PROCEEDINGS OF SCIENCE

Success drivers for large, high-technology projects: implications for the Square Kilometre Array

Philip Crosby[1]
International Centre for Radio Astronomy Research (ICRAR)/Curtin University/CSIRO
GPO Box U1987, Perth, Western Australia, 6845
E-mail: `phil.crosby@csiro.au`

Peter J Hall
International Centre for Radio Astronomy Research (ICRAR)/Curtin University
GPO Box U1987, Perth, Western Australia, 6845
E-mail: `peter.hall@icrar.org`

Abstract

Large projects having ambitious science goals and including new engineering technologies, significant infrastructure, and big budgets typically undergo much scrutiny prior to approval for expenditure. What is less clear is whether early stage planning takes proper advantage of potential indicators of success (or failure) based on learnings from relevant past experience, and whether early stage project development/planning can be made more effective.

While there is considerable literature concerning general management of large projects, and execution of complex programs, there is little material dealing with success drivers for large and complex high-technology projects typified by the ALMA and SKA radio-telescope projects.

Drawing on recent PhD research, we present the results of a new meta-study of the literature, informed and validated through interviews with high-technology project managers, scientists and engineers from selected case studies. Our conclusions address definitions of success, project function and structure, authenticity, and strategic procurement. Dimensions of project complexity are examined, looking beyond technical and programmatic challenges into the internal and external project environment. Project resilience qualities are revealed, as well as less obvious traits of successful project managers. Review methods are discussed, together with effective processes for organisational learning. We identify critical success factors in relation to the development of the SKA project, and offer a practical checklist of indicators and drivers for high-technology mega-project success.

Resolving the Sky - Radio Interferometry: Past, Present and Future
Manchester, UK
April 17-20, 2012

[1] Speaker

1. Introduction and Background

Much has been written regarding general project performance, and the literature is rich in empirical studies of tens, and sometimes hundreds, of projects in an effort to distil factors governing their success or failure. Case study work, involving report analyses, interviews and questionnaires offer insight through evidential data complemented by qualitative judgement [1]. Other studies have derived conclusions through statistical analyses and although meaningful, require more interpretation by the practising project manager.

Many studies stem from a perception that large, publically funded projects, often launched in a fanfare of optimism, frequently overrun in terms of cost and time and occasionally become the *fiascos* described by Flyvbjerg et al. [2] and Grün [1]. This is no less so in the realm of large, high-technology (high-tech) projects that fail in one or more performance criteria, and contribute to the long and (dis)honourable history of mega-project failure [3], [4], [5], [6].

Cost overruns and schedule slippage of >25% are common in mega-projects, and are often accompanied by severe and sustained operational problems. Flyvberg et al. [2] found little outcome change in 100 years of project management, and despite forensic dissection of individual failures, few mechanisms (and sometimes little will) emerges to learn from failures. Optimism bias is nearly always a key factor, compounding blatant dishonesty in order to get projects funded [7], [8], [9].

The good news is that about 40% of mega-projects *are* successful [2], and this led to the present research question: what was special about these projects, and can their traits be applied at start-up and early management of new high-tech projects, particularly the Square Kilometre Array (SKA)? In particular, we investigated whether early stage planning takes proper advantage of potential indicators of success based on learnings from relevant past experience, and whether early stage project development/planning can be made more effective.

Our early research showed that much more than good project management practice was involved, and success is often contingent on both project environment , and human factors. The conclusions presented below emerge from our analyses and applications of published data, and from knowledge extracted and tested through our casework.

2. Methodology

Our research was underpinned by a comprehensive review of the published literature on the topic of project success and adjacent subjects, as well as a study of related project management texts, institutional and project reports, recorded interviews, and articles from in-house and public publications. Evidence was supported by specific project documentation wherever possible.

A core component of the research effort was a meta-study of the literature by Crosby [10], mainly drawn from peer reviewed journal publications, and supplemented by published reports and case study extracts from academia. Data were sought from a purposely broad range of studies from the Western world covering the past 35 years, containing diverse project characteristics in terms of purpose, budget, location, engineering innovativeness, and sponsor. The only selectivity applied was to ensure a representative and statistically significant sample of high-tech projects with some systems engineering component. In total, 29 general studies were examined encompassing 2,820 projects (cases), as well as success factor summaries drawn from two other papers dealing with different projects. A sub-set of 20 studies (928 cases) were classed as high-tech projects.

Complementary to our research were field investigations at 16 mega-science project sites (Table 1). Important data and project artefacts were gathered at these facilities; however, it was the 'lived experience' related by project management and staff that was most enlightening. This case study material proved immensely valuable in validating the scientifically and empirically derived conclusions from the research[2].

The chosen sites each satisfied the criteria of having substantial and specialised infrastructure, > US$100 million budget (except the Antarctic LIDAR), and a science goal concerned with astro, particle, or nuclear physics. Visits of 2-3 days were pre-planned to ensure access to key project management representatives. Formal interviews were conducted, each typically lasting 3-5 hours. Use of a question list ensured a systematic approach and consistency of topic coverage; however interviewees were free to amplify their responses as necessary.

Project Acronym	Location	Description
ALMA	Northern Chile	Radio telescope array of ~66 dishes. Under construction.
ASKAP	Mid-West of Western Australia	Radio telescope array of 36 dishes, and precursor for the SKA project. Currently under construction.
ATCA	Northern NSW, Australia	Radio telescope array of 6 dishes. Completed in 1988.
HIPER	Site not yet decided, but most likely Oxfordshire, UK.	High power laser to demonstrate the feasibility of laser-driven fusion. Currently in early stage planning.
ILC (DESY) XFEL (DESY)	Site not yet decided. Possibly Russia. Hamburg, Germany	Dual opposing linear colliders of super high power. X-Ray high power free electron laser
ITER	Provence, France.	International Thermonuclear Experimental Fusion Reactor that aims to demonstrate energy from fusion. Under construction.
LHC	Beneath the French-Swiss border.	Large Hadron Collider – a gigantic particle accelerator. Began operating in 2010.
LIDAR	Davis Station, Antarctica.	A light detection and ranging instrument configured to probe the mesosphere . Commissioned in 2004, and since upgraded.
LOFAR	Centred in Northern Netherlands	Radio telescope consisting of thousands of omni-directional dipole antennas. It commenced operations in 2010, and is continually being expanded.

[2] The case study as a research method is supported by Yin (2009), who describes the methodological approach which we followed to ensure conclusion validity and produce useful distilations from complex phenomena.

PoS(RTS2012)047

MEERKAT	Northern Cape of South Africa.	Radio telescope array of 7 dishes (to be expanded to ~80). A precursor for the SKA project currently under construction.
OPAL	South of Sydney, Australia.	A state-of-the-art 20 mega-watt open-pool research reactor. Commissioned in 2009.
SKA	Location is either Southern Africa, or Australasia.	A giant radio telescope with 1 million square metres of collecting area using thousands of receptors, in early design phase.
SYNCH (Australian Synchrotron)	Melbourne, Australia.	A particle accelerator accommodating 30 beamlines. It began operations in 2007.
TOPSAT	RAL (UK). TOPSAT is still in earth orbit	A micro-satellite with advanced, down-looking, imaging cameras. Launched 2005.
VISTA	Northern Chile	A visible and infra-red survey telescope. Commissioned in 2009.

Table 1. List of case study projects and organisations

3. Study conclusions

In the paragraphs below we summarise 14 major conclusions from our study.

3.1 Grasping the challenge

Multi-billion dollar, high-tech projects are inherently risky, yet their international scale and huge cost implications demand that success is achieved and project performance maximised. Success criteria must be objectively set via analysis of hard and soft critical success factors. Traditional project management techniques are insufficient to meet project demands, and a fuller understanding of success drivers is required to lift project performance.

3.2 Multi-dimensional complexity

Large high-tech projects, while not ‘wicked’ problems, are more than just complicated and difficult. Technical complexity requires comprehension through mathematical analysis or typology characterisation. Collaborations introduce further complexity and uncertainty through compatibility and cultural issues (including institutional-industry differences).

3.3 Project structures

High-tech mega-projects with their own identity and operating legal entity do best, however a case also exists for building on existing institutions. Member obligations must be extremely clear, with shares, credits, and *juste retour* policies agreed and formally stated. Locating the project headquarters close to the site is shown to be beneficial, as is a dual leadership between an influential science/engineering figure, and an experienced and qualified project practitioner.

3.4 Procurement approach

Procurement is shown to be strategically important to success, and an informed, holistic approach can improve effectiveness and underpin more productive and open relationships with suppliers. Several key procurement strategies can directly influence project success, including; early establishment of functions and policy, appropriate contracting models and instruments, an agreed policy for specifications, risk, and purchasing process, and transparent relationships.

3.5 Instilling resilience

Three ‘attitudinal’ resilience factors are identified: (1) curbing of enthusiasm for excessively optimising the project picture, and facing facts with realism, (2) the use of analogous lessons-learned to inform stakeholders of the risks and major challenges ahead, and (3) cognisence of project complexity, periods of ambiguity, peripety (shifts of fundamental understanding enabling project evolution), and uncertainty.

3.6 Project launch conditioning

The quality of resilience is also strengthened through six manageable ‘launch conditioning’ factors. (1) The early setting of project mission and success definitions, and (2) clear and consistent structures and processes for reporting and decision-making. (3) Establishment of an holistic project information office with a remit beyond the technical arena to cover all data and media traffic. (4) Adequate preparation for unknowns – those risks or events that cannot be identified by nature, but statistically are likely to occur [3]. (4) Keen awareness of the extra-project landscape (political, environmental, societal, etc.) , and (6) the deployment of a mission assurance function to add rigour to early project definition and requirements setting activities.

3.7 Planning, schedule and budget

A baseline description is required at project start – a bundled set of dynamics incorporating stakeholder assumptions, constraints, and a reference point from which to plan. The project plan must adequately describe the project lifecycle and contributing phases, and a tested cost and schedule budget,. Casework shows that, even when the required urgency is instilled, the ‘marching army’ effect means that cost or schedule slippage beyond ~20% is unrecoverable.

3.8 Theory derived success drivers

Crosby’s meta-study of project success factors based on 2820 cases [10] concludes that sound project management control and execution systems, and a clear project definition and goal set, are by far the most important drivers of project success. Competent information management systems ranks third, followed by sustained commitement from top management. Many of the study’s top ranked success drivers (Table 2) are wholly or partly newly ranked ‘soft’ drivers, indicating the importance of leadership, motivation, expectations, and team engagement.

[3] For example, one effective response strategy is to pre-form task force(s) in readiness to act swiftly in the face of any threat to mission delivery – backed up by a calculated contingency reserve.

Success Driver	Rank / Score
Project management (PM) control & execution systems in place, with robust policies, planning, procedures, document control, audit, etc	1 / 23.87
Clear project definition, requirements, goals, objectives, scope, and project mission; sound business case	2 / 19.53
Mature project communication, information systems; effective public relations management	3 / 11.18
(Top) management (or sponsor) support with sustained commitment, appropriately engaged	4 / 8.96
Project baseline, estimates accuracy, project phasing, effective project performance (reviews) and measurement	5 / 8.96
Leadership skills, PM experience & stability; motivating & socially capable PM	6 / 5.97
Agreed realistic customer / user expectations; frequent customer contact	7 / 3.37
PM/Organisational understanding & competence in project management	8 / 3.37
Adequate resourcing of the project	9 / 2.37
Aligned perceptions of project goals & success - management and team; sense of urgency instilled	10 / 2.37
Effective stakeholder engagement / partnership (e.g. client, contractors, etc)	11 / 2.37
Organisational responsibilities assigned to right-sized capable team	12 / 1.64
Mature, effective project management change control process; effective deviations handling & configuration control	13 / 1.64
Understanding & continuous management of risk; visibility of risk register	14 / 1.13
Project Manager & PM systems matched to project complexity, and culturally aligned	15 / 1.13
Effective means of learning from experience and continuous improvement environment	16 / 0.78
Full understanding, and early engagement, of host government environment and institutional requirements	17 / 0.78
Right-sized systems engineering; managing and procuring in right sized project 'chunks'	18 / 0.78

Table 2. Success drivers tabled by occurrence within the study population literature

3.9 Personal traits

Our investigation of the less obvious characteristics of successful project managers points to eight personal characteristics, traits, or skills that are strongly indicated as subtle, though significant, factors in driving high-tech project performance. These are (1) The ability to deal with the temporary and uncertain nature of mega-projects, (2) Having and demonstrating personal authenticity (though not necessarily charisma), (3) Applying persuasive skill in the management of collaborations, (4) Having an appropriate balance of management and leadership talent, (5) Motivating strategic influence through persuasion, encouragement, and negotiation, (6) Knowledge-sharing and trust-building in a diverse cultural environment, (7) Having a personal profile and competence well matched to the project, and (8) Driving a clear sense of project urgency while managing deviations.

3.10 Project management models

Practice guides, often in the form of 'Books of Knowledge' (e.g. PMBoK) contain much good task oriented material and have some application in project manager certification. However they are of limited use for developing and managing success strategies in the very complex environment of high-tech projects. Recently introduced maturity models (e.g. CMMI) offer more promising frameworks for execution and assessment of complex projects.

3.11 Authentic endeavour

High-tech projects must be constantly alert to deceit. Our study found that dubious practices can emerge where no plausible quest exists and success metrics are meaningless. We revealed examples of unrealistic promises, potential fad-science, and embellished reports. In times of financial constraint, expensive high-tech projects are more closely scrutinised and legal action is not unknown. In cases of 'blue-sky' research, all stakeholders must are aware of the risks and the basis of project approval.

3.12 Project reviews

Project reviews are not only essential to monitor and measure effort, but also mark progress and allow for course corrections and renewed funding decisions. Our research supports the case for the adoption, or shift towards, an industrial model for project reviews by pre-planning these as formal stage gates mapped to project phase at defined intervals, followed by an 'issues' close-out process to ensure timely and accountable responses.

3.13 Post project reviews

Timely holistic review can reveal extremely useful knowledge for both individuals and the organisation, and form a valuable (though under-exploited) avenue of process improvement. We posit that such events should include participants outside the high-tech project team such as support staff, contractors and users. For added effectiveness, we commend subsequent cognitive mapping techniques using cause-chains to reveal useful intelligence for the organisation – and for the high-tech mega-project community.

3.14 Learning lessons

The post-project review will have limited effect if the outcomes are not effectively captured within a knowledge system or database. If project amnesia is to be avoided, the lessons learned must be transferred to the organisation so that searches by the wider project community can readily source and apply the wisdom. Our study shows that a learning culture is critical to lifting organisational performance, and may prove advantageous when competing for funds.

PoS(RTS2012)047

4. The CHiPS Tool

Having identified and validated important indicator areas of high-tech project success, we developed these into a practical tool that can be applied by project practitioners, funding approval agencies, reviewing panels, and project auditors. The resulting *Checklist for High-tech Project Success* (CHiPS) tool sets out key success indicators for high-tech mega-projects, grouped by project phase. Against each of 60 indicators we present example evidence that might support validation of the indicator. The tool is most usefully applied at the conceptual and approval for expenditure (AFE) stages, although the indicators bear review throughout project execution. The aim is to achieve a repeatable, objective assessment of where the requirements are addressed, and where gaps remain. Figure 1 shows a small section of the CHiPS tool.

The Checklist for High-tech Project Success (CHiPS) Tool ver 1.4

Project Phase	Key Indicators	Example Evidence	Findings	✓ or X
Approval for expenditure	25. There is a detailed project budget and schedule containing realistic budget and schedule contingency for both identified risks and unknown unknowns. Optimism tendencies are exposed and corrected. Resources are allocated for capturing project lessons. The project scope can genuinely be accomplished within the proposed budget and any contingency reserves.	Detailed budget for project commencement plus 2 years. Medium level budget for remainder of project lifecycle. Contingency reserves are calculated or otherwise assessed, and valued. Detailed schedule with critical path and project dependencies identified.		
		Budgets are based on traceable cost models or data, with adequate margins, and benchmarked against analogous situations, or certified for accuracy by qualified cost accountant. Schedules are independently reviewed and certified as practicable.		
		The budget includes provision for post-project reviews.		
	26. The project mission, broad goals, and specific objectives are clear. Project success criteria and critical success factors are expressed.	Project mission, goals, and specific objectives are declared in project documentation. Success criteria and critical success drivers are recorded, and reflected in project artefacts.		
	27. A coherent and complete system description, and systems engineering approach, is embodied in project plans	Project plans contain a clear description of the project system, interconnects, and dependencies. A systems engineering approach is underpins all artefacts.		

Fig 1. Example sheet from the CHiPS tool

5. Conclusions for the SKA project

The SKA project is in transition from the concept design phase to the pre-construction phase. There are many timely and readily applicable lessons for the SKA project which can be derived from our work , and the consideration of the full CHiPS tool is suggested. Nonetheless, considering the deep study summarised in this paper, we consider the areas set out in Table 3 are those requiring immediate attention in order to underpin future project stages.

(Re-)Define the mission	Agree and announce the overall success metrics Declare a 'shared construct' of project complexity
Get the collaborations right	Set up the SKA Project Advisory Committees as Task Forces to: - build on current foundations of industry engagement - set key project IP & procurement policies - re-engage with SKA community

Get tough, and get real	- Instill qualities now to build resilience - Address optimism and contingency factors - Set rules for project information flows - Urgently implement a project staffing plan - Monitor and maintain project pace – every day

Tabel 3. Principal areas of the SKA project requiring attention (as at the date of this paper).

References

[1] O. Grün, *Taming giant projects (management of multi-organisation enterprises),* Springer-Verlag, Berlin 2004.

[2] B. Flyvbjerg, N. Bruzelius, W. Rothengatter, *Megaprojects and risk*, Cambridge University Press 2003.

[3] E. W. Merrow, *Understanding the outcomes of megaprojects*, The RAND Corporation, 1988.

[4] P. W. G. Morris, G. H. Hough, *Preconditions of success and failure in major projects,* Templeton College, The Oxford Centre for Management Studies, Oxford. 1986.

[5] F. Hartman, R. Ashrafi, *Development of the SMART project planning framework*, International Journal of Project Management, *22,* 499-510, 2004.

[6] MoD, *Major projects report 2008,* UK Ministry of Defence, House of Commons Public Accounts Committee, HC 165, 2009.

[7] G. Butts, K. Linton, *Joint confidence level paradox – A history of denial*, NASA 2009 Cost Estimating Symposium, 2009.

[8] A. J. Shenhar, D. Dvir, *Reinventing project management: the diamond approach to successful growth and innovation,* Harvard Business School Press, Massachusetts, USA, 2007.

[9] M. Cavanagh, *The conspiracy of optimism – a position paper*, International Centre for Complex Project Management, Canberra, 2009.

[10] P. Crosby, *Key Success Drivers – Meta-Study Findings Applicable to Large High-Technology Projects.* Int. J. Information Technology and Project Management, 3, *2*, 2012.

[11] R. K. Yin, *Case study research: Design and methods*, fourth edition, Sage Publications, California, USA, 2009.