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DGNSS Re-Capitalization

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ABSTRACT: The General Lighthouse Authorities (UK & Ireland) DGPS service came into operation in 1998. In common with other maritime DGPS services the equipment will need replacement over the next few years, in fact computing and communications equipment have already been replaced. Replacement of existing hardware with similar, dedicated Reference Stations and Integrity Monitors (RSIM) is the baseline option and will form a fallback plan if other options prove not to be feasible. However, the choice of suppliers is limited and once chosen, it would be difficult to diversify. Three other options can be identified: software RSIM, Virtual Reference Station (VRS) and integration with Satellite Based Augmentation Systems (SBAS). The software RSIM option draws on the experience of the United States Coast Guard. The VRS and SBAS integration options are treated as potential alternatives to an onsite hardware or software RSIM, but the possibilities of combining either or both with the software RSIM are also considered. All options took into account the need for validation of system performance. This paper draws conclusions about feasibility, performance, risks and costs of the different options and makes recommendations on the course to adopt.

1 INTRODUCTION

1.1 *Purpose and Scope*

The General Lighthouse Authorities (GLA) DGPS service came into operation in 1998. The DGPS equipment has a typical operational life of 5-10 years and the computers and communications equipment have already been replaced. The Reference Stations and Integrity Monitors (RSIM) currently in use are no longer in production and may not be supported beyond 2008. Also, the communications between RSIM and control station need to be upgraded as they are currently based on proprietary protocols of the RSIM supplier. Furthermore, the present GLA DGPS system will not meet all the requirements set out in IMO Resolution A.915(22) for Future GNSS (IMO 2001). Four routes have been considered:

- Replacement of the existing hardware RSIM;
- Replacement with RSIM implemented in software;
- Virtual Reference Station (VRS) approach, using an existing network;
- Integration with Satellite Based Augmentation Systems (EGNOS).

In order to investigate these options and provide recommendations, NSL has carried out a study on behalf of the GLA, the results of which are presented in this paper.

For each route, several options for integration will be analysed. All options will take into account the need for validation of system performance. The possibility of building in the necessary infrastructure, data processing, analysis and reporting will be considered.

1.2 *Study Logic*

The study itself was divided into the following tasks:

- Concept Evaluation: Activities in this task will propose and evaluate a concept for the incorporation of the “selected option” into the DGNSS ser-

vice in order to meet the requirements set out in IMO Resolution A.915(22) (IMO 2001). The task will define the physical components and operating processes as well as the monitoring, control and deployment concepts.
– Technical Analysis: This task will provide a baseline definition of the overall functionality and architecture of the proposed DGNSS service options, as well as identifying the validation infrastructure and tools will be required to monitor the performance of the service.
– Performance Assessment: The performance of the DGNSS service architecture will be assessed and analysed by simulations using NSL's NEMO tool. The main performance criteria to be analysed will be the ability to deliver the necessary levels of accuracy, integrity, availability and continuity performance across the GLA coverage zone.
– Critical Items and Risks: This task will identify critical functions, interfaces and core elements that are essential to the DGNSS service in order to meet the requirements. The task will identify associated technical and operational risks that may impact the delivery or performance of the DGNSS service.
– Economic Analysis: The activity will provide information on the incremental costs for development, deployment and operation of the DGNSS service that can be attributed to the inclusion of the option. Costs will be sourced from suppliers and through discussions with European bodies.
– Recommendations: The final activity will be to present a summary and conclusions of the tasks and to provide a series of recommendations for implementation.

2 CONCEPT EVALUATION

2.1 *Introduction*

As the developments in GNSS will be incremental, it is unlikely that a single option can be identified that can be implemented now and will cover all future requirements set out in IMO Resolution A.915(22) (IMO 2001). In fact, the timeline of DGPS re-capitalization makes it clear that it will be a two stage process. Therefore each considered option will be assessed in terms of both backward compatibility with legacy users and flexibility for modification /upgrade as new signals/systems come on line.

In addition, it may not be most efficient to have a single solution to cater for both global and regional solutions and local high accuracy services. Therefore the assessment of options for local high accuracy operations (possibility of 0.1 m accuracy) is separated from the section detailing possible options for providing global and regional services (10 m and 1 m accuracy).

2.2 *Global/Regional Solutions*

To provide global/regional solutions, a number of options were identified. After initial analysis, the following options were chosen as the best to take forward for further study:

– **Procurement of upgraded HW RSIM**: This option involves a direct replacement of the existing HW with upgraded COTS HW RSIM, along with upgraded transmitters;
– **Procurement of upgraded HW + SW RSIM**: This option involves implementing the main RSIM functionality in SW that is external to the GNSS receivers. This allows for greater flexibility than the baseline option as it should be easier to upgrade SW to for new message types and signals rather than having to procure new HW;
– **OSNET VRS (DGPS)**: Instead of operating separate RSIM sites, in this option a central processing facility uses data from 3rd party network to compute corrections for all virtual reference stations, that are then sent to the transmitters;

Table 1. Summary of global/regional re-capitalization options

DGNSS Option	Backward compatibility	Maturity of Technology	Flexibility for message upgrade	Flexibility for future GNSS signals	Possible Reduction in Infrastructure
Procurement of upgraded HW SIM	Yes	High	Medium	Medium	No
Procurement of upgraded HW + SW RSIM	Yes	Medium	High	Medium	No
OSNET VRS (DGPS)	Yes	Medium	High	Low (*)	Yes
SW Radio receiver + SW RSIM	Yes	Low	High	High	No
EGNOS RTCM	Yes	Low	High	Low (*)	Some
EGNOS RTCA	No	Low	High	Low (*)	Some

(*) – Any upgrades are dependent on 3^{rd} party evolution plan and are therefore not controllable by the DGNSS service provider

Table 2. Summary of local high accuracy options

DGNSS Option	Maturity of Technology	Infrastructure costs	Coverage	Existing standards	Reliance on 3rd party
OSNET VRS (RTK)	Medium	Medium	Good within network – up to 20 km outside	Yes	Part
EGNOS WARTK	Low	Low	Good	No	Yes

- **SW Radio + SW RSIM**: This option is similar in architecture to the Procurement of upgraded HW with SW RSIM option. However, instead of a HW GNSS receiver and beacon receiver at the RSIM sites, SW Radio technology is used;
- **EGNOS RTCM**: In this option the RTCM correction messages are computed using the EGNOS correction messages, obtained via EDAS. Therefore the reference stations simply retrieve the EGNOS messages and morph them into RTCM format for broadcast. The Integrity Monitor architecture and functionality is unchanged;
- **EGNOS RTCA**: In this option the EGNOS correction messages are obtained via EDAS and simply re-broadcast via the DGPS transmitter network so that users in high latitudes, or in areas where the view to the EGNOS GEO is restricted, can enhance their solution using the EGNOS RTCA corrections.

Table 1 summarises the main advantages and disadvantages of the identified re-capitalization options.

2.3 *Local High Accuracy Solutions*

To provide local high accuracy solutions, a number of options were identified. After initial analysis, the following options were chosen as the best to take forward for further study:

- **OSNET VRS (RTK)**: The architecture of this option is very similar to the OSNET VRS code option, except that RTK messages rather DGPS messages are produced for virtual reference stations;
- **EGNOS WARTK**: In this option, instead of operating separate RSIM sites, a central processing facility computes corrections for the whole area that are then communicated to the transmitters. The input data used to compute the corrections is obtained from the EGNOS RIMS via EDAS.

The following table summarises the main advantages and disadvantages of the identified re-capitalization options.

2.4 *Conclusions of Concept Analysis*

One of the main drivers for re-capitalization will be the maturity of the technology and the possible dates at which such a service could become operational. Based on best estimates for operational dates, a timeline illustrating DGPS re-capitalization schedule and possible dates when the different options may be available is shown in the Figure 1.

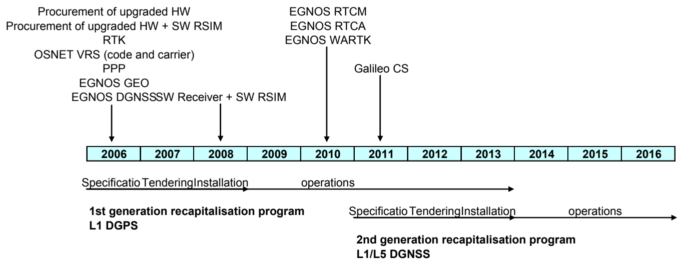

Fig. 1. Timeline of DGPS re-capitalization an availability of options

Therefore there are 4 options that are considered for 1st generation re-capitalization and a further 4 that are considered for 2nd generation:

- 1st Generation Options
  - Procurement of upgraded HW RSIM
  - Procurement of upgraded HW + SW RSIM
  - OSNET VRS (DGPS)
  - OSNET VRS (RTK)
- New 2nd Generation Options
  - SW Radio + SW RSIM
  - EGNOS RTCM
  - EGNOS RTCA
  - EGNOS WARTK

NB It should be noted that those options considered as potential 1st generation options can also be considered for upgrade to 2nd generation.

3 PERFORMANCE ASSESSMENT

3.1 *Methodology*

The performance assessment has been carried out using NSL's NEMO SW tool. NEMO is a Service Volume Simulator (SVS), and is a fully interactive PC-based Windows application. It provides a flexible and extendible platform for analysing GNSS systems over a service volume at specific moments in time, with the capability to then inspect at specific locations within that service volume.

For the performance assessment, the strategy is that the satellite geometry and UDRE values are used to compute the accuracy and integrity (protection level) values at a grid of analysis points within the defined coverage area for a number of different times.

There are defined minimum maritime user requirements for many different applications from IMO (2001). Generally, the operations can be grouped into high (0.1m accuracy, 0.25m integrity), medium (1m, 2.5m) and low (10m, 25m) accuracy/integrity requirements.

We can compare the performance results against the required navigation performance to see if the option has the potential to provide an adequate service.

3.2 *Summary of L1 DGPS Performance*

From the results of the L1 DGPS performance assessment the following conclusions can be drawn:

- All the code positioning options under consideration for 1st generation re-capitalization are very close to meeting the low accuracy/integrity requirements for horizontal performance with L1 GPS data. The simulation results show that the horizontal accuracy can meet the 10m requirement 100% of the time for coastal areas and the horizontal integrity meets the 25m limit about 95-99% of the time;
- For the new 2nd generation re-capitalization options, then the SW Radio + SW RSIM option is the only one that can match the 1st generation options in terms of horizontal performance for legacy users (L1 GPS);
- The vertical performance is slightly worse than the horizontal performance for all options. This is a function of the satellite geometry and is unavoidable when using only GNSS measurements. However, the vertical performance requirements only apply to certain specialised applications and so the majority of users' needs are met;
- None of the code positioning options are close to meeting the medium accuracy/integrity requirements;
- The OSNET VRS (carrier phase) option is the only one that is even close to meeting the high accuracy/integrity requirements, although the area where the service is available is limited to the area within the reference station network and up to 20 km outside of it (Cruddace 2005).

3.3 *Summary of L1/L5 DGNSS Performance*

For the results of the L1/L5 DGNSS performance assessment the following conclusions can be drawn:

- All the code positioning options from both 1st generation and new 2nd generation options can easily meet the low accuracy/integrity requirements;
- All the 1st generation code positioning options are very close to meeting the medium accuracy /integrity requirements in the horizontal domain. The simulations show that the 1m accuracy requirement can be met 99.9% of the time in the majority of coastal locations, except for a few areas around the Irish coast. The horizontal integrity can meet the 2.5 m requirements around 95% of the time at all locations;
- There is the possibility that the OSNET VRS code option could improve the performance in certain areas by changing the locations of the virtual reference stations, without having to move the transmitters;
- For the new 2nd generation re-capitalization options, then the SW Radio + SW RSIM option is the only one that can match the 1st generation options in terms of horizontal performance;
- The vertical positioning/integrity performance is worse than the horizontal performance for all options due to the satellite geometry. However, the vertical performance requirements only apply to certain specialised applications and so the majority of users' needs are met;
- The OSNET VRS (carrier phase) option performs better than the EGNOS WARTK solution and is very close to meeting the high accuracy/integrity horizontal requirements. However, the area where the service is available is limited to the area within the reference station network and up to 20 km outside (Cruddace 2005) whereas the EGNOS WARTK service would be available at all locations within the area served by the GLA.

4 RISK ANALYSIS

4.1 *1st Generation Options*

For 1st generation re-capitalization then there are 3 DGPS code options and one high accuracy option. The high accuracy option (OSNET VRS RTK) is an extension of the OSNET VRS code option but they are not interlinked, and so it is possible to operate the OSNET VRS code service without the OSNET VRS RTK service, and vice versa. Therefore the risks are considered separately, although many of them are common.

For the 3 DGPS code options (HW RSIM, SW RSIM and OSNET VRS code), the following results are apparent:

- Considering only those risks relevant to the 1st generation re-capitalization, the option with the highest technical risk is the OSNET VRS code option. This is due to the fact that the architecture is quite different from the existing DGPS service and the SW is more complex and so there is a slightly greater probability for this option that it will not be available in time for 1st generation;
- The option with the highest operational risk is again the OSNET VRS code option. This is due to the fact that this option relies on 3rd party data input, and any timeliness or reliability issues with the data will affect the ability of the solution to provide correction messages with correct accuracy and integrity. As there is a single processing facility that computes corrections for all sites, any complete interruption to the OS data means that messages from the whole DGPS transmitter network are affected;
- The HW RSIM and SW RSIM options have the same technical risk. However, the SW RSIM option has a higher operational risk related to the fact that an upgrade of the operating system (e.g. from Windows NT to XP) may cause incompatibilities and affect the availability of the service. Although the HW RSIM option has the same risk, the consequence is lower because this option is based on HW and will not be affected so much;
- Overall, the option with the least risk for 1st generation re-capitalization is the HW RSIM option. The OSNET VRS code option is by far the riskiest option with several risks that have a high total score;
- When considering the risks associated with upgrade of these options for the 2nd generation programme, the option with the highest technical risk is the OSNET VRS code option. This is due to the fact that this option is reliant on 3rd party enhancement of the reference receiver network so that L1/L5 GNSS measurements are available;
- For upgrade to 2nd generation then the option with the lowest risk is the SW RSIM option. This is because there is potentially greater cost involved in upgrading the HW of the HW RSIM option to meet 2nd generation requirements compared to the upgrade for the SW RSIM option.

The OSNET VRS RTK option is the only one of those considered that could potentially be used for a high accuracy service. However, it has significant risk, especially on the technical side:

- The high technical risk is due to the fact that the high accuracy solution is limited to the area within, and up to 20km outside of, the reference network (Cruddace 2005). This means that the option cannot provide a high accuracy service at all locations within the coastal region up to 50 nautical miles from the coast;
- For the operational risk then the highest score is due to the fact that the existing transmitters cannot be used because their bandwidth is not great enough and so a different broadcast method has to be used. The actual method is not consolidated but some of the options, e.g. GSM, may not provide the required level of message availability;
- When considering the risks associated with upgrade for the 2nd generation re-capitalization programme, the OSNET VRS RTK option has a high risk due to the fact that this option is reliant on 3rd party enhancement of the reference receivers so that L1/L5 GNSS measurements are available.

Such high risks for the OSNET VRS RTK option make it unsuitable for implementation and so this option is not considered further in this study.

4.2 *New 2nd Generation Options*

Although the new 2nd generation re-capitalization options are not considered for 1st generation re-capitalization, they should be able to provide an L1 DGPS service to cater for legacy users. There are 3 options for providing a DGPS code service and 1 option that could potentially be used for a high accuracy service (EGNOS WARTK).

For the new 2nd generation DGPS code options, the remaining risks after mitigation should be considered. The following results are apparent:

- The option with the highest technical risk is the EGNOS RTCA option. This is due to the fact that the messages are not compatible with RTCM version 2.X and so legacy users cannot be supported with this option alone;
- The EGNOS RTCA and EGNOS RTCM options also have high risk due to their degraded performance compared to the other DGPS code options;
- The EGNOS RTCA and RTCM options also have a high technical risk due to their reliance on a 3rd party enhancement programme. At the present time, EGNOS is almost operational to provide corrections for GPS L1. In order to be considered for 2nd generation, EGNOS must have been enhanced so that it covers both GPS and Galileo on L1/L5, and also the EDAS must be operational. There are evolution plans for

EGNOS, but until the plans are implemented it remains a risk that the products will not be available in time;
- The SW Radio + SW RSIM option has the lowest technical risk of all the new 2nd generation DGPS code options. However, the risk for this option is still slightly higher than for the upgrading of HW and SW RSIM options from 1st generation;
- All options have an equally high operational risk due to operating system upgrade, and the fact that any upgrade result in incompatibilities and impact availability. However, the EGNOS RTCA and EGNOS RTCM options have an additional operational risk due to reliance on 3rd party input data.

For these points, the main finding is that the EGNOS RTCA should not be considered further in this study because it does not support legacy users, and so will not allow the GLA to fulfil all their core obligations.

For the high accuracy service option (EGNOS WARTK) then the following points are observed:

- EGNOS WARTK has a very high technical risk because the solution relies on dual frequency data at both the system and user level, and so it is not possible to provide a service for legacy users;
- The EGNOS WARTK option also has a high technical risk due to the unavailability of suitable processing SW for purchase at the current time. In fact, this approach has only been demonstrated in research papers and so there is little evidence that a feasible service can be provided;
- It is also the case that the existing DGPS transmitter network cannot be used for broadcasting the EGNOS WARTK messages because the bandwidth is not sufficient. Therefore alternative transmission means will have to be found.

Because the EGNOS WARTK option has a high technical risk and cannot support legacy users, this option is not considered further. Unfortunately this means that both high accuracy options (OSNET VRS RTK and EGNOS WARTK) have been discounted due to excessive risk.

5 COSTS

The aim of the economic analysis is to provide the estimated costs for the different re-capitalization options. Following the risk analysis, the remaining candidate options are as follows:

- 1st generation re-capitalization options
  - Procurement of Upgraded DGPS equipment
  - Procurement of upgraded HW in combination with SW RSIM
  - OSNET VRS (code)
- New 2nd generation re-capitalization options
  - SW Radio in combination with SW RSIM
  - EGNOS RTCM

It is not the aim of this task to determine the exact final costs for every single piece of HW and SW and all running costs associated with the options. Rather it is expected that this analysis will give ball-park figures for each of the options in order to allow a simple comparison of order of magnitude costs.

Only the initial costs have been included at this stage. Whole-life costs, including running costs and decommissioning would give a better assessment, preferably taking account of the interaction between 1st and 2nd generation options. However, due to uncertainties and lack of data on many of the options, this was considered out of the scope of this study.

From analysing the final costs for each option, the following points are observed:

- For 1st generation re-capitalization,
  - The option with lowest procurement costs is the VRS with OSNET option. This is because the option operates on a central Processing Facility architecture and so the costs are reduced compared to the separate RSIM site options;
  - However, the operational costs associated with the VRS with OSNET option are currently unknown because the information on data access costs to the OS reference data has not yet been provided. This increases risk for this option as the full costs cannot be estimated;
  - Disregarding the VRS option, the baseline HW RSIM option has lowest cost;
  - The SW RSIM option is significantly more expensive than the Procurement of upgraded DGPS equipment (HW) option. This is because any saving in GNSS Rx cost (because of reduced functionality) is more than wiped out by the additional RSIM SW costs;
  - For both the HW and SW RSIM options, planning for easy upgrade to 2nd generation requirements at this stage adds significant extra cost to the procured GNSS equipment
- For 2nd generation re-capitalization;
  - The cheapest option is the HW RSIM option;
  - The EGNOS RTCM option offers some saving over the SW RSIM option because the reference station SW is less complex. Further savings could be achieved if the EGNOS RTCM option moved to a central Processing Facility approach (like the VRS option) but this

puts extra burden on the comms and would need further study;
- The operational costs for the EGNOS RTCM option are not confirmed as information on costs to access the EGNOS messages via EDAS is not available. It is assumed to be free but this may not be the case and so this therefore increases risk for this option as the full costs cannot be estimated;
- The most expensive option is the SW Radio + SW RSIM option. However, due to the immaturity of the technology, and the long time into the future we are looking at, the costs estimates may be unreliable.

6 CONCLUSIONS AND RECOMMENDATIONS

The lowest cost, lowest risk option would be to replace existing hardware with similar, dedicated RSIM based on known, commercially available technology. However, the choice of suppliers is limited and once chosen, it may be difficult to change it to meet emerging requirements.

The flexibility provided by the SW RSIM option could overcome this problem and it should not be ruled out at this stage. Therefore the following recommendations are proposed for the DGPS re-capitalization:

1 The Hardware RSIM option should be adopted for the 1st Generation Re-capitalization, on grounds of lowest cost and risk;
2 Transition to the SW RSIM option during the lifetime of the 1st Generation system should be considered, if suitable proven software becomes available at reasonable cost;
3 Study of the 2nd Generation options should be a continuing project, running in parallel with the 1st Generation Re-capitalization work.

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