Managing Complex Collaborative Projects: Lessons from the Development of a New Satellite

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ABSTRACT. This paper examines the case of a Complex Product System (CoPS)—a new satellite—and the combination of international firms and agencies that contributed to its development. Despite many political, organisational and interpersonal tensions, divergent objectives and strategic misjudgements, the satellite was successfully launched in 2002. It was found that a number of factors contributed to the successful conclusion of the project, including the evolution of organisational structures between different actors as the project progressed, the use of a range of innovation management tools accompanied by personnel with significant discretion and judgement, and a unifying methodology for satellite production called the Small Satellite Philosophy (SSP), which helped provide an approach for its effective integration. The paper describes the satellite project and the problems of technology transfer it confronted, then examines whether the solutions adopted could be appropriate for other complex innovative projects, particularly those involving joint public–private investments. It also describes the interaction between development time, mission cost, risk and return in reduced resource CoPS. Although the satellite itself was a technical success, government policy objectives for the project were not realised and the paper considers mismatches between policy objectives and mechanisms in complex projects.

Keywords: managing complexity, Complex Product Systems, innovation in Satellites, space industry, technology transfer

JEL Classification: O032

1. Introduction

On the 14th December 2002, FedSat, a small Australian satellite, was launched in Japan with a payload of research experiments. FedSat was the first Australian satellite to be launched in over 30 years, and was designed to give Australian industry the capacity to become involved in the international space industry. The 4-year project involved the participation of numerous organisations in Australia, and research groups and government agencies in the UK, Japan, Canada and South Africa.

One of the goals of the FedSat satellite project was to *re-ignite the Australian Space Industry* (CRCSS, 1999). As part of this larger goal, one of the core objectives of the project was the transfer of satellite technology to Australia, which became critical following the bankruptcy of the project's major subcontractor in England in June 2001. As well as being a threat to the project, this event also offered an opportunity for Australia to capitalise more fully on the satellite technology developed. The project drew on experiences with a number of other international agencies and firms employed in the manufacture of the satellite components with the opportunity to learn from international best-practice techniques in the management of satellite projects.

This paper presents the findings of a case study analysis into the FedSat project and provides insight into the innovation and management issues of this complex joint public- and private-sector initiative and the associated technology transfer problems. It also offers some observations on whether, given the extent of these problems, it is possible to create an indigenous industry made up of high-value, complex systems building upon international technology transfer.

Part 2 of this paper describes the emerging 'Complex Product Systems' (CoPS) approach to innovation and suggests that CoPS are not only an ideal mechanism for analysing a satellite project, but also a means of placing the space industry

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within the purview of the studies of innovation and technology transfer for future comparison with other projects across a range of industry sectors.

There has been little attempt in the technological innovation literature to study the development of satellite projects.[1] In addition, previous studies into technology transfer in the space industry (see for example Amesse *et al*., 2002; Herzfield, 2002) have focussed on the 'spin-off' benefits from the space industry to nations, rather than the transfer of space technologies into a country through a satellite project. Furthermore, although there have been many attempts to investigate the management of projects within the space industry, such as Callen (1999), NASA (1999) and Bearden *et al.* (1995), few have examined them with a research, innovation and technology transfer perspective. A search in the journal 'Space Policy' yields only five articles with the word innovation in the abstract, of which only Belleval (2002) studies the space industry from an innovation theory perspective and Austin *et al*. (1997) looks at the issues of foreign participation in R&D. The other three articles only use innovation to mean technical improvements (Woodell, 2000; Davis and Macauley, 2002; McCurdy, 2002). The FedSat project itself is described in Part 3 of this paper, which details the nature of the project and the case-study research methodology used to study the satellite's development.

The FedSat project was beset by numbers of problems, many of them common to all CoPS, but some of which, like the bankruptcy of the major contractor for the satellite, were extreme. Part 4 of the paper describes some of the major problems, or project 'hotspots', that were confronted and overcome. A number of high-risk areas in the FedSat project are identified, and details and ways in which these risks were ameliorated are described.

Part 5 highlights some of the solutions which helped to make the satellite mission a technical success. In particular, this section focuses on some of the uniting factors within the project, such as the temporal responses and changes in project structure within the overall network of project participants and the important role of individual experience combined with innovation management tools. The role of the 'small satellite philosophy' (SSP), designed by NASA to assist the development of satellites 'Faster, Better, Cheaper' (FBC) is also considered as a unifying factor. In particular, an investigation of the role of CoPS in projects where reductions in scale result in orders of magnitude reductions in timescale and cost are investigated using the satellite project as an example.

The conclusions in Part 6 locate the lessons from FedSat within the evolving CoPS research tradition. It is argued that the lessons from FedSat on how problems were managed and overcome hold lessons for technology transfer in CoPS. As Australian industry has not re-entered the international space industry the policy objectives of FedSat were not met and a number of questions are raised around the misalignment of goals in CoPS built in partnership with the public and private sectors. Nonetheless, the project *was* a technical success as the satellite was developed, built and launched, and was still conducting useful scientific experiments in late 2005. It is as a successful case of managing complexity across institutional borders that we first examine the FedSat project.

2. The complex product systems approach

Complexity is a feature of much contemporary scientific and industrial activity, and the design, production and launch of FedSat required the successful management of numerous complex technical and organisational problems across research institutions and firms. The relationship between complexity and innovation is receiving increased attention in academia. A growing literature, for example, is being developed on complex, adaptive systems in policy (Rycroft and Kash, 1999), management (MacCarthy, 2003) and innovation (Fleming and Sorenson, 2001). The term complexity is used in several ways in the innovation literature. Rycroft and Kash (1999, pp. 55–57) outline three definitions:

1. Complexity is measured by the number of parts in a system. This conceptualisation equates complexity with complicatedness.
2. The second view holds that complex systems can not be understood simply by looking at the parts, but that it is the parts and their interaction, particularly in the form of feedback loops, which constitute complexity.

3. The third view, and the one that is used in the majority of the work cited here is that complexity is a measure of the interactions between product, process and organisations. Complexity is a socio-cultural phenomenon. Rycroft and Kash simplify this conceptualisation to this definition: "simple technology can be understood by an individual expert—can be designed or described in detail by an expert and communicated across time and distance to another expert—while a complex one cannot (1999, p. 56)."

Of most value within this new research for our analysis is that focusing on Complex Product Systems (CoPS). The CoPS approach proposes that high-cost, one-off products have unique innovation, management and policy dimensions and as such require a distinctive approach to their analysis (Brady, 1995; Hobday *et al.*, 1995; Davies, 1997b; Hobday, 1998, 2000; Hobday *et al.*, 2000; Gann and Salter, 2000). Examples of CoPS include intelligent buildings, telecommunications exchanges, flight simulators, aeroplanes, weapons systems and manufacturing plants. Due to their high cost and complexity, they often have long service life expectancies and undergo continuous innovation and development (Davies,1996).

The conditions which define CoPS include:

- High costs with long product cycles.
- Involvement of several firms in design, development and production.
- High product complexity and emerging and unpredictable properties.
- Being of a one-off kind to meet requirements of individual business users.
- Involvement from policy and other regulatory sources.
- Being user driven rather than market driven, with a high degree of user involvement.
- Project based, rather than product based;
- Markets typically characterised by oligopolies.
- Requirement of distinct management capabilities.

CoPS are developed under a customer-driven rather than a supply-driven system. As opposed to many mass-produced systems where the product is produced and then a customer is found, CoPS production only begins after an order has been placed. This results in a customer-pull, rather than a supplier-push system of innovation.

It has also been suggested that CoPS make up a large proportion of a nation's net earnings. A study by Heighs (1997) suggested that CoPS may account for as much as 11% of value added Gross Domestic Product. Also, although CoPS are only one category of production process, they often have an impact on the other categories, ranging from small-batch to mass produced to continuous process projects. Many modern services, from banking to transportation to telecommunications depend on CoPS to operate.

CoPS industries are typically bilateral oligopolies with a few large suppliers conducting business with a few large customers. They can, however, as our study suggests, also include smaller players. Governments are often involved directly as partners (Davies, 1997a) or through the purchasing of equipment and the establishment of standards. As a result of this involvement, CoPS industries may often become highly politicised as alliances are formed between system suppliers, large users, standards setting bodies and regulators.

CoPS development requires a strong focus on systems integration (Prencipe *et al.*, 2003). Systems integration is an element of systems engineering, which was developed after the Second World War to manage complex defence and aerospace projects as the complexity of weapons and other systems increased in the 1950s and 1960s (Sapolsky, 2003). As outlined in Johnson (2003) systems engineers coordinate, and in some cases control, the overall technical direction of a project, and systems engineering itself is subject to the effect of the social environment in which the project is being created.

The role of systems engineering and integration is crucially important in many complex systems, and involves innovative organisational structures and administrative processes. Any analysis of these systems requires some understanding of the social and technical elements that interlock in a myriad of ways in their design and development process (Prencipe *et al.*, 2003). One of the major dimensions of product complexity is the breadth of knowledge and skills required of the project. The need for elaborate systems integration can increase the number of skills required of individuals or specialist firms brought in to complete the work, which adds to the complexity of projects.

This area of investigation has facilitated the development of an approach known as Integrated Systems and Services (ISS) solutions in CoPS (Brady *et al.*, 2001; Davies, 2002; Brady *et al.*, 2003). It highlights the fact that systems integration activities are essential to manufacture and service provision (Pavitt, 2003) and that modular design is shaping the development of increasingly more complex products. In addition, Dosi *et al.* (2003) have explored the theoretical aspects of the economics of systems integration by placing it within the context of evolutionary economics. Hobday (2001) has looked at this issue at the firm level by looking at the 'business model' for ISS solutions, with the proposition that there is much more money to be made in downstream service and sales than in the sale of the upstream CoPS product. From this and preceding discussion it should be clear that reference to 'complexity' here refers to more than 'complicatedness'; it refers to high levels of interdependence between organisations and technologies and emergent, rather than pre-defined characteristics. This has implications for discussion of 'reduced resource' CoPS, which might be less complicated, but are no less complex.

Through analysis of the FedSat case study we examine the effective management of reduced resource CoPS, and especially the trade-offs that can be achieved between risks and resources, and also the issues that arise in complex public/private partnerships when there are differing objectives and approaches to risk, and how they might be managed.

3. FedSat

The ambitions for FedSat were enormous. Its launch was planned to be one of the signature events of Australia's Centenary of Federation (named the *Fed*eration *Sat*ellite). It was hoped that FedSat would help re-establish a previously vigorous but currently dormant industry. The central role of government policy in the FedSat project is seen in the way it was managed by a Cooperative Research Centre [the Cooperative Research Centre for Satellite Systems (CRCSS)], one of the most important institutions created by the Australian government designed to increased research links and technology transfer between science and industry (DITR, 2002; Howard, 2003).

The satellite

FedSat is conducting communications, space-science and engineering experiments while orbiting 800 km around the earth. The physical structure of the satellite is quite compact. Consisting of a 3-axis stabilised micro-satellite with a mass of 58 kg, the structure is a variant of the Space Innovations Limited Pty Ltd (SIL) standard MicroSIL™ structure adapted to interface with a Japanese H-IIA launcher. The cubic satellite is 50 cm in length, with a small addition on one face for the stowed boom.

The satellite is controlled by the Data Handling System (DHS), which provides the interfaces between all of the other main subsystems; S-band Communications, Power Conditioning System (PCS) and Payloads. The technical specifications and details of FedSat's payloads are included in Appendix A.

The functional structure of a small satellite architecture is shown in Figure 1, illustrating the large number of complex components.

The project

The development of the FedSat project was reasonably typical of most CoPS projects, in that it followed a traditional development path of bid, design, analysis, fabrication, test and delivery.

The project involved a number of key players, including:

The CRCSS. Based in the Australian national capital, Canberra, the CRCSS was the key player in the project, and was designed to be a commissioning agent.

The Commonwealth Science and Industrial Research Organisation (CSIRO) which hosted the CRCSS and its centre operations.

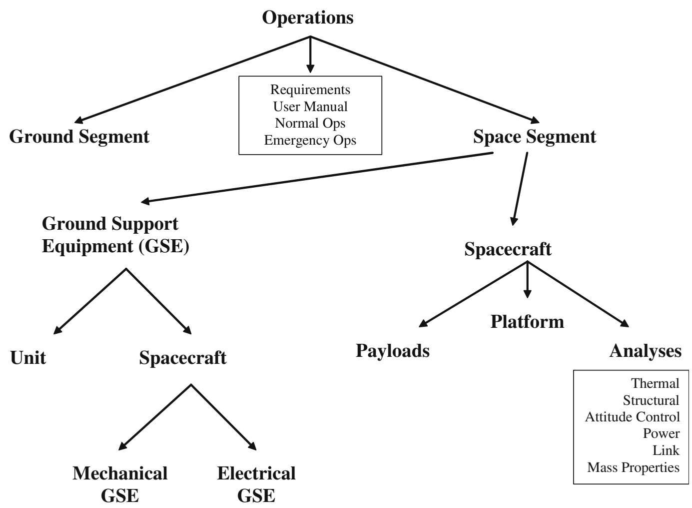

Figure 1. Small satellite architecture.

The Japanese National Space Development Agency (*NASDA*[2]). NASDA donated a free "piggyback" launch on a Japanese HII-A rocket, originally scheduled for launch in 2000.
Space Innovations Limited (SIL) a UK-based subcontractor chosen to build the satellite. Much of the original design was undertaken by SIL during the early phases of the project. Unfortunately, SIL became bankrupt fifteen months into the project's development, and the satellite was returned to Australia to be finished by the:
FedSat Project Team (FPT), comprised mainly of two commercial partners of the CRCSS, *Auspace Pty Ltd* and *Vipac Pty Ltd*, who undertook much of the development and testing work of the satellite project.
The Institution for Telecommunications Research (ITR). Based in Adelaide, South Australia, ITR provided the ground station for the project.

Additional players included the providers of the payloads, the research experiments, from universities in Australia and overseas.

FedSat's origins lay with a senior committee of civil servants, academics and businesspeople, and the decision to use the Australian Government's Cooperative Research Centres (CRC) scheme as the means to realise the project. The CRC programme was seen as a novel way of developing the satellite as it provided an existing framework for funding and coordination and did not require any changes to government policy or regulations (Kingwell, 1999).

The CRCSS had a flat management structure with the CEO and an Executive made up of representatives of the major partners. The board comprised senior executives of the partners and independent industry representatives and the executive, which would meet on a weekly basis, was the coordinating mechanism. Partners for the most part acted independently of each other and autonomously; for example, each would hire its own staff. The public nature of the CRCSS also required strong accounting and disclosure practices, but had the advantage of having guaranteed funds for the project.

Project goals

There were a number of different goals within the CRCSS as part of the FedSat project from both a technical and policy perspective. The main technical goal of the satellite project was "To build and operate a satellite". From this goal, a number of technical success criteria for the satellite were established by the CRCSS executive after the satellite returned to Australia (Vesely and Moody, 2003). These are outlined below.

Technical Success Factors	Success
(i) The transfer of space technology into Australia	Achieved, with much internally generated
(ii) Develop necessary space infrastructure to perform all system integration and testing in Australia.	Achieved in terms of project specific needs
(iii) Qualified and working ground station and spacecraft "Fit for Launch".	Achieved
(iv) Successful launch of the spacecraft and first communication.	Achieved
(v) Achieving nominal in-orbit operation of the spacecraft platform.	Achieved
(vi) Basic "low level" communication with the payloads.	Achieved
(vii) One month of operation of the spacecraft platform.	Achieved
(viii) Successfully perform an experiment campaign with each payload.	Achieved
(ix) Three months operation of the spacecraft.	Achieved
(x) Six months operation of the spacecraft.	Achieved
(xi) First anniversary of launch with continued spacecraft communication.	Achieved
(xii) Achieve design life of three years.	Achieved

Determining the success criteria for the development of the Australian space industry is more difficult, but are summarised below.

Industry & commercial success factors	Success
(i) Formation of a private company using the Intellectual Property of the CRCSS	Achieved
(ii) Development of products based on CRCSS technology	Not achieved
(iii) Income from contracts, royalties, licences and consultancies	$A95,000 over three years
(iv) Recruitment speed and first employment of graduating students	Mostly overseas

Industry & commercial success factors	Success
(v) Benefits to end users and changes in industry practice based on CRCSS's research programme	Unknown
(vi) Public awareness outputs	Achieved, with some media awareness particularly at launch
(vii) Opportunities for Australian scientists and engineers in the space industry	Achieved, but not continuing other than in research
(viii) The promotion of international cooperation around Australian Space Technology	Achieved, but not continuing
(ix) The formation an Australian concentration in space activities	Achieved, but no continuing projects
(x) The formation of a de facto Australian Space Agency	Not achieved
(xi) Continuing projects	Not achieved

The CRCSS successfully built a laboratory in space and, in doing so arguably increased Australian capability to be part of the space industry. However, based on the success criteria above, it is apparent that it did not meet its objective of promoting a sustainable Australian Space Industry. In essence, the CRCSS did not kick-start a new and vibrant space industry—it temporarily resuscitated a dormant one.

Research methodology

The FedSat satellite was chosen as case study for a number of reasons, including the wealth of information available about it. The project also provides a convenient unit of analysis of the space industry with measurable success criteria: the satellite either worked or it didn't, with degrees of operational efficiency. Experiences in the development of the FedSat satellite can be utilised to generate knowledge on issues such as the management and organisational challenges facing the development of CoPS, and the problems of technology transfer in private–public partnerships.

FedSat is also high on almost all of the critical dimensions of CoPS, as determined by Hobday (1998), but moreover it is a CoPS with very clear boundaries:

- It is highly technically complex;
- FedSat had a definable beginning and end;
- FedSat was a discrete, one-off, self-contained product (the satellite);
- FedSat exhibited a clear shift between the implementation and support phases of the project (i.e. before and after launch); and
- The project implementation team was small enough to analyse in depth.

For this analysis, a descriptive case study was undertaken to address the FedSat project from a CoPS perspective. As a research strategy, case studies have been used in a wide variety of situations, from policy and political science to organisational and management studies, and provide a good means for comprehensive analyses.

Data was collected using structured interviews from a CoPS interview template generously supplied by the UK's Economic and Social Research Council's CoPS Centre at CENTRIM/SPRU in Brighton and Sussex Universities. The six main areas focussed upon in the interviews were project characteristics, project phasing, innovation management tools, risks and opportunities, learning, and outcomes and performance. This standard interview template was chosen to allow future cross-case study comparisons with other CoPS industries and projects. The analysis of the case study in this paper closely follows the case study analysis performed in Hobday *et al.* (1995). Further details of the research methods used are included in Appendix B.

4. Project hotspots

In a project as complex and difficult as FedSat numerous problems inevitably emerge. The intention here is not to list them all, but to identify two of the most important categories: changing goals and objectives, and external relationships, and to examine the ways these affected the risks of the project.

Varied and changing goals and objectives

The many different organisations in the CRCSS saw the core goals of the project differently, ranging from technical and research (the universities, CSIRO, and the CRCSS staff), commercial (the private-sector firms) and industry-wide (the government) objectives. As a research organisation, the CRCSS had a number of performance measures relating directly to academic investigation, including the number of cooperative arrangements instituted, the number of publications generated, education and training, and applications of this research. As the CRCSS Executive Director put it in one interview: "I would imagine that there would be a problem no matter what, just because of the different types of goals from the different organisations. You've built an organisation on three opposing groups of people and then you have located them in different places and they don't know each other and work together."

The initial satellite development was planned around a launch date of November 2000 (i.e. nearly 2 years before it actually was launched). This necessitated an accelerated schedule, which in turn took time away from systems engineering and caused financial stress on the contractor, SIL. Indeed, in the minds of some of the CRCSS executive, it changed the course of the entire project; "If we had known in 1998 that we would be launching at the end of 2001 even, let alone the end of 2002, we would have chosen a very different path. I believe that we would have chosen to design and build our own satellite totally from the ground up, without having to have designs imposed on us, designs that are less than optimal for what we want to do."

Discordance within the different groups in the CRC arose when FedSat project resources needed to be shifted between projects, revealing disagreements on funding priorities. Retrospectively, it was appreciated how a strong emphasis on developing shared goals for the project, and then engaging project members to commit to goals would have reduced tension in these areas and limited disagreements within the organisation.

This diversity of and change in goals was compounded by the dispersed nature of the project. Partners were distributed around Australia and overseas and would only see the main satellite infrequently. As one manager put it: "There is little incentive for people to be unified about the goal. Most people were involved in the flying and going overseas but that doesn't engender any real commitment.''

The whole project began with an ambitious set of requirements to meet. These requirements placed challenging technical demands upon it, such as the need for 3-axis stabilisation and large power budgets to conduct experiments. Indeed, at the time of construction FedSat was one of only a few micro-satellites to incorporate three-axis stabilisation (Moody and Ward, 1999). The cooperative nature of the CRC meant that there were a large number of partners that had to be catered for during the requirements analysis of the satellite. In an effort to include experiments from all the different partners FedSat had to cater to a range of payloads, adding to the complexity of the project and CRCSS's reliance on SIL. The CRCSS had no single customer, rather providing an ''open-ended wish-list'' as the initial requirements document, without any real idea of how much that would cost. Having made the wish list and having secured the support of the partners with their payloads and the subsequent funding from the Australian Federal Government, there was no mechanism for denying them their desired outcomes or place on the satellite. The decision to include four out of five potential payloads on the satellite is seen in hindsight as an ambitious move for such a small satellite.

These requirements made the project an ambitious one from the start, and resulted in a risk, not only of the satellite failing to meet these requirements, but of the increased complexity and new technologies causing unexpected side effects. This may have been reflected by the fact that three out of the four tender responses from potential prime contractors were non-compliant with the original request for tender.

From the original requirements definition in the project bid to the final specifications, the project underwent a large number of changes. This was acknowledged early on by both the project manager at SIL and the head of the CRCSS management group as a potential risk area. These changes ranged from the addition of payloads (such as a Star Camera from the University of Stellenbosch in South Africa) to the abandonment of externally purchased Operations Control Centre software for replacement by an in-house system and the total redesign of the Attitude Control System (ACS).

Different partners in the project had different approaches to risk. For example, when the satellite arrived in Australia from the UK, one commercial partner wanted to stop and undertake an analysis of all of the spacecraft units while the other wanted to commence working on the hardware immediately. In the end a hybrid approach was decided upon, with some of the SIL staff reemployed to finish what they could in the following months before shipping the half-completed units back to Australia for inspection.

The nature of the CRCSS made it a risk-averse organisation. Being part of a 'public good' national programme with the potential for strong media interest, there was a perception that there was no room for failure in the project. The perceived inability to take risks was seen to manifest itself in the CRCSS being slow to react to issues of importance and unwilling to take risky decisions. For example, at one stage the CRCSS did not wish to withhold payments to SIL for failing to meet milestones as it was afraid that it may cause SIL to go bankrupt. This was further compounded by the fact that most of the research based around the CRCSS depended on FedSat meant that there was a single point failure in the research facility; if FedSat failed much of the research would fail with it. This was unlike many CRCs which have a number of different, independent and loosely coupled research programmes.

Inter-organisational relationships

Good communication between all the various players was seen by many as a core issue for the CRCSS. There was always a risk that the distributed nature of the project would result in communication difficulties around technology transfer, causing, for example, misunderstandings over requirements or incompatibilities in sub-systems. Due to the diversity of the payloads, for example, different components were built or acquired by four separate universities around Australia. This required effective interface management between each of the different partners and a strong flow of information between the various stakeholders. In addition, the nature of the project necessitated accurate and continuous communication with subcontractors. It was recognised by some that both the prime contractor and the CRCSS itself needed to involve suppliers more closely in the project design and the component specifications to mitigate this risk. A number of interviewees claimed that the co-location of members of the project team would have helped in managing some of this risk.

The most consequential event in the development of the satellite project was the demise of the prime subcontractor. Of all the responses to the call to tender, only SIL complied, but it was identified as a higher risk option; A British firm commissioned to undertake due diligence on SIL before the contract was awarded gave it a very poor credit rating and highlighted a risk that the company had very fragile cash flow. Rather than reduce the scope of the mission it was decided to continue with this provider, marking one of the first trade-offs between risk and cost in the project. However, the fact that SIL was the only compliant tenderer may have raised warning signals that the mission was too ambitious.

Actions to mitigate against the schedule risk included breaking the work into small work packages, ensuring transparency of SIL's operation and frequent (weekly) reports. Actions to mitigate against the financial risk included rigorous but 'sensible' acceptance tests for payment against tangible milestones. CRCSS personnel were also seconded to SIL in an effort to improve communications.

Nonetheless, at the first critical design review (CDR) it became apparent that the SIL delivery schedule was beginning to slip. However, the CRCSS decided to pay SIL for the milestone attached to a successful review. Due in part to the financial burden placed upon it by the satellite project, the sub-contractor began to have cash-flow issues. Delays were compounding the situation and the company was looking at restructuring.

A breakdown of trust between the CRCSS and the prime contractor occurred as the CRCSS management team eventually came to believe that the prime contractor was withholding information, or being deliberately misleading. There were also issues of trust and honesty within the SIL organisation. Many staff reported on breakdowns in communication, particularly with members of the executive and project managers.

Another problem in the relationships between the various players derived from the difference in management approaches between the satellite and ground groups (discussed below). These tensions surfaced as personal differences between the managers of each programme, and communication became strained. "I told him to stop wasting everyone's time. He wrote back asking for a public apology. I wrote back telling him that all mail from his account was automatically directed to the trash box. If I ever have to work with him again it will be interesting."

5. Solutions

A variety of factors led to the overcoming of these problems, and the eventual technical success of the project, including: the ways in which organisational structures evolved within the network, the use of innovation management tools combined with effective judgement, and the unifying SSP.

Combining and evolving management structures

Davies (1997a) describes the importance of 'organic' management structures being established in small scale or highly innovative production processes (cf Burns and Stalker, 1961). Organic approaches display the following characteristics in project management:

- Tasks are continually adjusted and redefined as the project develops. Knowledge and experience of working in project teams becomes more important than the specialised skills required by tightly-defined individual tasks.
- There is a commitment to the concerns of the project as a whole rather than the completion of individual tasks.
- Vertical integration among people of different rank is less important than the lateral communication that takes place among project members irrespective of their position in the hierarchy.
- Information and advice rather than formalised rules are more appropriate forms of communication.
- Overall commitment to the progress of the project is valued more highly than loyalty and obedience to immediate superiors.

Similar to many CoPS (Hobday, 1998; Gann and Salter, 2000), the FedSat programme was initially organised with the satellite project itself as the primary form of coordination. The project existed to communicate design and knowledge and to combine the resources and know-how from a number of sources and suppliers.

There were a number of different structures which formed during the implementation of the FedSat project. Figure 2 shows the evolution of the dominant organisational form during the duration of the FedSat project.

Although it was not intended from the beginning of the project, FedSat demonstrated one way to move from loose to tight management structures in a networked project. The network nature of the CRCSS showed a way to combine loose and tight organisation structure and leadership throughout various project stages.

The project began as a very loose, entrepreneurial structure during its inception at SIL, and remained organised in a flat, organic structure upon its return to Australia, to the extent that very few roles were formally defined. This organic structure continued throughout the project development, with only the project manager (and later the technical manager) given formal roles and responsibilities, and the other engineering staff being assigned to different areas across the project. The accelerated nature of the project and the small size of the team meant that a number of jobs overlapped within it. For example, the project manager for the platform was also the head of the ACS group, as well as the systems group.

This organic structure evolved into a more hierarchical construct towards the end of the project. This was partly due to a reduction in the number of sub-projects, but was primarily driven by the necessity to ensure that all of the appropriate checks and balances were being followed. This more hierarchical structure provided the security and familiarity of a stable infrastructure, specialisation of functions and division of responsibilities during the critical phase of the satellite delivery.

The blend of organic and hierarchical structures provided discipline when needed, but with the flexibility to accommodate new problems and adapt to changing external pressures. This transition from an organic to a highly organised structure allowed flexibility during the early stages of the project (when the number of feedback loops was high and there was a lack of understanding of the satellite) to a more formalised and disciplined group (Fairtlough, 1994). However, some problems were encountered with this structure in delegation and resource management, as some stakeholders believed that people were undertaking tasks inappropriate to their skills and experience (either above or below). With a small, focussed team this was seen as a necessity.

Procedures were developed on an as-required basis, then adhered to rigidly. In addition, project managers had to remain open to advice from both within the team and externally, with frequent reviews to measure progress. At the very end it was the dedication of a small team that saw the project through from inception to completion. Recruiting

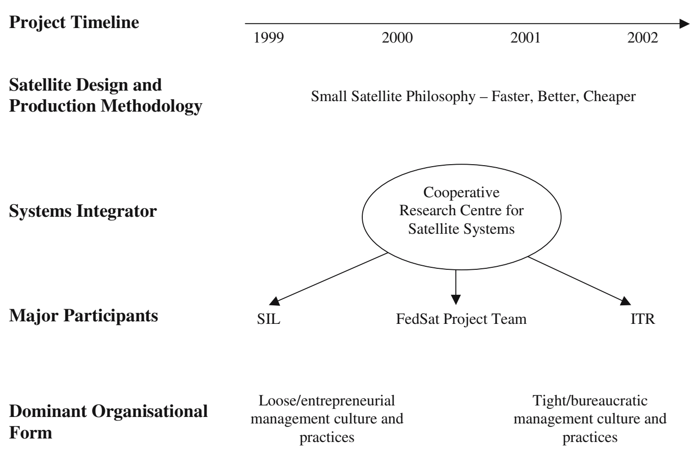

Figure 2. FedSat key aspects.

and retaining these people was essential to the project's success.

While this shift from an organic to hierarchical structure is not uncommon in space projects, it is worthy of note that in the case of the FedSat project most of the structural problems perceived to be preventing the project from being successful were attributed to the structure of the CRCSS, rather than the structure of the project team. Indeed, these structural issues surrounding the organisation of the CRCSS resulted in difficulties for the management team of the FedSat satellite. The network nature of the CRC structure with many goals and stakeholders was enforced by the legal status of the CRCSS; it was formed as an unincorporated joint venture between the different partner organisations with shares allocated according to the inputs promised by the partners. In addition, the CRC programme was designed primarily with research in mind, not for the development of a single product.

The unincorporated joint venture 'centre agreement' meant that not only was cooperation needed for every major decision within the CRCSS, but that the allocation of funds was made to match that of the money which was put in by different partners. The delay caused in the development and launch of the satellite resulted in a delay in starting the serious research projects and a significant reduction in funding of the research. Also, there were few commercial outcomes from the project, seen by partners as a result of not having a commercial focus from the beginning of the project. Finally, the CRC was constrained by the requirement to focus on research when the major project in the CRC was a development project.

The network structure of the CRCSS did work well in some other senses, in that there was a range of experience to draw upon from the project partners in building the satellite, and there was also leverage from the government involvement to create international partnerships and in-kind contributions from other national organisations such as the British National Space Centre (which contributed to the solar arrays), the Canadian Space Agency (which subsidised the acquisition of the ACS) and the National Space Agency of Japan NASDA (which provided a free launch). In addition, it can be said that the structure of the CRCSS worked in the sense that the Centre was able to successfully build and launch the satellite. Also, there was the potential to have project partners to draw upon if additional funds were needed, and it was possible to disseminate the results of the project and the lessons learnt widely among these partners.

The combination of tools and experience

In the implementation of the FedSat project a range of innovation management tools were used by project managers and engineers, similar to the management of other high-technology projects. Throughout the life of the project, traditional project management and scheduling tools were used from project conception and tender to design, implementation and finally Assembly, Integration and Testing (AIT).

Initially, a mixture of professional and in-house tools was used to develop both the request for proposal and the main proposal from the subcontractor. These tools used a mixture of information from previous projects and in-house research, with particular focus on tools that would help with systems engineering, such as SILBud (a power and weight budgeting tool) and SILPMP (a power management package). In addition, in-house accounting packages and engineering estimation tools provided information on costing for the project tender.

In the design phase, different techniques were used to manage the effective execution of the project. Once again, traditional scheduling and accounting tools were used to maintain control of costs and schedules, which including Microsoft Project with custom-made excel spreadsheets powered by a Visual Basic back end. In addition, as opposed to general procedures and systems, specific stand-alone management tools were designed to achieve particular tasks, ranging from Failure Modes, Error and Critical Analysis (FMECA) tools and tools for managing satellite wiring and harnessing.

Finally, in the AIT phases, software tools were used to transfer learning from the design team to the testing team, embedded both in the Operations Control Centre (OCC) and tools to simulate the Attitude Control Centre actuators. Much of the design knowledge was stored in these tools developed in-house to speed the operation of AIT.

Tools were also used to maintain company-wide technology and experience, essential for project-to-project learning. The prime-contractor developed a large number of in-house systems engineering and design tools for use in the development of satellite projects. These tools retained much of the engineering knowledge stored within the company and could have resulted in large efficiency improvements in later satellite development phases. A few were also used for 'qualification' of satellite units through design and simulation rather than through physical testing, which brought costs down but increased the project risk (Dodgson *et al.*, 2005).

The nature of this small satellite project meant that larger commercially available tools could not be bought due to their prohibitive cost. As a result, many management tools needed to be developed in-house, or existing tools were used in innovative ways. In addition, there were very few software management tools used in the development of the project software, other than a version control system. It was apparent in the case study that additional tools could have resulted in better management of the project. This was limited by the difficulty in finding the correct tools, as many were aimed at mass production industries and not at the speciality satellite market. It was also noted by some that certain tools were not being used effectively by management to maintain firm control of the project.

Using principles of the SSP, described in more detail below, it was believed that certain tools could be used to make the project significantly more cost and time effective. It was asserted that project costs and schedules could be reduced, for example, if much of the design and testing phases were performed using engineering prototyping and modelling tools.

The tools are helpful, but only in the right hands (Dodgson *et al.*, 2005). Before the launch of the satellite, the main factors for success were seen as a few people who knew what we were doing who would put in the exceptionally high effort required. In addition, there was a need for the creation of an environment in which the team would thrive and be encouraged to put in extra work. The best way to do this was seen as recognising to the individual's personal strengths; people management was seen as key to a successful mission. One of the key problems with SIL was that it possessed the innovation management tools, but failed to have the necessary experienced engineers with sufficient breadth and depth of satellite technology. Whilst SIL's placement of the head systems engineer as project manager recognised the importance of systems engineering it actually had the opposite effect, placing an inexperienced manager in charge of the project and forcing the systems engineering to be neglected.

In a complex system such as FedSat with a large number of interfaces, interacting components, a harsh space environment and unknown risk areas, engineering experience was seen as the key way of overcoming pitfalls in the project. Some also saw a strong partnership between experience and enthusiasm for hard work as a critical success factor. The correct mixture of experience with enthusiastic junior engineers would not only increase the chances of a successful mission, but would transfer skills for use in future projects.

The small satellite philosophy

The SSP is a management approach developed by NASA for the production of small satellites. It requires a number of issues to be resolved: reduced resources require trade-offs between risk and cost, complexity and utility; and compressed timelines have an impact on component ordering and project monitoring. Essentially innovation has to be managed more effectively at a much faster rate. Some of these key aspects of the SSP are summarised below in Table I.

In the case of the FedSat project the SSP was not only a management technique; it was a uniting approach to the project. The SSP allowed different members in the overall project network to discuss their approach to management with particular reference to tradeoffs involved between risk, cost and schedule.

All of the initial CRCSS partners, from SIL to the FedSat Project Team, aspired to implement the satellite project using the Small Satellite Philosophy. However, each of the organisations implemented the project according to their own perceived methods of implementing this philosophy, and with definitions of that philosophy from different points of view.

The case of SIL. One of the main approaches followed by the SIL management team in their

Table I
SSP key aspects

Separation of Project Management and Technical Management
Strong systems engineering
Quality assurance
Small integrated teams
Empowerment
Experienced managers
Frequent reviews
Accelerated development
Minimal documentation
Requirements flexibility
Partner-like relationship with vendors
Exchanging risk for cost
Removal of redundancy—keep it simple stupid
Qualifying by design or similarity
Use of modern technologies
Use of software
Standardised interfaces

implementation of the SSP was that of consciously swapping risk for cost within the project. The lack of experience within the company, however, meant that they were not necessarily taking appropriate risks, and there were a number of cases in which they were required to repair the damage to flight hardware at a greater cost than the original implementation would have required. Similarly, although SIL had a strong focus on reducing documentation it did not have the experience to know what the impacts of its decisions would be. Many of the critical design choices and inputs were required to be investigated, again due to lack of knowledge about the system.

The company also outsourced some work, but didn't empower the sub-contractors to become involved in the project or understand the need for particular requirements. This resulted in specification and manufacturing problems which cost more money later in order to rectify manufacturing defects or mismatched interfaces. In addition, it neglected to take up the offer of the CRCSS to undertake work in areas in which it had experience, which would have resulted in an 'automatic' partner-like relationship with the sub-contractors.

The timescale of the project was compressed and there was neither a good review process nor a philosophy of continuous improvement in certain areas of the company. Employee motivation in the company was very low. In addition, despite the company being small, the employees remained in small groups, each not trusting the other to the detriment of intra-organisational communication.

The case of the FedSat project team. Once the satellite had returned to Australia, the FedSat team assumed management of the project. The SSP approach taken by this team may be grouped into four different areas; accelerated development, a small integrated team, experience and empowerment.

The project was almost always under pressure from the launch provider. This caused the management of the project to take an accelerated path for development. The team members were committed to the project's success and would often work long hours to see the project meet its launch deadline.

The small, integrated team that formed the core of the project was also seen as the best mechanism for decision making within the project. The team members would be involved in project reviews and choices to use particular technologies, and were multi-skilled across many areas of the satellite development. This allowed the amount of documentation in the project to be reduced with little impact on communications within the project. In addition, the executive organised frequent reviews with external experts to either endorse the direction that the management and engineering teams were taking or to suggest areas for improvement.

Finally, the management attempted to empower the members of the project team and to give them the freedom to innovate within the project environment. Flexibility was also promoted, as was honesty, and trust was built up between members of the project team.

There were, however, a few core areas of the Small Satellite Philosophy that were neglected. For example, while the project undertook frequent internal and external reviews, there were few quality management systems in place. This was partly addressed towards the end of the project when the team would follow more rigorous procedures in the lead up to the launch of the satellite.

While it is not clear cut, comparing the SIL and FedSat project team implementation of the SSP it is apparent that the FedSat team was closer to implementing the philosophy than SIL was. SIL understood the philosophy behind the implementation of the SSP, but did not have the experience or capacity to back up the choices that it made in this implementation, a critical difference between the two approaches. While SIL was unable to deliver the satellite, the FedSat project team successfully delivered to the launch facility on time and budget. However, it should be noted that without the additional time provided by a delay of the launch platform and additional funds provided the federal government, there would have been insufficient time or money for the completion of the project in Australia. It is very likely that the funds and timeframe remaining after the collapse of SIL would have made it an impossible task for the Australian team no matter which management style was used.

Relationship between complexity, resources and risk

One of the core purposes of the SSP is to allow better returns through the implementation of smaller, riskier and potentially less complex projects, producing returns 'FBC'. One of the key aspects of this approach is the relationship between different metrics of development time, mission cost, risk and science return, and the interaction between these when a FBC approach was applied. The FedSat project embraced all three areas of FBC; including reduced scope and complexity, the SSP management style and a preparedness to accept increased risk.

As investigated in Dornheim (2000), The FBC approach is touted as a mechanism to promote creativity and responsibility on the part of the mission teams, obtaining an *order of magnitude* improvement in schedule and cost while maintaining mission effectiveness. However, as illustrated by failures in NASA missions, there is much confusion about the nature of this philosophy, and the means to implement it successfully (Bearden *et al.*, 1995).

FBC is a methodology that is designed to focus on "competence, empowerment and responsibility" (Watzin *et al.*, 1998). It espoused an environment to scrutinise all of the elements that contribute to the life cycle cost of a scientific mission to ensure that it delivered the most cost effective implementation of that mission. Mission time was seen as an essential component to reduce cost and as such any non-value added activities were to be "ruthlessly eliminated" (Figueroa and Moos, 1999). More importantly, while quality-based management practices were to be used to continually deliver process improvements, there was an understanding that a degree of mission failure was "acceptable" (Dornheim, 2000).

A study by the Aerospace Corporation (Bearden *et al.*, 1996) also found good returns in implementing FBC strategy. Using a model developed for large satellites (Wertz and Larson, 1998) the estimated costs for a number of small satellites were determined and plotted against their actual costs. It was found that the costs were indeed an order of magnitude less that those predicted by the large satellite model.

However, a further study by the Aerospace Corporation (Dornheim, 2000) found that when missions reached a certain threshold they became too fast and too cheap and were almost certainly doomed to failure. It found that the failure of FBC spacecraft such as the NASA Lewis and WIRE satellites and the Mars Climate Orbiter may be predictable, when they crossed into an area of high complexity and low development time. The study took into account nine planetary and 12 earth-orbiting FBC missions and developed a means to analyse the mission risk based on its complexity.

It found that "when examined after the fact, loss or impaired performance is often found to be the result of mismanagement or miscommunication. In combination with a series of 'low probability' events, these missteps, which often occur when the programme is operating near the budget ceiling or under tremendous schedule pressure, result in failure due to lack of sufficient resources to test, simulate or review work and processes in a thorough manner" (Dornheim, 2000).

The FedSat project had reduced complexity compared to other satellite missions. Compared to larger missions, FedSat had fewer interfaces, although some of this was due to the removal of redundant units and the use of off-the-shelf (OTS) units. This reduction reduced some of the risks inherent in a complex system, but this was offset by the use of commercial-grade components and a lack of redundancy of subsystems such as the Transmitter and Receiver. In addition, while FedSat contained five payloads, these were power limited due to the amount of power that was able to be delivered by the solar arrays. Many of these payloads could only be operated for a few hours a week which decreased the science return compared to larger satellites with more power availability (Table II).

As discussed in the previous section, the FedSat team also used a management style akin to that of the SSP. The smaller, integrated team aimed to draw upon appropriate experience, motivation, flexibility and leadership. This approach reduced management overheads and the overall number of staff required, while leaving the risk to the project unchanged. The staff also aimed to make intelligent decisions to reallocate resources; an example of this was the elimination of Thermal Vacuum tests in order to spend more money and time on integrated systems testing (Table III).

Finally, the project further reduced the resources available and accepted a higher risk of overall mission failure. FedSat used commercial components where possible, eliminated time consuming procedures and relaxed the cleanliness requirements on the satellite. This trade off between risk and cost was not always explicit; some of the decisions made, such as a reduced focus on some quality procedures, were as a result of the inexperience of the project team (Table IV).

Table II
Faster, Better, Cheaper (FBC) effects due to reductions in complexity

Reduced complexity			
Metric	Units	Techniques used	Outcome
Development time	Years	Fewer interfaces (evident in wiring harness) OTS units (e.g. reaction wheels, magnetorquers)	*Reduction*
Mission cost	$US	Less redundancy (no redundant components except for ACS and some DHS boards)	*Reduction*
Flight rate	Fights/year	–	–
Failure rate	Percent	–	–
Increased science return	Instrument-months	Less power available to payloads (only 20 W available max)	*Reduction*

Table III
Faster, Better, Cheaper (FBC) effects due to SSP management

SSP Management			
Metric	Units	Techniques used	Outcome
Development time	Years	Accelerated schedule, experience, motivation, flexibility and leadership	*Reduction*
Mission cost	$US	Reduced management overheads and documentation	*Reduction*
Flight rate	Fights/year	–	–
Failure rate	Percent	–	–
Increased science return	Instrument-months	–	–

Table IV
Faster, Better, Cheaper (FBC) effects due to increased risk/mission

Increased risk/mission			
Metric	Units	Techniques used	Outcome
Development time	Years	Eliminated some procedures (e.g. thermal vacuum testing) Relaxed some procedures (e.g. comprehensive ACS testing)	*Reduction*
Mission cost	$US	Commercial components (e.g. ACS system) Relaxed cleanliness costs	*Reduction*
Flight rate	Fights/year	–	–
Failure rate	Percent	Risk of failure increased as a result of actions above	*Increase*
Increased science return	Instrument-months	–	–

The combination of these three factors indicates a reduction of resources, with some increased risk and reduced science return (see Table V).

It is important not to draw too many conclusions from this analysis, as some of these factors may have varying impacts on the overall reductions in cost, mission and risk of the project. However, it is fair to say that by aiming for the reductions cited in the FBC literature, there are three drivers for reductions in time and cost, offset by drivers for increased risk and a reduction in science return. This is consistent with the findings of (Bearden *et al*., 1996) in showing that there is an order of magnitude reduction in cost when compared to large satellite missions.

When taking more than one mission into account, it can be seen that this reduction in science return and mission success may be offset by an increased number of missions. Increased mission numbers increase development time and cost, but decrease overall programme risk while providing improvements in science return. An example of the interactions between the different metrics with an increase in mission numbers is shown in Table VI.

Table V
Small Satellite Philosophy (SSP) relationships per mission

Metric	Units	Reduced complexity	SSP management	Increased risk/mission	Summary
Development time	Years	*Reduction*	*Reduction*	*Reduction*	*Significant reductions*
Mission cost	$US	*Reduction*	*Reduction*	*Reduction*	*Significant reductions*
Flight rate	Fights/year	–	–	–	–
Failure rate	Percent	–	–	*Increase*	*Increase*
Increased science return	Instrument-months	*Reduction*	–	–	*Reduction*

Table VI
SSP relationships over a number of missions

Metric	Units	Satellite impacts	Increased flight rate	Mission impacts
Development time	Years	*Significant reduction*	*Increase*	*Notable reduction*
Mission cost	$US	*Significant reduction*	*Increase*	*Notable reduction*
Flight rate	Fights/year	–	*Increase*	*Increase*
Failure rate	Percent	*Increase*	*Reduction*	–
Increased science return	Instrument-months	*Reduction*	*Reduction*	–

This finding also supports the results of (Mosher *et al*., 1999) which concluded that for an individual mission it was not possible to have FBC, but if all three metrics were combined, the overall mission cost-effectiveness (the cost/time metric for the same science return) for FBC missions was higher than for traditional missions. It also illustrates how when scientific return (the Better component of FBC) is included into the understanding of mission effectiveness the support for an order of magnitude improvement is greatly reduced.

Understanding the relationship between the complexity, risk and management of small satellite projects may give rise to greater understanding of these relationships in CoPS. The key question in determining how these reductions may occur is to know how far to take the lessons learnt from the SSP when applying them to other CoPS projects. In particular, the SSP was based on the decrease in scope of a particular project through the reduction of the size of the satellite. This reduction in scope would reduce the complication of the project and the team size and prompt the implementation of different management models.

Using the cost model developed for large satellites (Wertz and Larson, 1998), the FedSat satellite bus should have cost in the order of \$A50 million. The satellite was successfully launched for one fifth of this price in under 4 years. However, there was a strong perception that the risk of the mission was high, and the available power limited the science return from the satellite.

It is important to stress the importance of the reduction in a critical dimension (such as the size) of the satellite to this analysis. This strengthens the case for further analysis within CoPS projects of 'Reduced Resource' CoPS. For example, in the telecommunications industry could a reduction in the overall number of base stations (BTSs), but an increase in the range and the number of users connected to BTS, accompanied with a new management model, give an order of magnitude reduction in time and cost of implementation? Or are smaller missiles more cost-effective in the long run? Finding the critical dimension for reduction in a CoPS which allows a new management philosophy, reduced complicatedness and a trade-off between risk and cost while maintaining a similar architecture and outcomes may potentially offer large gains in other industries.

6. Conclusions

This study has detailed the development of the FedSat programme within the CRCSS. It outlines the nature of the project within the important new CoPS perspective on innovative projects, and highlights some risk areas and ways to manage these. The definitions of CoPS used are broad ranging from small batch items such as flight simulators to large arrays such as the telecommunications industry. FedSat matches all of the CoPS criteria, and has an easily definable timeframe, fixed success criteria and measurable parameters. The FedSat project may indeed be seen as a good template for the analysis of CoPS.

Although beset with problems, a number of factors contributed to the successful technological conclusion of the project, including the evolution of organisational structures between different actors as the project progressed, the use of a range of innovation management tools accompanied by personnel with significant discretion and judgement, and a unifying methodology for satellite production called the SSP, which helped provide an approach for its effective integration.

The question arises of how far to take the management lessons learnt from this case study and apply them to other CoPS projects. With the FedSat project, the SSP was implemented based on the reduction in scope of a particular project based on the size of the satellite, while maintaining the basic components of the satellite architecture as a CoPS. This allowed a reduction in complication and a single team to be involved with all major aspects of the satellite implementation. Finding the critical dimension of scope reduction in CoPS may be a significant factor in deciding whether to employ these techniques or not.

The reduction in resources in FedSat was coupled with a distribution of the risk of a mission across a number of repeated projects. In other words, a particular programme would consist of an increased number of smaller missions that would return fewer scientific benefits, such as was the example of the missions to Mars in 2000. In effect, the increased risk of each mission was able to be spread over the entire programme, reducing the overall programme risk. This spreading of increased risk may be replicated in other CoPS industries such as distributed power networks or communications systems, providing that individual 'mission' failures are acceptable (i.e. that the systems are not mission or life critical).

The CRCSS FedSat team used the SSP to draw upon and focus appropriate experience, motivation, flexibility and leadership. The approach reduced management overheads and the overall number of staff required, while leaving the overall risk to the project unchanged.

One of the most important areas believed to have resulted in the success of the FedSat project was the use of a single small, committed team with overlapping and complementary skills. This team was made up of a proportionately large number of systems engineers and displayed depth in particular areas of specialisation and knowledge across the breadth of project. In the FedSat case the different implementation phases of the project were blurred, with phases added as required, such as the rework phase of the satellite just before launch. This flexibility of implementation phases—which can only be done with a small team that can be across everything—may be a key to a successful reduction of resources required in such projects. The reduction in team size also had the impact of reducing the number of overheads required to manage the project. In CoPS with reduced resources the key may be to reduce the scope of the mission to the point where despite its complexity the team can understand and oversee the totality of the project.

Experience with the SSP showed the importance of leadership as opposed to traditional project management methods. Effective leadership explains the successful implementation of this project, and may apply to other CoPS projects. Building a core shared vision for such projects aligned to common goals is critical, as is a focus on finding the correct balance between experienced decisions and trading risk for cost. Relationship building in the FedSat satellite (such as the emphasis on developing trust and honesty between the project engineers) is potentially an area for investigation in other CoPS projects wishing to reduce costs. The organisational behaviour aspects of the project, with the evolving organisational forms and the way that the project was structured, with a small integrated team willing to see the satellite launched at any cost, also points to areas for future investigation within the CoPS framework.

There are a number of institutional issues that may potentially be applied from the FedSat project into the broader CoPS domain and for the management of complex research, engineering and technology transfer projects more generally. For example, it was found that there were a number of limiting structural factors in the cooperative nature of the CRCSS, ranging from the various goals of different stakeholders to mismatches in authority and the risk management approach taken. Also the approaches taken in the satellite project, such as using the operation of the spacecraft to define requirements and the use of OTS components are areas where CoPS theory may benefit from lessons learnt from building satellites. Overall, FedSat was a success in many of its technical requirements but not in its public policy and commercial requirements, and there are lessons to be learned about how to align goals in public-sector projects.

Some of the structural issues constraining the successful implementation of the FedSat project have been described. The satellite project had to be matched to the CRC framework, rather than the other way around, and many of the limitations in the project resulted from the structure of the CRC programme itself. These included the divergent range of goals identified by its participants. Despite this diversity, the CRCSS structure required cooperation at every stage, placing considerable management demands on its executive. As the CRC was unincorporated it was difficult for the management of the CRCSS to enforce decisions on the partner organisations, which were responsible for the day to day management of their own staff. We question the applicability of the cooperative research-based CRC-type structures to develop CoPS such as satellite projects.

The success of the CRCSS was also bound largely on the success of FedSat. If the satellite were to fail, the majority of the research outcomes for the centre would be lost. This 'single-point' failure accompanied with a perception that CRCs are not designed to fail catastrophically, meant that there were differences in approach between the different project partners, some opting for a more risk-averse approach than others.

One of the goals of the CRC programme is to commercialise the research arising out of the work of the centre. In order to commercialise a single product with large costs, partners need to be able and willing to invest significant resources, something not present in the CRCSS. However, it may be that the Centre could commercialise less complex spin-off technologies (such as sub-systems), add-on technologies (such as the payloads) or valuable services (such as the ground station). However, as many of the original requirements were not developed with a commercial focus, this commercialisation has not yet been successful.

As far as the structure of the project is concerned, at the time of its inception, the CRC programme was the only funding mechanism available. Simply, however, the CRC programme was an inappropriate policy mechanism to 'reignite' the Australian satellite industry. The complexity of the project, overlaid with its national symbolism and associated effect on risk management, laid far too great a strain on the management capabilities of a new and in many ways experimental organisation. Whilst many of the management problems experienced could conceivably have been foreseen, and the solutions found could potentially have been introduced earlier or pre-emptively, this requires a sophisticated managerial capability usually unavailable in a 'start-up' industry. Ironically, once the hard-won lessons of effectively supplier and project management, organisational change and unified approaches to design and production had been learned, the CRCSS's funding was discontinued by the government.

However, the project was a technical success, which indicates that it is possible to develop indigenous CoPS building upon international technology transfer, particularly as in this case when they have 'reduced resources'. Expenditure on the space industry is often justified by the spin-off benefits to other industries, ranging from materials science to communications technologies. A fertile area for investigation is the role that reduced resource CoPS play in the creation of these spin-offs and how they might be promoted in justifying investment into the development of CoPS industries. This is particularly important in determining the best way to fit one-off projects into different industries in the national system of innovation. The technique of dividing a complex industry into its constituent parts and differentiating between large and reduced resource CoPS may also assist in this analysis. More effective policy would distinguish between levels of complexity in projects and adjust supportive mechanisms accordingly. Research into the supportive institutions, relationships and incentives within national innovation systems that can support international technology transfer projects, such as FedSat, would also be welcome.

Although these findings reported here are applied within the context of a particular form of collaborative research and technology transfer project, it is believed that they hold implications and lessons for the increasing number and range of collaborative partnerships created to manage complex, shared research and engineering endeavours.

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Notes

1. There were, for example, no articles on innovation in the satellite industry in *Research Policy* between 1994 and 2004, and only one article in *Technovation*, which looks at using satellites to build complex systems competencies for developing countries. This is somewhat surprising given the extent of the technological challenges in the space industry and the significant size of the industry, estimated to be over $80 billion in 2001 (Euroconsult, 2001, p. 38).
2. NASDA changed its name to JAXA (the Japanese Aerospace eXploration Agency) in late 2003.

Appendix A

FedSat platform technical specifications
• Physical dimensions of approximately 500 mm^3 and a 2.5 m deployable boom. The total mass is 58 kg. • All on-board processes are controlled via the Data Handling System (DHS) • 3-axis stabilised Attitude Control System (ACS) incorporating: 3 digital sun sensors and magnetometer to determine orientation 3 reaction wheels and 3 magnetorquers to provide orientation torques. • Power Conditioning System (PCS) providing a regulated +28 V bus that generates an orbit average power of >35 W in the summer season. The energy sources are:

Appendix A continued

FedSat platform technical specifications
Body mounted GaAs solar cells on 4 sides of the spacecraft
A NiCd battery split into 2 packs
• S-Band communications providing:
Uplink: up to 4 kbps
Downlink: up to 1 Mbps

The five payloads flown on FedSat are:

- The Communications Experiment developed by the Institute for Telecommunications Research at the University of South Australia, the University of Technology Sydney and CSIRO Telecommunications & Industrial Physics. It includes UHF and Ka-band equipment to study the transmission characteristics of Ka-band, store and forward at UHF and new coding methods.
- The NewMag Experiment developed by the University of Newcastle. It comprises a three axis magnetometer mounted on the end of a 2.5 m boom to study dynamics of the Earth's magnetic field.
- The Global Positioning System (GPS) payload developed by the Queensland University of Technology will test GPS precise orbit determination, timing and meteorology.
- The High Performance Computing Experiment (HPCE) also being developed by the Queensland University of Technology will study reconfigurable gate arrays in the space environment.
- The Star Camera developed by the University of Stellenbosch in South Africa.

Appendix B

Preliminary interviews were undertaken with many of the key stakeholders in the FedSat project, including CRCSS management, CRCSS engineers and representatives from the project prime contractor. The formal interviews were approximately 90 min in length and were undertaken at three phases of the satellite development; the first at Space Innovations Limited during the fabrication of the satellite bus, the second after Space Innovations Limited had declared bankruptcy and the satellite was being transferred to Australia, and the third after the satellite had been assembled and was undergoing final integrated system tests. The targets of the interviews were the staff at all levels of management and technical development, from both the CRCSS and SIL. The number and types of interviews are outlined in Table A.1.

Notes were taken at all interviews, with the interviewer attempting to capture direct quotes as often as possible. The first interview with each of the participants was done without a tape recorder so as not to intimidate the interviewee and to promote open and honest comments. However, from the second interview onwards recordings were made, with reference to the comments made from the first interview if there was a lack of clarity in the initial responses and to verify the information provided.

The FedSat project also underwent a large number of internal and external reviews during its implementation, providing a wealth of data towards the case study. One of the authors had both the opportunity to sit in on a number of reviews and access to the final reports. The reviews undertaken during the project are outlined in Table A.2. At the end of each review, the reviewer was required to submit a report to the CRCSS

Table A.1
Structured interviews

Phase	Type	No. interviews
Satellite in production at SIL *November 1999*	SIL – Upper management	2
	SIL – Middle management	3
	SIL – Technical engineering & support	2
	CRCSS – Middle management	2
SIL bankrupt *July 2000*	SIL – Upper management	2
	SIL – Middle management	3
	SIL – Technical engineering & support	2
	CRCSS – Upper management	1
	CRCSS – Middle management	2
Satellite finished construction at CRCSS *May 2002*	CRCSS – Upper management	4
	CRCSS – Middle management	3
	CRCSS – Technical engineering & support	6
Total		32

Table A.2
Project reviews

Year	Date	Review
1998	30th November–4th December	Systems design review
1999	5th–8th March	Technical review held in the UK at SIL and DERA
2000	14th–17th February	Stage 1–2nd year review
2000	3rd–6th April	Technical review held in the UK at SIL, Surrey and RAL
2000	2nd–3rd May	Stage 2–2nd year review
2000	13th–16th November	Tiger team review after bankruptcy of SIL
2001	14th–15th June	Internal FedSat review
2001	27th–29th June	DISR review of project
2001	18th July	FedSat material review
2002	14th March	Internal review of FedSat schedule and milestones
2002	20th May	AusIndustry review of FedSat project
2002	9th July	5th year review

executive, which outlined the findings of the review and gave some recommendations for the further operation of the CRCSS. Access to these reports provided external opinion on the development of the project.

In addition, a large amount of internal project documentation, including all of the documentation outlining the project tools and systems, was available for the case study. Copies of the project documentation from the bankrupt Space Innovations Limited were also able to be accessed.

One of the authors was a member of the project team, and had the opportunity to gain information and experience as part of the larger project throughout its implementation, as one of the systems engineers for the project. As a member of the project team, the researcher was first invited to fully integrate with the systems engineering department at SIL, and then later with the core project team after the satellite had moved to Australia. As such, the researcher gained entry into the internal project structures and operations, giving a tight connection between the research and the project.

While this tight connection should increase the weight of the researcher's conclusions, it was important that all information gathered through first-hand experience was verified by other sources, to ensure that the researcher's judgement was not clouded by a close association with the project. Inevitably, there were be some processes of decision-making and actual decisions where the participation of the researcher affected the outcomes, but an effort was made to keep these minimal.

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