REQUIREMENTS-DRIVEN SATELLITE SYSTEM DESIGN

Iain Inglis, Aegis Systems Limited
Richard Vinnicombe, QinetiQ

1. INTRODUCTION

The Skynet 5 system will provide military satellite communications to all three UK armed services, and is to be procured as a 'private finance initiative' (PFI). Though there are many PFI projects across all parts of the public sector, this is the first time that such an approach has been taken for providing military satellite communications. On 26 February 2002, the Ministry of Defence announced the selection of Paradigm Secure Communications as the preferred bidder for the £1+ billion contract.

Over the last decade the Defence Evaluation & Research Agency, Space Dept (now QinetiQ) has developed a simulation-based method for analysing payload designs based on requirements for communication services, as expressed by users. This method is implemented in a computer model called the Satellite Communication System Analysis Package (SCSAP), which has helped to size the 'public sector comparator' for Skynet 5.

2. SIMULATION IN PROCUREMENT

In 1995, the Chancellor of the Exchequer said, 'We are changing the role of Government. We are moving Government to being a provider of private investment opportunities and a purchaser of services …'. This intention has been implemented in the PFI and other public-private collaborations, in which the public sector transfers some non-core activities (including risk management) to more capable external service providers.

Some early public-private arrangements were criticised for a failure to systematically examine public sector alternatives to a private sector supply [1]: it is now standard practice to include such a review — and the process is formalised as the 'public sector comparator' [2] (i.e. the hypothetical, whole-of-life, risk-adjusted cost of government delivering the project outputs [3]).

PFI procurement is expected to show a saving against the public sector comparator, as well as offering possible non-monetary value (such as schedule advantage). Having demonstrated PFI feasibility, therefore, one thing can be said with some confidence about the design implicit in a PSC: it must be 'credible and realistic', but it won't be built — it is, in the general sense of the word, a *model* of a potential future system. It is quite natural therefore that a public agency constructing a PSC, particularly in a technical area such as military satellite communications, might find detailed simulation useful.

In particular, both the Skynet 5 Design Phase contractors (Paradigm and Rosetta) were asked to consider third-party markets as a method of reducing the overall charges to MOD. It was expected that both parties would secure some third-party interest and hence build larger spacecraft than would be required for solely MOD requirements. In such circumstances, it is clearly important for MOD to establish its own requirements with some confidence. The SCSAP was used as part of the effort to establish those requirements (CR2000).

3. THE MODEL

The Skynet 5 requirements capture method is based on the enumeration of several thousand Information Exchange Requirements (IERs). When filtered into likely operational scenarios, the SCSAP was used to reduce the large number of IERs into the reduced set of Communication Requirements (CRs) that must be supported by the spacecraft. This reverses the usual process in which assumed mass, power and other constraints determine the satellite capability, which is then assessed for compliance against the service requirements. Starting with the user requirements enables different requirements to be compared in 'cost' terms — long before a detailed design is available.

The simulation software comprises two parts: the Satellite Communication System Model (SCSM — developed by Aegis Systems Ltd) and the Database Tool (DBT — developed by Systems Engineering & Assessment Ltd). SCSM models the space system and user terminals based on service requirements supplied to it by DBT. The two applications are used interactively to establish consistency between a set of service requirements and a payload design.

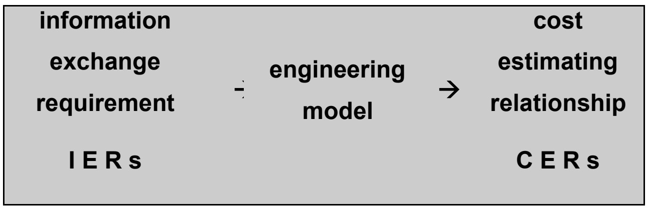


Fig. 1 : Requirements-driven costs

SCSM provides satellite and user terminal positioning, link budget analysis for a variety of access and modulation schemes, connectivity and bandwidth analysis, and cost estimation (see Figure 1) — as well as the graphical and tabular reporting of the model for publication. Note, however, that the explicit cost outputs are intended only for sensitivity analysis: for Skynet 5 use, the relationship between IER-derived input scenarios and the required payload size was explored — the SCSM cost model was not used.

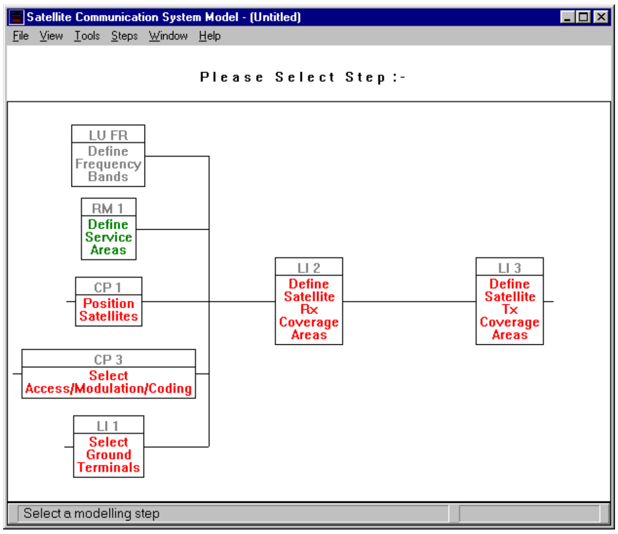


Fig. 2 : SCSM 'novice' user interface

The user builds an SCSM model by completing a series of steps, as in Figure 2. The software is fully interactive, so a step can be revisited — with the effects of the change propagated throughout the rest of the model. When the number of requirements is large, the model is imported from a database, and the user then examines whichever step is of current interest. Alternatively, the model can simply be exported back to the database, complete with all calculations and reports.

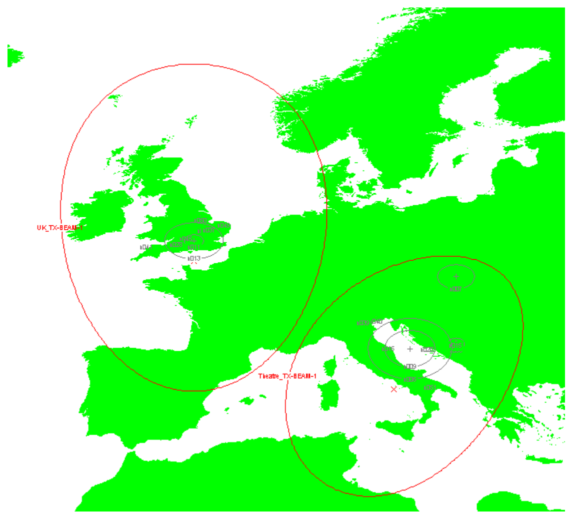


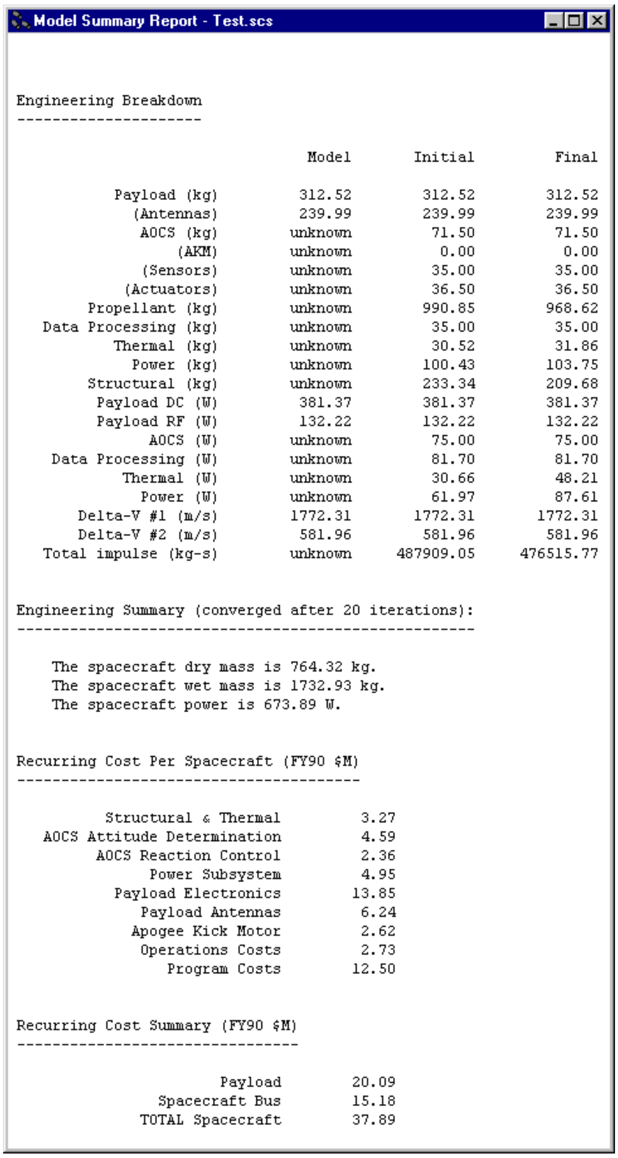
Fig. 3 : Graphical model display

Requirements
Define Networks
Define Service Areas
Define System Requirements
System Definition
Select Access, Modulation & Coding
Select Ground Terminals
Relate Services To Earth Stations
Position Satellites
Assign Channels to Satellites
Define Satellite Rx Coverage Areas
Define Satellite Tx Coverage Areas
Define Satellite Antennas
Payload
Configure Transponders
Define Payload Redundancy
Summarise Payload

Fig. 4 : SCSM model steps

The scope of the original project included spacecraft subsystems, launch, operations and reliability, but the weaker dependence of these areas on the input service requirements meant that implementation could be deferred, enabling effort to be concentrated on modelling the payload (see Figure 4). Nevertheless, a number of steps are partially implemented in order to drive the cost part of the model: AOCS (including launch), power, data processing, thermal and structure. In addition, the user can specify look-up tables to customise frequency bands, Earth station characteristics, access & modulation techniques and transponder characteristics.

As each step in the model is completed, a progressively more comprehensive summary report can be produced, which relies on a simple rule-based expert system to provide the best outputs given the information available for a particular model (Figure 5). These outputs allow a sensitivity analysis to be performed to identify 'problem' requirements or technologies (see [4] for a discussion of cost modelling and Cost Estimating Relationships).


Model Summary Report - Test.scs

Engineering Breakdown

	Model	Initial	Final
Payload (kg)	312.52	312.52	312.52
(Antennas)	239.99	239.99	239.99
AOCS (kg)	unknown	71.50	71.50
(AKM)	unknown	0.00	0.00
(Sensors)	unknown	35.00	35.00
(Actuators)	unknown	36.50	36.50
Propellant (kg)	unknown	990.85	968.62
Data Processing (kg)	unknown	35.00	35.00
Thermal (kg)	unknown	30.52	31.86
Power (kg)	unknown	100.43	103.75
Structural (kg)	unknown	233.34	209.68
Payload DC (W)	381.37	381.37	381.37
Payload RF (W)	132.22	132.22	132.22
AOCS (W)	unknown	75.00	75.00
Data Processing (W)	unknown	81.70	81.70
Thermal (W)	unknown	30.66	48.21
Power (W)	unknown	61.97	87.61
Delta-V #1 (m/s)	1772.31	1772.31	1772.31
Delta-V #2 (m/s)	581.96	581.96	581.96
Total impulse (kg-s)	unknown	487909.05	476515.77

Engineering Summary (converged after 20 iterations):

The spacecraft dry mass is 764.32 kg.
The spacecraft wet mass is 1732.93 kg.
The spacecraft power is 673.89 W.

Recurring Cost Per Spacecraft (FY90 $M)

Structural & Thermal	3.27
AOCS Attitude Determination	4.59
AOCS Reaction Control	2.36
Power Subsystem	4.95
Payload Electronics	13.85
Payload Antennas	6.24
Apogee Kick Motor	2.62
Operations Costs	2.73
Program Costs	12.50

Recurring Cost Summary (FY90 $M)

Payload	20.09
Spacecraft Bus	15.18
TOTAL Spacecraft	37.89

Fig. 5 : Summary report

The CERs are driven primarily by two parameters: mass and power (volume was not considered). The power requirement follows the link budget, which in turn derives from the service requirements and the antenna characteristics (including Earth cover horn, spot/shaped reflector beams, multi-matrix antenna, and direct/imaging phased arrays). Similarly, the payload mass estimates depend on bandwidth and connectivity considerations, which in turn depend on the access and modulation schemes (FDMA, spread spectrum and TDMA). Both transparent and regenerative links can be modelled.

4. THE SOFTWARE

The software started life in 1992 as the Engineering Cost Model and was initially implemented as a prototype, in the Actor object-oriented programming environment: this enabled features to be implemented rapidly, but within familiar Microsoft Windows patterns of use. The prototyping approach was adopted because the modelling functionality was evolving, but there was nevertheless a need to demonstrate the modelling concept as software, and to validate the model against existing geostationary satellites for which requirements, design and cost information could be obtained. The prototyping and validation results were encouraging — and the project continued.

Eventually, the Actor prototype was unable to cope with the number of communications requirements required for likely military communications satellite concepts (i.e. what would become Skynet 5) and the 9,000 lines of Actor code were ported to Borland C++, which shared Actor's Object Windows Library. Ultimately, as the amount of functionality increased, the model was ported again, from 16 to 32 bits. The SCSM software now contains 33,000 lines of C++ which, averaged over the five contracts awarded to Aegis, represents a production rate of approximately 30 DSI/day [5].

As the system became operational, further work concentrated on support for new antenna types, more sophisticated treatment of access schemes, better handling of connectivity issues, performance improvements and a large number of usability enhancements. Importantly, an interface with the requirements database was developed, and the database ultimately became a separate tool (the DBT, implemented in Microsoft Access). By this time the focus had moved away from cost modelling as the primary objective, and the name was changed to the Satellite Communication System Model: the complete set of tools is now known as the Satellite Communication System Analysis Package.

5. SUMMARY

The paper has presented the Satellite Communication System Analysis Package and its use in the context of a significant satellite system development. The simulator capitalised on the IER requirements capture process in Skynet 5 and helped MOD to size the public sector comparator for that procurement.

The SCSM was developed using a collaborative, prototyping approach, with the able and active support of its project sponsors — it has, as a result, enjoyed an unusually long life for an engineering simulator.

REFERENCES

[1] Public Accounts Committee Report on Skye Bridge, 1998

[2] Technical Note No. 5, How to construct a Public Sector Comparator, Treasury Taskforce – Private Finance

[3] Partnerships Victoria, http://www.partnerships.vic.gov.au

[4] Space Mission Analysis and Design, Wertz & Larson, Kluwer

[5] Software Engineering Economics, Boehm, Prentice-Hall