Abstract

This paper documents a case study into the Availability, Reliability and Maintainability (AR&M) modelling activity undertaken for the Skynet 5 Beyond Line Of Sight (BLOS) service programme between January 2006 and July 2011. The AR&M modelling activity was completed using the Monte Carlo simulation tool SPAR, produced by Clockwork Solutions. SPAR is a flexible software tool which allowed the development of models to include the end-to-end Skynet 5 system, its complex logistic support network, and the calculation of bespoke Service availability metrics. The development of this end-to-end type approach has provided a number of benefits, including: highlighting potential areas of weakness in the support solution; understanding the impact on global AR&M performance; and validation of consolidated spares recommendations and identification of areas with insufficient spares, at multiple levels of support (as many as the user requires). Furthermore it has the ability to demonstrate the impact of management system downtime; which would not directly impact the availability of the system, but may delay the identification (and hence repair time) of a co-incident failure.

Keywords: Availability; Reliability; Maintainability; Modelling; Satellites; Skynet 5.

1. An Overview of the SPAR Modelling Platform

The SPAR simulation uses Monte Carlo simulation techniques to model the life-cycle behavior of systems. The SPAR modelling platform includes a wide range of distributions (including bathtub and non-parametric distributions), to represent the time-dependent behaviour of failure, repair, shipment, replacement and other time-dependent phenomena.

A SPAR model is described using Reliability Block Diagrams (RBD), statistical distributions and operation rules expressed in simple logic code. SPAR uses the system operating rules and logic to model the effects of events (direct effects as well as cascaded ones) on the behavior of the system. SPAR's logic modelling capabilities include, among others, active-passive and standby relations, cannibalization of spares, induction of failures, changing the age and the load of components, and many other operations that enable illustrating any real life phenomena of the system and its supportive resources.

An assessment was completed into the different modelling tools available at the time. There were a number of reasons for utilising SPAR, including the following:

- All other modelling tools assessed used pictures/flow diagrams/RBDs to describe the system in question. Since some elements of the Skynet network are so complex in terms of all the different routing options based on which equipment had failed, it was not possible to construct all the different possibilities in pictorial form. SPAR uses a bespoke logic code to describe what happens when, for example, components fail, and based on any number of other conditions (e.g. which particular communications services were effected, if any other components are failed at the same time, or if a particular remote terminal was in the field at the time) the end effect on Service and Operational availability can be investigated.
The SPAR models created were completely transparent: The fact that logic code was used to describe the systems meant that checks in the code could be included throughout to ensure that the models were correct, and to pull out results at any point in the model run. This gave confidence in the results produced and also enabled the identification of the point at which, for example, a particular component ran out of spares or a particular communication service failed. This feature is limited in the other modelling tools.

The modelling tool was required to calculate the availability of communications services passing through the Skynet network. The Service availability was not equal to the equipment availability due to the ability to route communication services between network paths with different switching times (dependent on the availability of paths and the bandwidth). Only SPAR was identified as being able to perform such calculations.

2. A Brief Overview of Skynet 5

The Skynet 5 programme provides the UK Armed Forces with secure BLOS services (forthwith referred to as Services). Management of the Services takes place at two Satellite Ground Stations (SGS) (see Fig. 1). The Services are then broadcast over military hardened Skynet 5 communication satellites (see Fig. 2) in orbit, to two types of remote terminals; SCOT5 Maritime terminals (see Fig. 3) and Reacher ground mobile terminals (see Fig. 4). Each remote terminal undertakes a number of missions throughout its life, with each mission including defined periods of transmitting and receiving Services, periods of transit and periods of maintenance.

Two exam questions were placed on the Skynet 5 system, to be answered using the SPAR modelling platform:

1. Calculate the predicted end-to-end Service availability to Reacher and Maritime terminals. This involves calculating the average availability of Services passing through an SGS, a satellite and a remote terminal (Reacher or Maritime);

2. Calculate the predicted operational availability for Reacher and Maritime terminals.

3. Modelling the Skynet 5 System in SPAR

Construction of the models in SPAR began through identification of equipment and systems directly and indirectly required to support Services (creating Service paths through the Skynet 5 system) and to achieve the operational availability of the remote terminals.

The equipment within the remote terminals was divided into two groups: those responsible for carrying Services and operational success, and those just required to achieve the operational availability. RBDs were constructed within SPAR for each remote terminal to represent the successful achievement of Operational and Service availability.

The SGSs and satellites utilise sophisticated redundancy paths and routing options to ensure minimal downtime in the event of equipment failure. The complexity of these systems meant that it was not possible to construct conventional RBDs such as those used for the remote terminals. Instead, logic code within SPAR was used to model the in-built redundancy and failure management systems.
The SPAR models were developed with no common spares between the remote terminals and SGSs. Therefore they could be modelled separately (with the metrics combined after each model run) to simplify the problems and allow them to be developed, verified and validated in stages. User-defined data arrays were employed in the SPAR models to identify various equipment features to influence and direct the logic code. These features include:

- Statistical distribution parameters representing the time to repair/replace the equipment and the time taken to restore Services carried by each equipment (the restoration time can also represent the time taken to re-route Services to an alternate path within the SGS or Satellite);
- The quantity of Services carried (and therefore affected) if each equipment type fails;
- For SGSs and Satellites, parameters identifying the redundancy configuration of equipment types, for example the minimum number of items required to be operational to carry Services.

Using equipment failure distributions input by the user (from manufacturer data, in-service data, etc.) the SPAR modelling platform utilises Monte Carlo simulation techniques to generate failure events. At each failure event the logic code randomly selects (from the Services defined in the data arrays) the specific Services affected by the equipment failure. The time to restore the Services (taken from the data array) is then applied to each affected Service and the average Service availability is then calculated at the end of the model run. For remote terminals, the time to repair/replace the equipment is also recorded for each Terminal and the average operational availability is calculated.

The total time to repair/replace the equipment is dependent on a complex logistic support network, which is also represented in the SPAR models and logic code. Fig. 5 in Appendix A presents a representation of the Skynet 5 logistic network. As shown in Fig. 5, each Maritime terminal is supported by its own on-board spares holdings and by the spares depot whereas each Reacher terminal is supported by three spares holdings:

- On-board spares
- A Forward Spares Pack (FSP) supplying spares to a number of Reacher terminals
- A spares depot, supplying the two SGS’s, all Reacher terminals and all Maritime terminals.

Spares holding are represented in the SPAR model by ‘Storages’, containing a user-defined quantity of spares at the beginning of the model run. If equipment fails, the logic code interrogates the Storages in turn to determine where the closest available spare is located. The logic code uses this spare to replace the failed equipment and the Storage is then replenished by spares (if available) from the next holding in line (e.g. as shown in Fig. 5, Reacher terminal on-board spares are replenished by the Forward Spares Pack, which is then replenished by the Spares Depot).

Upon failure, repairable items are returned through the support network to the Repair facility (as shown in Fig. 5). These items are repaired before re-entering the support network to act as a spare. Non-repairable items are removed from the model upon failure and replaced with a spare. If all spares have been used, the system is defined as failed for the remainder of the model run.

All timings associated with the forward supply of spares and return of failed equipment (shown in Fig. 5 as purple and blue dotted lines respectively) is contained within another user-defined array and the logistics delay times for each type of equipment on each terminal can be modified individually.

Each remote terminal undertakes a pre-defined number of missions throughout its life. These missions are defined within the SPAR platform as periods of uptime (i.e. sending/receiving Services) and downtime (i.e. undergoing planned maintenance and transit). Failure events can occur during periods of uptime or downtime, however only those occurring during the period of uptime contribute to Service and Terminal Operational availability.

4. Conclusion

The development of the end-to-end modelling approach to the Skynet 5 system, including its complex logistic network, through the flexibility provided by the SPAR modelling platform, has allowed the following validation and scenario modelling activities to be performed:

- Highlighting areas of weakness in the current support solution by updating model inputs with in-service reliability and maintainability data.
- Varying mission profiles to model future deployments and highlight potential problem areas early to allow for prompt contingency planning. This included demonstrating the impact on Service and Operational availability of changing the mission profiles of remote terminals – i.e. if a terminal is going to be used for a longer period, the Service and Operational availability drops to a certain level, if the sparing levels are not replenished.
- Validating long-term sparing recommendations, especially pertinent with life-time buys for obsolete equipment where there will be no opportunity to replenish supplies in the future. Spares were recommended for individual sub-systems in isolation; the SPAR model was used to validate that sufficient spares (in order to meet the Service and Operational availability requirements) had been recommended for the system as a whole.
- Modelling scenarios to aid trade-off studies.
- Investigating the impact of supply chain issues such as equipment losses and increased logistics delay times. The SPAR model was used to demonstrate the impact of extending the logic delay times on Service and Operational availability.

By developing this end-to-end type of modelling, it has been possible to take a holistic approach to the Skynet 5 system: identify and account for all the interdependencies and
interactions and show the impact the above scenario modelling activities have on each aspect of the system.

The Skynet 5 SPAR models have increased the confidence in the system designs and support solution, forms part of the system assurance case (by answering the exam questions), and provides potential long-term through-life cost savings. For these reasons, it is recommended that all large and complex programmes should consider developing this end-to-end style of modelling.

Appendix A. Skynet 5 Logistics Network Overview Diagram

![Skynet 5 Logistics Network Overview Diagram](image-url)

Fig.5. Skynet 5 Logistics Network Overview

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