GNSS Evolution
Next Enhancement of System Infrastructures
Executive Summary

DRL No: D10

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1 INTRODUCTION

1.1 CONTENT AND SCOPE

This report describes in concise form the major achievements of this study.

1.2 DOCUMENT STRUCTURE

After this introduction section,

Section 2	Describes the major achievements of GENESI study
Section 3	Presents the conclusions and way forward

1.3 REFERENCE DOCUMENTS

ID	Reference
[RD.1]	D1, *Forecast on Mid and Long Term Users Needs,* ESYS-TN-Task1-001 2.1
[RD.2]	D2, *Assessment of Planed GNSS Capabilities,* NSL-GEN-TN2-2.1
[RD.3]	D3, *Identification of Evolution Constraints,* R78-7133-D3-V10-7.0
[RD.4]	D4.1, *Definition of Trade-off Criteria,* AASI-GEN-TNO-0003-2.0
[RD.5]	D5.1, *Identification of Evolution Mission Drivers,* AASI-GEN-TNO-0003-3.0
[RD.6]	D5.1b, *Allocation of Mission Drivers and SoC of Architectures,*
[RD.7]	D6, *Definition of System Architectures,* AASI-GEN-TNO-0004-5.0
[RD.8]	D7, *Architectures trade-off,* GMV-GEN-TNO-0001-1.0
[RD.9]	D11, *Final Report*

Table 1-1: Reference Documents

2 MAJOR ACHIEVEMENTS OF GENESI STUDY

The study logic after CCN approval is presented in the following figure.

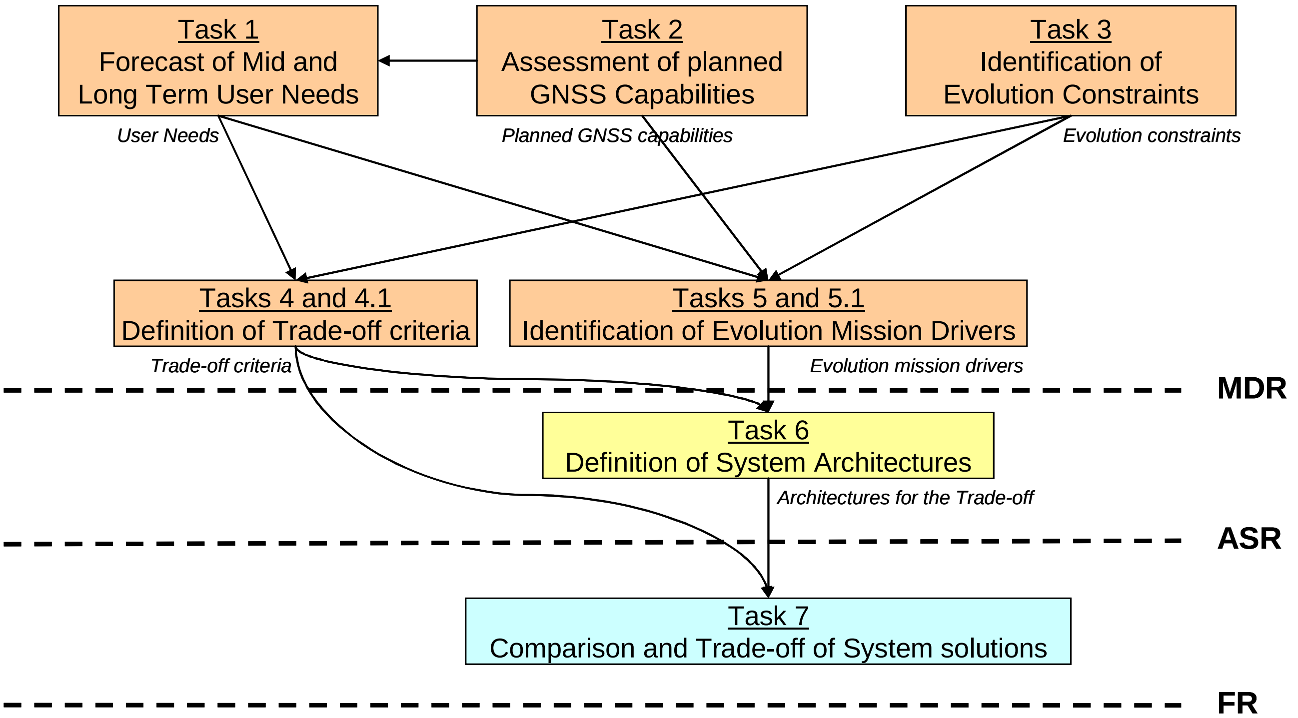

Figure 2-1: GENESI Study Logic

As shown in this Study Logic, Task 1 to Task 3 focus on the identification of the basic inputs (mainly needs and constraints) which will be used for the definition of the Evolution Mission Drivers (Task 5 and 5.1) and of the trade-off criteria (Task 4 and 4.1).

Evolution Mission Drivers are the basis for the definition of enhanced GNSS architectures; they have been derived from the comparison between user needs and planned GNSS capabilities (thus highlighting all the needs not covered by planned evolution) but taking also into account all possible constraints.

After MRD, the trade-off criteria output of Task 4 and 4.1 are applied, as part of Task 7, to the architectures identified in the frame of Task 6 for the final selection of a single GNSS architecture.

Mission Evolution Drivers serve to perform the identification of architectural options, in the frame of Task 6 activities. A sub-set of proposed architectures (which has been identified at APR) has been detailed into ground, space and user segment analysis, especially in terms of new/modified elements as a consequence of implementation of Mission Drivers.

Consequently, in the frame of task 7 these architectures have been evaluated and compared, according to specific timing milestones, thanks to the trade-off criteria as defined in task 4-4.1.

This technical report focuses on the major results of the GENESI study, i.e.:

- Definition of Identified Evolution Mission Drivers (Task 5- 5.1)
- Definition of final Architectures (Task 6)
- Results of the final architecture trade-off (Task 7)

It is however highlighted that large part of the effort in the GENESI study has been dedicated in the identification of a complete set of mission drivers, to be used also in future studies to drive the definition of European GNSS evolution.

Further details on the activities performed under Tasks 1 – 4.1 are provided in the final report [RD.9].

2.1 EVOLUTION MISSION DRIVERS

The evaluation of the "future scenario" and the understanding of what will be needed and of what will be possible, are the bases of the GENESI project. The evaluation of the future scenario has been obtained through:

- the forecast of (Mid and Long term) user needs (Task 1)
- the planned GNSS capabilities (Task 2)
- the identified constraints (Task 3)

With all these pieces of information gathered, the identification of Mission Drivers for the evolution of European GNSS systems has been achieved (Task 5-5.1).

The logic so far described is presented hereafter:

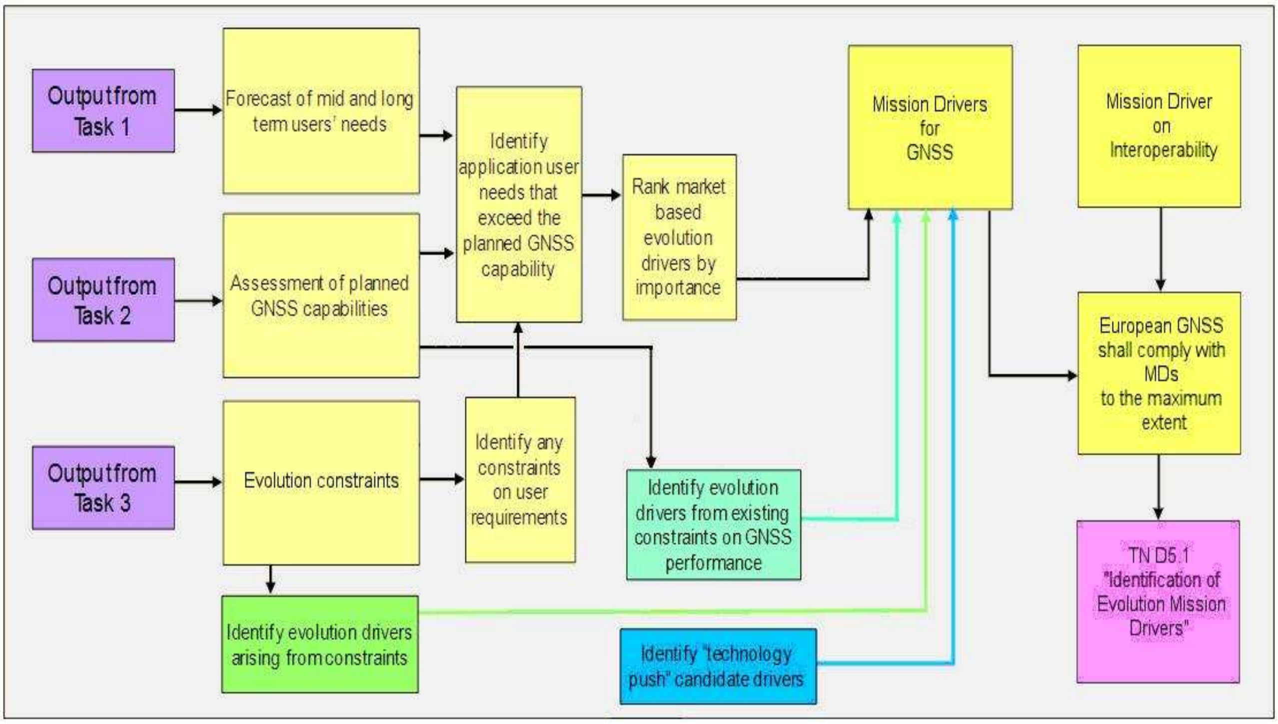

Figure 2-2: Logic of Task 5- 5.1

Additionally to User Need Drivers, other mission drivers are derived from:

- European GNSS system shortcoming
- Technology/system aspects in light of advances that could improve users' satisfaction and/or GNSS system performance,
- Findings from MRS study
- Galileo and EGNOS MRDs
- Security issues

The complete list of the evolution Mission Drivers identified in [RD.5] based on the above approach is recalled in Table 2-1.

MD #	MD text
0	*The contribution of the European GNSS to the achievement of all the performance required in the related MDs shall be balanced with the contributions of the non-European GNSS through the implementation of interoperability between European and non-European GNSS systems.*

1	*GNSS systems shall support an Open Service that shall provide an accuracy of at least [0.5m] horizontal (95%) and a vertical accuracy of [0.75m] (95%) without the need for local accuracy enhancing augmentation.* *Note: TRAIN CONTROL and ADAS milestone in time is 2020*
2	*GNSS systems shall [optionally] support a Precise Service that shall provide an accuracy of at least [0.05m] horizontal (95%) and a vertical accuracy of [0.075m] (95%).*
3	*GNSS systems shall be designed to facilitate the use of accuracy enhancing augmentations providing horizontal accuracies (95%) in the range at the 0.001 to 0.05m.*
4	*The availability of the Safety of Life Service alone, shall be better than 99.75% over the nominal operational lifetime of the GNSS systems.* *Note: TRAIN CONTROL and ADAS milestone in time is 2020*
4a	*The availability of the [optional] Precise Service alone, shall be better than 99.5% over the nominal operational lifetime of the GNSS systems.*
5	*The characteristics of the signal in space (power, waveform etc.) shall be designed to maximise the availability performance of the system in urban and indoor environments. In particular, the signal waveform shall be optimised to facilitate signal tracking with low signal levels and high levels of multipath.*
5a	*The characteristics of the system constellation shall be designed to improve the performance of the system in urban environments through the provision of high elevation satellites within these environments.*
6	*The characteristics of the signal in space (power, waveform etc.) shall be designed to facilitate interoperation with availability enhancing technologies such as pseudolites and future indoor navigation systems in order to provide a seamless navigation service.* *Note: PRS milestones in time are 2013, 2018 and 2023*
7	*The characteristics of the signal in space (power, waveform etc.) shall be designed to provide an improved anti-jamming performance relative to that provided by GALILEO 1.* *Note: PRS milestone in time is from 2018 and then at intervals determined by the rate of progress (or not) identified in 2018*

8	*GNSS systems shall support a Safety of Life service that shall provide an integrity performance as follows: Integrity Risk < 1.2×10^{-9} /15 s Horizontal Alarm limit < 1.25 m Vertical Alarm Limit < 1.875 m Time to alarm < 1 s Note 1: This is based on the Aviation CAT III requirement. Alarm limits of 2.5 times the accuracy requirement have been used in order to cater for the enhanced accuracy needs of non-aviation requirements. Note 2: Integrity requirements are application specific and so it should be possible to satisfy a range of alarm limits, TTAs and integrity risk values. Note 3: Such performance level shall be met with the contribution of the User Segment (through RAIM techniques).*
9	*GNSS systems shall support an [optional] Precise Service that shall provide an integrity performance as follows: Integrity Risk < 1×10^{-5} per hour Horizontal Alarm limit < 0.125m Vertical Alarm Limit < 0.2m Time to alarm < 10s*
10	*GNSS systems shall support Open Service signal in space that provides a continuity of (1-(2x10^{-6})) per 15 seconds for vertical guidance and (1-(2 x 10^{-6})) per 30 seconds for horizontal guidance. (Note: this requirement is based upon the current requirements for CATIIIB, however it is understood that these requirements are still to be finally agreed. Note2: TRAIN CONTROL and ADAS milestone in time is 2020.)*
11	*The GNSS systems shall achieve a TTFF of 3s using the Open Service signal in space. Note: TRAIN CONTROL milestone in time is 2020*
12	*European GNSSs shall aim at reaching interoperability negotiations with their foreign counterparts: Interoperability between EGNOS and the other SBAS systems (WAAS, GAGAN etc); Interoperability between Galileo and the other Stand-Alone GNSS; Interoperability between Galileo and EGNOS; Note: SBAS augmentation, if required, should aim to address all the GNSS systems.*
12a	*Interoperability concept applied to Open/Civil services of GNSSs shall be the focus of future negotiations between GNSS System Providers as Open/Civil services will profit the most from interoperable GNSS systems.*
12b	*Interoperability applied to the Safety of Life service of GNSS systems shall focus on reaching interoperable integrity concepts among GNSS systems through coordination and harmonisation negotiations between different System Providers, Programmatic bodies and involved countries.*

12c	*Interoperability concept applied to Military/Public Regulated services shall be supported due to the potential benefit in terms of performance in the use of a combined receiver. Nonetheless, a certain level of independence among Restricted Services shall be maintained in order to guarantee security-related aspects.*
12d	*Interoperability concept applied to Galileo Commercial Service shall offer better performance in critical environments in order to attract user communities.*
12e	*Interoperability concept applied to Search and Rescue services shall be supported as it offers better performance in critical environments.*
13	*European GNSS shall support LPV-200 precision approach operation, this meaning a safe descent to a 200 ft decision height with vertical accuracy of 4 meters 95% of the time with a vertical alert limit (VAL) of 35 meters.*
14	*Alternative communication channel(s) shall be provided to carry the EGNOS correction and integrity messages so as to extend its operational service coverage at sea/ ground level to the northern-most parts of the EU land mass for safety critical applications.*
15	*The extension of EGNOS coverage area shall be supported in order to provide EGNOS services over the Mediterranean Region, Africa and at high latitudes.*
16	*A suitably designed receiver shall be able to verify that Galileo navigation signals are genuine Galileo signals, i.e. the signals can be authenticated.* *NOTE – Due to current uncertainties (see Section 4.4) this MD shall be reconsidered as soon as new inputs on the matter are available, starting with the outcomes of the related GSA study [39].*
17	*The use of augmentation data to improve accuracy without increasing integrity should not degrade accuracy, nor continuity, nor availability of the non-augmented position solution. In particular, degradation of accuracy when operating at fringes of SBAS coverage shall be resolved in order to maintain the required system performance characteristics.*
18	*It shall be possible to receive a valid integrity signal from Galileo E1 using receivers with only a single frequency capability.*
19	*The GNSS signal characteristics (e.g. power, frequencies, modulation, and alternative frequency bands etc.) shall be improved so as to minimise the impact of interference on GNSS receivers.*
20	*The design of the overall GNSS system should take full advantage of ongoing advances in receiver technology and the resulting improvements in receiver functionality.*

21	*GNSS evolution shall take advantage of future advances in atomic clock technology, in particular, improvements in accuracy, but also at system level through improvements in the Ground Segment management and in the Space Segment design.*
22	*Evolution of European GNSS systems shall consider advances in User Terminal Clocks and the resulting benefits.*
23	*GNSS evolution shall consider the advantage of the use of Inter-satellite links to improve system functionality and performance in light of potential future communication services.*
24	*Evolution of European GNSS systems shall consider the use of ISL to provide additional communication capacity for future integrated Nav-Com services.*
25	*The use of additional navigation signals at higher frequencies shall be considered for future GNSS services.*
26	*The evolution of the European GNSS system shall be designed and implemented without reducing or restricting GNSS services to all pre-evolution users throughout the world and without any need for such users to update or modify their terminal equipment.*
27	*The evolution of the European GNSS system shall be designed to increase the current message capacity provided for the Galileo commercial service, after comparison with alternative communication channels.*
28	*Planned evolution of other GNSS systems must be taken into account in the evolution of the European GNSS system in order to preserve competitiveness and attractiveness for users within this "system of systems".*
29	*The Evolution of European GNSS systems shall not only continue providing an SBAS (Satellite-based Augmentation System) service to L1 users but shall also augment GPS L5 and Galileo L1 and L5 users and GLONASS modernised users ."*
30	*The GEO SBAS shall employ a Transparent/regenerative payload to allow better ranging performance and the accommodation of additional services.*
31	*The Galileo signals shall be modified in order to improve ERIS capacity.*

32	*Unless specified differently for a particular service, the evolution of European GNSS system performance shall apply for all the users having a masking angle no greater than 5 degrees.*
33	*The evolution of European GNSS systems shall include a worldwide Data Exchange Service providing raw measurement data and processed data in real time.*
34	*The evolution of European GNSS systems shall guarantee no degradation in the provision of the required services during design/deployment/ qualification/upgrade phases.*
35	*Standardisation and Certification of the evolution of European GNSS system shall be pursued within the appropriate bodies, at EU and global level, without interference with the on-going activities.*
36	*The evolution of European GNSS systems architecture from one phase to the next shall be done by deployment/removal of elements, but not by re-design of concept/parts of the systems.*
37	*The space segment shall be designed such that no interventions will be required from ground to ensure satellite survival for a period of more than one day.*
38	*The evolution of European GNSS systems shall allow maximum reuse of existing infrastructures, whenever technically possible and economically beneficial, while keeping the independence of both systems and guaranteeing robustness against failure.*
39	*The operations of a next more advanced phase shall incorporate the operations defined and deployed of the previous program phase to assure backward compatibility.*
39b	*The schedule of the various phases and versions of the European GNSS systems must be respected in order to assure correct management of all phases.*
40	*The Galileo evolution shall at least guarantee the same level of security and protection countermeasures of current Galileo-1.*

41	*The entire new system shall devise the accreditation according to the Galileo rules.*
42	*Galileo-1 residual vulnerability shall not be reduced by new evolution systems.*
43	*New security solutions shall not impact (when applicable) the safety performances of the system itself.*
44	*The evolution of the European GNSS system shall guarantee that during any transition phase no impact is cause to the integrity of the overall security.*
45	*European GNSSs must be flexible enough to allow the possibility to re-address their services and their plans and priorities so as to take into account a Down-Side market scenario.*

Table 2-1: Summary of Identified Evolution Mission Drivers from TN5.1

In summary, 54 MDs have been identified. MDs can be grouped in categories so as to better evidence similarities.

- 11 MDs on User Need Forecast
- 8 MDs on Robustness (in terms of system and service performance)
- 8 MDs on System Shortcomings
- 6 MDs on Technology Push
- 6 MDs on Security issues
- 7 MDs on Interoperability
- 6 MDs from Galileo and EGNOS MRDs
- 1 MD on Flexibility (Downside Market)

2.2 SYSTEM ARCHITECTURES

Based on the identified list of mission drivers, 2 architectures have been identified considering the implementation of ISL/ISR capability as option for both, thus leading to the definition of 4 different architectures.

The main capabilities included in each architecture (fully described in [RD.7]) are summarised here below.

Architecture 1	Architecture 1 +ISL/ISR	Architecture 2	Architecture 2 + ISL/ISR
Common SBAS architecture (Ground, Space and User segments) derived from: ✓ EGNOS second generation payload ✓ MRS concept			
Common GNSS architecture (Ground, Space and User segments) derived from: ✓ Galileo FOC ✓ MRS concept ✓ Other ESA evolutionary studies (e.g. FEATURE)			
Additional C-Band Navigation Signal		Additional S-Band Navigation Signal	
	ISL/ISR payload		ISL/ISR payload

2.3 FINAL ARCHITECTURES TRADE-OFF

The identified candidates for the future evolution of uropean GNSS infrastructure have been compared, considering an agreed set of criteria and two different milestones in the system evolution (2018 and 2023).

The ranking of the architectures in the 2018 Milestone is reported here below:

2018 Milestone		
Architecture	**Score**	**Conclusion**
Arch#2 + ISL/ISR	121.27	More compliant than reference
Arch#1 + ISL/ISR	121.27	More compliant than reference
Arch#2	121.27	More compliant than reference
Arch#1	121.27	More compliant than reference
Reference	100.00	Reference

The ranking of the architectures in the 2023 Milestone is reported here below:

2023 milestone		
Architecture	**Score**	**Conclusion**
Arch#1	121.27	More compliant than reference
Arch#2	118.73	More compliant than reference
Arch#1 + ISL/ISR	116.19	More compliant than reference
Arch#2 + ISL/ISR	107.30	More compliant than reference
Reference	100.00	Reference

Architecture 1 seems therefore to be the most suitable architecture according to the defined trade-off process. However Architecture 1 + ISL/ISR could reach better results than Architecture 1 in the defined trade-off process if risks related with the introductions of ISL/ISR new technologies are reduced.

Architecture 2 is the one that presents less technological risks although some concerns have appeared with respect to the use of an S-band open service. Architecture 2 +ISL/ISR shows the worst score due to the combination of the S-band concerns plus the novelty of the ISL/ISR capabilities that have a negative impact on Technology category

It is finally highlighted that EGNOS evolution is not determinant in the selection of the best architecture since it is the same for the four candidate architectures. Notwithstanding, its impacts on the different criteria contribute significantly to raise the final scores of all architectures.

3 CONCLUSIONS AND RECOMMENDATIONS

Considering the additional complexity that this approach introduces and the fact that ISL/ISR has not been used yet either in Galileo or EGNOS, it is recommended to carry out further studies on the Inter-satellite link and ranging capabilities, in order to further detail the definition of such additional capabilities and their possible implementation in the two described architectures.

END OF DOCUMENT