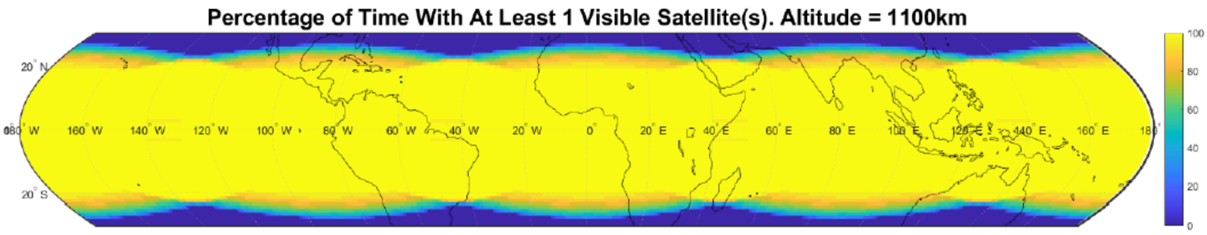

Figure 3: Visibility map for a 4×15 orbital configuration with an inclination of 15° at 1100km

Finally, it is also needed to consider the ground stations, that will be in charge of the telemetry and telecommand tasks, as well as the raw data downloading. The selection of the Ground Station (GS) network has been driven by the GS visibility frequency and contact interval duration, and by the data flow and data volume issues. For low inclined orbits, like the one selected for the EQSATCONDR service, ground stations should be located within the latitude band covered by the orbit inclination. For this preliminary analysis, **two ground stations has been considered, one located over the Equator in Africa and the other one placed at 15º latitude in South-East Asia.**

3.3. Launcher Analysis and Constellation Deployment

The launch strategy for a satellite mission is driven by the target injection orbit and by the performance profiles of the launcher. Furthermore, from a cost point of view, the intention is to minimize the number and size of satellites to reduce launch costs, together with a minimization of orbital planes.

In order to reduce costs and constellation deployment time, it is proposed to deploy the constellation with 4 launches: each launch will deploy 15 satellites belonging to the same orbital plane, thus requiring a phasing of the satellites to reach the nominal position in the corresponding orbital plane. Given the low inclined orbit selected, it is not expected to be able to share the ride with some main payloads. For that, each EQSATCONDR launch will be a dedicated launch.

Ariane 62 rideshare launch service solution is selected as baseline with a deployment strategy of 4 dedicated launches.

4. MISSION OPERATIONS CONCEPT

The dual service provided by EQSATCONDR will deliver High Throughput Satellite (HTS) communications and Earth Observations (EO) services from space. The service provided to the user will be a broadband data connection over land areas with a minimum speed of 10 Mbps suitable for use on transportable equipment, coupled with Earth observation weather data capable of informing decisions on construction work, mining, and other weather dependent activity. Furthermore, exploiting the comms payload, EO data can be sent to ground at any time with a responsiveness of less than 10 min.

The ground segment definition is important to understand the constellation's interaction with this and the wider system. From the architecture below, **four major segments can be identified in the system: Space Segment (satellite in the space containing communications and EO payloads); the Ground Segment (VSAT gateway); the User Terminals (UTs); and the Mission Control Centre (MCC).**

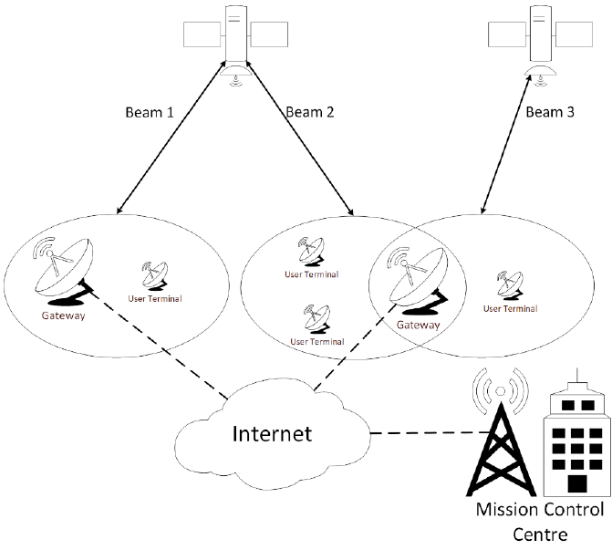

Figure 4: Architecture diagram of the HTS communication system

The gateways are envisioned to use three 4.5m parabolic antennas to maintain connectivity with up to 3 satellites, with site diversity such that significant fading in the link to one gateway does not lead to a breakdown in the feeder link to the satellites.

The user terminal shall use either a 1m parabolic dish or flat panel phased array depending on the most up to date technology at the time and ability to mitigate rain fading with each technology. The VSAT terminals shall be suitable for mounting on a moving platform as per user needs stated earlier.

5. SPACE SEGMENT DEFINITION

To define the space segment, it shall be considered that it will be composed of a constellation of small satellites, each of them including the platform (and avionics); the HTS communication payload; and the EO payload.

The platform selected for the EQSATCONDR mission will be a Deimos existing small satellite product, the mini4EO platform. Some modifications are envisaged to adapt an Earth Observation platform to the dual purpose of HTS communications + EO services. Several aspects have been considered, such as the payload volume allocation; the power budget allocation and consequently the thermal assessment; the mass budget; and the avionics allocation.

Notice that the platform design most critical point is the generation of the required communication payload power. After the proposed modifications to the EPS, but taking into account the limitations of a small satellite in terms of both power generation and power dissipation, the maximum power that can be handled is approximately 500W for the COMMS PL. Notice that **this value constraint the capacity of the service, as only 8 users per platform could be served simultaneously.**

For the payloads, starting with the EO payload, it should provide the service of extreme weather nowcasting. A survey has been performed to select the most suitable EO payload for the EQSATCONDR, taking into account that it shall be selected among commercially available imagers. Several points have been analysed, including the previous experience on the H2020 project EO-Alert. In terms of performances, it was desired to include several bands: Visible (VIS), Near Infrared (NIR), and Long-Wavelength Infrared (LWIR). **The HyperScout-2 camera, provided by Cosine, has been selected as baseline for the EQSARCONDR EO service**, offering both VNIR hyperspectral channel and TIR spectral channel.

As already mentioned, the satellite shall perform onboard processing of the EO data before transmitting it to the users as needed and as requested. For that purpose, the on-board avionics architecture considered is the Zynq-7000 SoC from Xilinx.

For the **HTS communications payload**, different frequency bands to be used by the EQSATCONDR service were evaluated. Several aspects were assessed, as the ITU regulations, the link budget, the availability, the impact of the atmospheric attenuation, the technology maturity, etc. **Finally, the Ka band has been selected as the most suitable option to comply with user and service requirements.**

In terms of the design of the payload itself, it is proposed that the communication system uses phased mini-horn array antennas, utilising monolithic microwave integrated circuits (MMICs) based on SiGe technology to control the feed.

As anticipated above, due to the platform limitations in terms of available power, an analogic Beamforming network (BFN) of maximum 8 users have been selected. In this way, **the payload must serve up to 8 users located in different positions.** Moreover, the payload must be able to connect up to 4 gateways taking into account that gateway redundancy is required to cope with weather conditions that could force switching to another gateway.

The communications payload capacity has been sized to be able to transmit at least 10Mbps for each user under rain conditions, thus assuring 99% availability despite of Weather conditions. Thus, the total capacity of a satellite will be 80Mbps. When there is no rain, a total capacity of 500Mbps could be achieved.

6. DEVELOPMENT PLAN SUMMARY

Following scheme represents the development philosophy for the product; linking its TRL evolution with the model philosophy described.

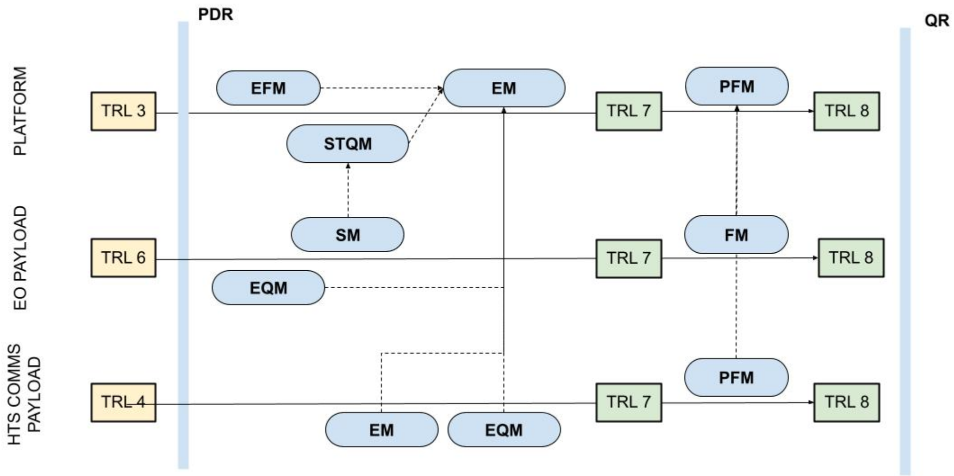

Figure 5: EQSARCONDR Development Plan

The preliminary master schedule of the EQSATCONDR project is included in the document Preliminary Technology Development Plan (DP-1) [RD12]. For the complete mission, the main milestones associated to the end of project phases are listed below:

Table 3: EQSATCONDR Flight Segment Milestones

Milestone	Description	Date
KO	Phase 0 Kick-Off	T0
PRR	Preliminary Requirements Review	T0 + 6
SRR	System Requirement Review (End of Phase B1)	T0 + 12
PDR	Preliminary Design Review (End of Phase B2)	T0 + 18
CDR	Critical Design Review (End of Phase C)	T0 + 30
QR	Qualification Review	T0 + 57
AR	Acceptance Review	T0 + 58
ORR	Operational Readiness Review (End of Phase D)	T0 + 59

Note that the content of the final project reviews (QR, AR, ORR) will be reviewed and optimised in future phases, as this is a PFM-based modelling philosophy.

At this stage, a three-month contingency has been added to the schedule at the end of the project to take into account possible delays that may arise when the concept starts to mature in following phases. For example, one of the most important programmatic risks is the LLI Procurement (Long Lead Items).

In terms of constellation production, Deimos would be able to optimise its processes and increase its facilities in order to integrate and test 4 satellites per month. Notice that the involvement in the production of a 60-satellite constellation with a ~1000 MEUR contract could situate Deimos at the lead of the European minisatellites integrators, achieving a strategic asset for Europe, enlarging its capabilities of massive integration of constellations. This contract would open many doors for the involvement in future projects, so the investment is expected to be internal.

7. COST ESTIMATION

Total cost of the proposed service has been estimated for the follow phases of the project up to the deployment of the full constellation. For that purpose, the following levels have been considered: total satellite (platform and payloads); launch; total ground segment (gateways, user terminals, and control centre); and the operations and maintenance.

The total cost of each satellite, including platform, EO payload and HTS payload, would be around 25M€ for the first unit (non-recurrent unit), and 14.5M€ for the rest 59 satellites (recurrent units). The total cost of deploying the constellation (four Ariane 62 launches) would be around 300M€. All of this, plus the ground segment, would lead to a total system cost (for a lifetime of 7 years) of approximately 1300M€.

8. BUSINESS ANALYSIS

For the **HTS system**, the proposed use cases would be medium to long-term installations such as civil engineering works or open-cast mining which require data connectivity in the range supplied by the EQSATCONDR system, and short-medium term weather forecasts and warnings of rain and lightning to plan their activities. These use cases were selected as a focus in the underserved equatorial region as there is projected to be demand for the service and there would be lower competition from large constellation operators such as Starlink or Inmarsat, which focus on larger use cases such as home broadband or maritime shipping.

With regard to the **EO service**, it will focus on meteorological applications for disaster management of extreme weather conditions, applications which require lower resolutions, not in competition with VHR products. On-board processing will be able to generate an alert that can be delivered to ground with very short latency (heritage of H2020 EO-ALERT project). Leveraging the satcom part of EQSATCONDR, the alert can be delivered to the ground, thus enabling a unique very low revisit time and very low latency EO product service.

To evaluate the business feasibility of the dual service, it has been approximated the Net Present Value of the constellation based on projected cash flows for revenues and costs. Two scenarios have been analysed in terms of the revenues obtained from each service, a baseline scenario and an upside scenario.

As a result, the system would only recoup the total investment in the upside scenario, since total cumulative cash flow through the system's lifetime would be positive in the last year of operations. In contrast, in the baseline case the total cumulative cash flow at system lifetime would remain negative. Therefore, the NPV of the EQSATCONDR system in its current configuration is negative for the baseline case, but positive for the upside case. This result indicates that, **although the service has been evaluated to be technically feasible, it is not feasible in its current configuration from a business point of view, since the negative NPV indicates that the investment would not be profitable**

END OF DOCUMENT