SKA COSTING STRATEGY

Document number MGT-040.070.000-MP-001
Revision C
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Date 2010-10-07
Status .... Draft

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DOCUMENT HISTORY

Revision	Date Of Issue	Engineering Change Number	Comments
A	2010-08-02	-	First draft released internal to SPDO for review
B	2010-09-11		Second draft released following comments
C	2010-10-07		Draft following inputs from the SKACost Busy Week

DOCUMENT SOFTWARE

	Package	Version	Filename
Wordprocessor	MsWord	Word 2007	SKA Costing strategyv7.docx

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1 SKA Costing Strategy - Executive Summary

The development of a costed system design for Phase 1 of the Square Kilometre Array (SKA) is a prime deliverable for PrepSKA, the EU funded SKA co-ordination project. This deliverable is due to be completed by the end of 2012. In addition, the international community is engaged in a process of design and costing of the full SKA facility with a view to establishing funding by 2017. Cost estimates of systems designs for use in this endeavour will need to be well documented, comprehensive and credible.

Establishing a costing strategy will be key to achieving these goals. An SKA costing strategy will ensure consistency in approach to cost estimation across a widely distributed group of collaborators and enable cost and performance trade-offs to occur based on equitable comparisons.

The costing strategy can be briefly described, in the first instance, by its objectives and working principles.
The objectives of the costing strategy are:

1. To support the delivery of a detailed costed system design for Phase 1 of the SKA.
2. To establish a methodology for the costing of the full SKA.
3. To support the cost/performance trade-offs as the design proceeds.
4. To set out the common cost policies, and a dictionary of terms for all SKA stakeholders to use.

The costing strategy described in this document is based on two simple principles:

1. That cost estimation will be an ongoing and iterative process throughout the design, development and build stages of the SKA.
2. That the confidence levels attributed to cost estimates are predicated on both the maturity of the SKA design and the substantiating evidence in support of the cost estimate.

As described in the objectives above, the costing strategy will support the delivery of a detailed costed system design for Phase 1 of the SKA. That costed system design for Phase 1 will have three main components:

1. Costs estimates for those designs developed for SKA Phase 1 systems and subsystems, as part of WP2
    - These costs will include hardware costs, associated software costs and operational costs
2. Cost estimates associated with the site, for SKA Phase 1, as part of WP3
    - These costs will include infrastructure and siting costs
3. Cost estimates for project overhead costs
    - These costs include such items as contingency, taxes and system integration costs
    - In the first instance these costs will be estimated as a percentage of the build costs. They will be further refined and substantiated using data collected from analogous projects in the next phase of the project, when PrepSKA has finished and further resource becomes available.

Cost estimates will also be required in order to refine the design for Phase 2 SKA. The ability to make decisions based on the cost performance trade-offs of various design choices will be essential to ensure that the SKA design converges over time.

In order to achieve the aims and objectives described above the following work will be undertaken in PrepSKA:

- Identification of cost components in the system design to deliver broad coverage of potential costs.
    - A detailed list of cost components is described in this costing strategy and appended to this executive summary. This list is the core of the costing work and describes in specific terms the costs that will be included in the completed costed system design, for both Phase 1 and Phase 2 of the SKA. Every effort will be made to make this list as comprehensive as possible.
- Collection of cost estimates from design groups undertaking sub-system design.
- Support of performance cost trade-offs in order to refine and optimise the SKA design.
- Development of SKACost models for analysis of performance cost trade-offs.
- Formation of costing methodologies for future phases of the SKA design process.

List of cost components for inclusion in the costed system design.

Item	Capital	Operations	Inflation Index	Notes
Tax, customs and duty	✓	✓	Project overhead	
Bias and Confidence Modifiers	✓	✓	Project overhead	
Classic Contingency	✓	✓	Project overhead	
Acquisition costs	✓	✓	Project overhead	
Project Management	✓	✓	Project overhead	
Travel	✓	✓	Project overhead	
Training	✓	✓	Project overhead	
Transport (if EXW quoted for hardware)	✓	✓	Project overhead	
Insurance	✓	✓	Project Overhead	
Software licences	✓	✓	Project overhead	
Security	✓		Project Overhead	
System EMC	✓		Project Overhead	
System H&S	✓		Project Overhead	
System Integration, Test & Commissioning	✓		Project Overhead	
Temporary construction & integration facilities	✓		WP3	
Site operations infrastructure	✓	✓	WP3	
Construction incl Network trenching	✓		WP3	
Annual fibre costs		✓	WP3	
Antenna siting costs incl of foundations, land acquisition.	✓		WP3	
Power Infrastructure	✓	✓	WP3	
Software development	✓	✓	WP2	
Subsystem Hardware costs; Costs are incl of: • Component cost • Safe Operation • Internal M&C • Internal Power • Internal Software & licences • EMC • Integrated diagnostics • Test, Verification, Validation • Internal Integration • Spares • Repair and rework • Quality control • NRE development costs • Labour (manufacture & field installation) • Simulators • Test Equipment	✓		WP2	Subsystems are described by the system hierarchy and are inclusive of: Dish Array antennas, feeds, PAFs. AA receptors, beamformers and beam management. Channeliser and Correlator, Non Visibility Processor. Data Transmission, LO & Timing distribution. High performance computing, M&C computing & transmission.
Hardware Sub-system Operations costs incl: • Maintenance • Annual power costs • Upgrades • Labour		✓	WP2	

2 Contents

3 List of Figures

4 List of Abbreviations

€k	1,000 Euros
AAVP	Aperture Array Verification Program
AN	Another
BECL	Basis of Estimate Confidence Level
BoE	Basis of Estimate
CDR	Critical Design Review
COCOMO	Constructive Cost Model
CoDR	Concept Design Review
COTS	Commercial Off the Shelf
E.G	Example
EMC	Electromagnetic Compatibility
EXW	Ex Works
Fig.	Figure
HPC	High Performance Computing
ICC	International Chamber of Commerce
ICD	Interface Control Document
ICRAR	International Centre for Radio Astronomy Research
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INCOTerm	International Commercial Terms
ISO	International Standards Organisation
JBCA	Jodrell Bank Centre for astrophysics
JCL-PC	Joint Confidence Level Probability Calculator
km	Kilometre
LCI	Labour Cost Index
MIL-STD	Military Standard
NASA	National Aeronautics and Space Administration
NDA	Non-Disclosure errors
NRAO	National Radio Astronomy Observatory
PDR	Preliminary Design Review
PPPI	Product Producer Price Index
PPR	Pre-production Review
PrepSKA	Preparatory phase for the SKA
R&D	Research and Development
RACI	Responsibility, Accountability, Consult, Inform
RAM	Reliability, Availability and Maintainability
Rev	Revision
RFI	Radio Frequency Interference
RFT	Request For Tender
SEMP	System Engineering Management Plan
SKA	Square Kilometre Array

SKACost	SKA Parametric Cost Model
SKA-ICA	SKA International Collaboration Agreement
SLIM	Software Lifecycle Management
SPDO	SKA Program Development Office
SPPI	Services Producer Price Index
SRR	System Requirements Review
STaN	Signal Transport and Networks
TBD	To be determined
UCAM	University of Cambridge
WBS	Work Breakdown Structure
WP2	PrepSKA Work package 2 - Design
WP3	PrepSKA Work Package 3 - Site
WP4	PrepSKA Work Package 4 - Governance
WP5	PrepSKA Work Package 5 – Procurement & industrial involvement
WP6	PrepSKA Work Package 6 – Funding

5 Overview and Strategy

5.1 Introduction

This document will provide details of how we aim to collect, verify, model and report cost estimation data. It will describe how the costing process will be tied directly to the design process in order to ensure full system coverage of cost estimates.

A system cost includes many aspects of the construction of a facility beyond hardware costs. The costing strategy will be essential in ensuring that cost estimates for the SKA system provide comprehensive coverage of as many cost components that may be foreseen as possible.

In conjunction with the collection of cost estimates from the design groups the SKACost modelling tool will be further developed to provide the project with a controlled and peer reviewed model of the design blocks and the cost scaling laws therein. It will provide the means to undertake parametric analysis of costs and undertake sensitivity analysis. In addition, the modelling work undertaken in PrepSKA will provide the groundwork for subsequent cost performance tradeoffs to be undertaken, as well as for examining the cost effects of design or requirement changes.

5.2 Objectives and Scope.

The objectives of the costing strategy are:

1. To support the delivery of a detailed costed system design for Phase 1 of the SKA.
2. To establish a methodology for the costing of the full SKA.
3. To support the cost performance trade-offs as the design proceeds.
4. To set out the common cost policies, and a dictionary of terms for all SKA stakeholders to use.

The SKA PrepSKA project is made up of a number of work packages. This costing strategy applies to WP2-SKA Design and WP3-SKA Site. It will lay the ground work for the detailed design phases of the SKA, but will describe in detail the work to be undertaken in PrepSKA.

Procedures for cost control and Earned Value Management will not be a part of this strategy. These procedures will be necessary in the future, but will be prepared by those experts tasked with cost control and project management in the SKA build and construction phases.

The cost estimates developed in WP2 will cover those parts of the system that are required to service a working telescope, but not those costs associated with the following:

- Outreach
- Local communities, environment & cultures
- Sources of interest & human factors
- Users, Operators & Scientists
- Set-up costs of the SKA corporate infrastructure
- Interaction with Industry (WP5)
- Accessing existing infrastructure
- Performing science operations whilst construction is proceeding
- Academic & Science institutions (local & global)
- Upgrades (except when considering upgrading from Phase 1 to Phase 2 of the SKA)
- Decommissioning

5.3 Approach

The costing strategy described in this document is based on a two simple principles:

1. That cost estimation will be an ongoing and iterative process throughout the design, development and build stages of the SKA.
2. That the confidence levels attributed to cost estimates are predicated on both the maturity of the SKA design and the substantiating evidence in support of the cost estimate.

This costing strategy has been developed using a pragmatic approach, adapting to the project as it exists, today, in the SKA project. Fig 1. Illustrates the main milestones along the road to the completion of a full SKA facility. The costing strategy will need to support this process within the constraints of time and resource available. The first main milestone for costing will be delivered at the end of 2012. This will be a costed system design for phase 1 SKA. The costing strategy described in this document will support the delivery of a detailed costed system design for Phase 1 of the SKA. That costed system design for Phase 1 will have three main components:

1. Costs estimates for those designs developed for SKA Phase 1 systems and subsystems, as part of WP2
    - These costs will include hardware costs, associated software costs and operational costs
2. Cost estimates associated with the site, for SKA Phase 1, as part of WP3
    - These costs will include infrastructure and siting costs
3. Cost estimates for project overhead costs

- These costs include such items as contingency, taxes and system integration costs
- In the first instance these costs will be estimated as a percentage of the build costs. They will be further refined and substantiated using data collected from analogous projects in the next phase of the project, when PrepSKA has finished and further resource becomes available.

Cost estimates will also be required in order to refine the design for Phase 2 SKA. The ability to make decisions based on the cost performance trade-offs of various design choices will be essential to ensure that the SKA design converges over time.

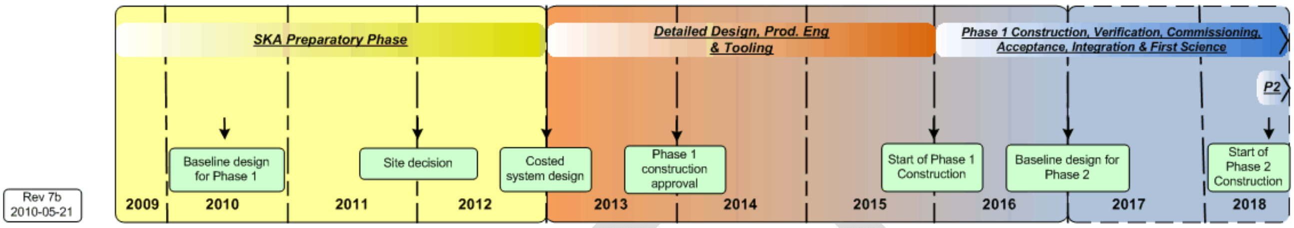

Figure 1 Milestones in the plan for the SKA.

In PrepSKA the following work will be undertaken:

- Identification of cost components in the system design to deliver comprehensive coverage of potential costs.
- Collection of cost estimates from design groups undertaking sub-system design.
- Support of performance cost trade-offs in order to refine the SKA system design.
- Development of SKACost models for analysis of performance cost trade-offs.
- Establish costing methodologies for future stages of the SKA design process.

In the first stage of the SKA project – “SKA Preparatory Phase” the costing activity will concentrate on developing a comprehensive list of cost components to deliver as complete coverage as possible. Cost estimates will be compared to this list to ensure they include as many of the required cost components as possible, or, that those cost components that have not been costed are identified. This will require a system approach to design of SKA subsystems. This approach is described in the SKA System Engineering Management Plan[1] (SEMP).

The cost estimation process will follow the procedures laid out in the SEMP. Whilst cost estimation should be a constant process undertaken by the design groups, delivery of cost information is a requirement of the design review process. This document provides details to the design groups on the form and quality of the data required at the design reviews. Over time, as the system design for the SKA is refined, the cost estimate of that design should become more accurate and include less risk. This will be measured using a Basis of Estimate[2] system laid out at the System CoDR. An objective assessment of risk in cost estimates is essential to maintain the credibility of the costed

[1] SKA System engineering Management Plan – WP2-005.010.030-MP-001. http://wiki.skatelescope.org/bin/view/SystemEngineering/WebHome#System_Engineering_Management_Pl

[2] SKA Strategies and Philosophies – WP2-005.010.030-TR-001. http://wiki.skatelescope.org/pub/LiaisonEngineers/CoDRDocsLE/08a-WP2-005.010.030-TR-001-E_Strategies.pdf

system designs delivered by the project. The processes outlined in this costing strategy will reinforce an objective approach that is based on supporting evidence and comprehensive analysis of the data.

In addition to the collection of costed designs developed by the design groups the cost information will support the cost performance trade-offs necessary to develop a convergent design for the SKA. The process adopted to undertake cost performance trade-offs is described in the System CoDR document, “Strategy to Proceed to the next phase”[3]. The nature of large science projects, such as the SKA, is that the scope of the requirements is large, but to a certain extent fluid. There is an iterative process that requires balance and compromise between the science requirements, the capabilities of advance technologies to deliver those requirements and the constraints of budget, manpower and time. Figure 2 shows how these three factors can create a locked cycle that is difficult to break. Each factor is dependent on definitive information from another factor to proceed.

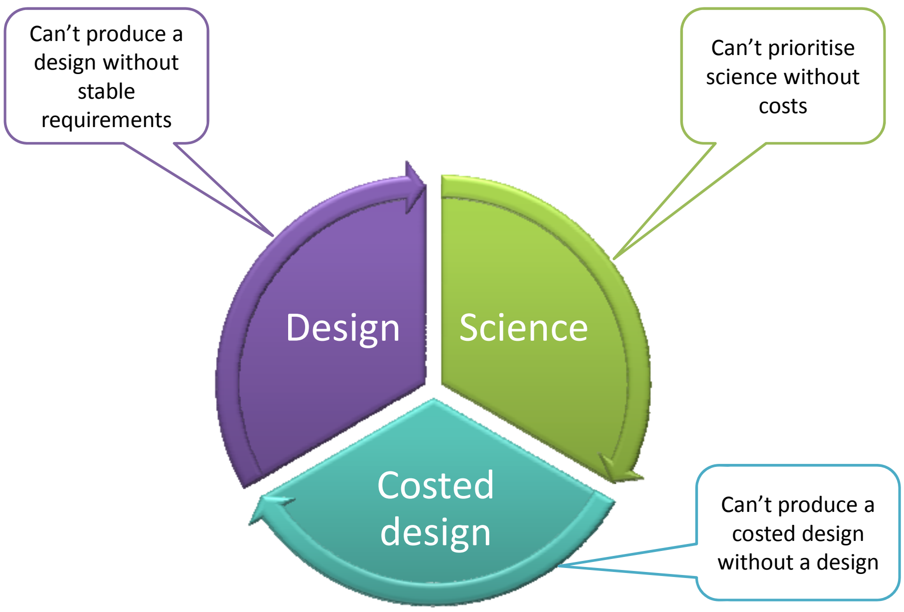

Figure 2 Design factors in a locked cycle.

In the SKA preparatory phase ‘rough’ cost estimates will be required in order to break this locked cycle. The ‘rough’ cost estimates will not necessarily be a costed system design, but a necessary initial step in order to proceed with refinement of science goals and designs. They should be as complete as possible and, where possible, be a deliverable of the design reviews, as described in the SEMP. Sensitivity analysis will be undertaken to identify which costs are critical in the decision making process. This will be supported by the SKACost modelling work that will be undertaken in parallel with cost estimate data collection.

[3] Strategy to proceed to the next phase – WP2-005.010.030-PLA-001 Rev D. http://wiki.skatelescope.org/pub/LiaisonEngineers/CoDRDocsLE/16-WP2-005.010.030-PLA-001-D_NextPhase.pdf

A model for the SKA will be established using SKACost[4]. The design blocks included in the model will include cost scaling laws developed by the design groups in conjunction with the domain specialists at the SKA Programme Development Office (SPDO). Modelling of this kind has been shown necessary for costing the SKA. Other methods of developing system costs, such as excel spreadsheets have been shown unsatisfactory for parametric modelling of a system of this level of complexity. Excel spreadsheets will support the generation of point estimates and support identification of large component costs.

Following the design process SKACost modelling will iteratively refine the model of the SKA, starting at a high level at first and gradually increasing in detail and complexity. SKACost has the ability to model to the component level. The aim in PrepSKA is to develop a controlled model to sub-system level and to subject this model to peer review from community experts. In this way at the end of PrepSKA users will have confidence in the tool, the model and the scaling laws therein. In conjunction with the collection of cost estimates from the design groups this tool will provide the means to analyse the costs of the SKA. In addition, the modelling work undertaken in PrepSKA will provide the groundwork for subsequent cost performance tradeoffs to be undertaken in refining a design for the full SKA, as well as for examining the cost effects of design or requirement changes.

Finally, the costing work undertaken in the SKA preparatory phase will also provide important groundwork for establishing methodologies for the next phase of work – “SKA- detailed design, production engineering and tooling”. In the construction stages of the SKA cost control procedures will need to be established. This is outside the scope of this cost strategy and will be prepared by those experts tasked with cost control in the SKA.

5.4 Process and Plan

The SKA costing process will follow the project plans of the wider SKA project. Figure 3. Illustrates how these plans interlink.

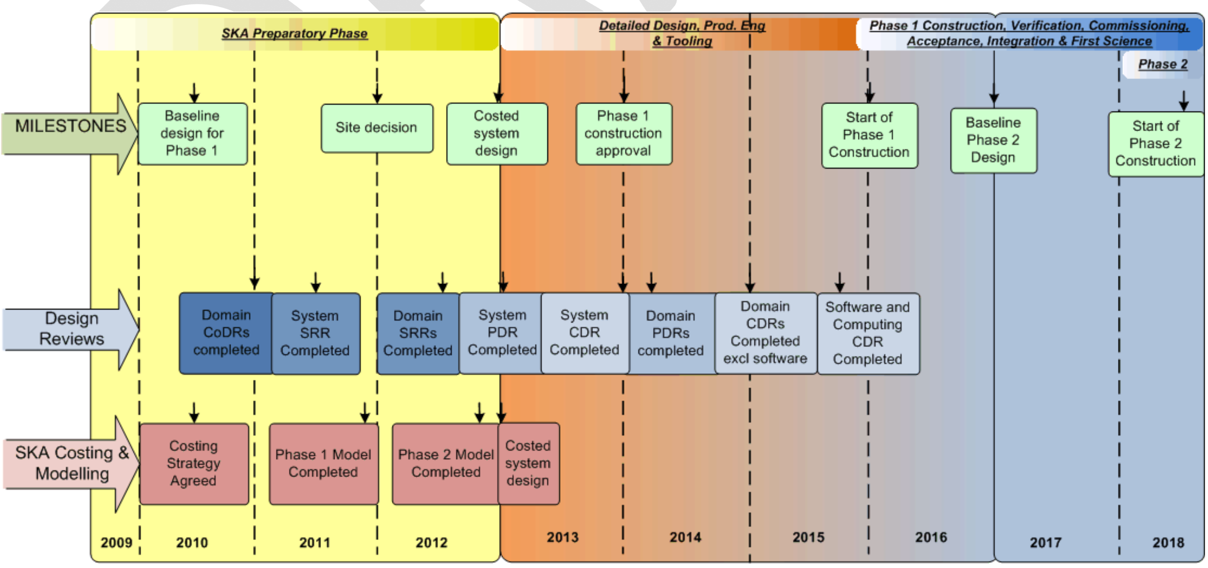

Figure 3 SKA milestones linked to Cost and Modelling activities

[4] SKA Memo 120 SKA Cost and Design Tool, D. Ford et al. http://www.skatelescope.org/PDF/memos/120_Memo_Ford.pdf

The costing of an SKA design has four basic process components:

1. Cost Strategy and definitions
2. Cost information collection and verification
3. Modelling
4. Analysis and reporting

Figure 4 illustrates the detailed stages of these basic process components and the iterative loops that will mean that the analysis will be refined over time. It is anticipated that this process will be completed twice within the PrepSKA timescale. Once to include the costs collected at the domain CoDRs and to include the Phase 1 design captured in SKACost and a second time to include the costs collected at the domain SRRs and to include a Phase 2 representative design captured in SKACost.

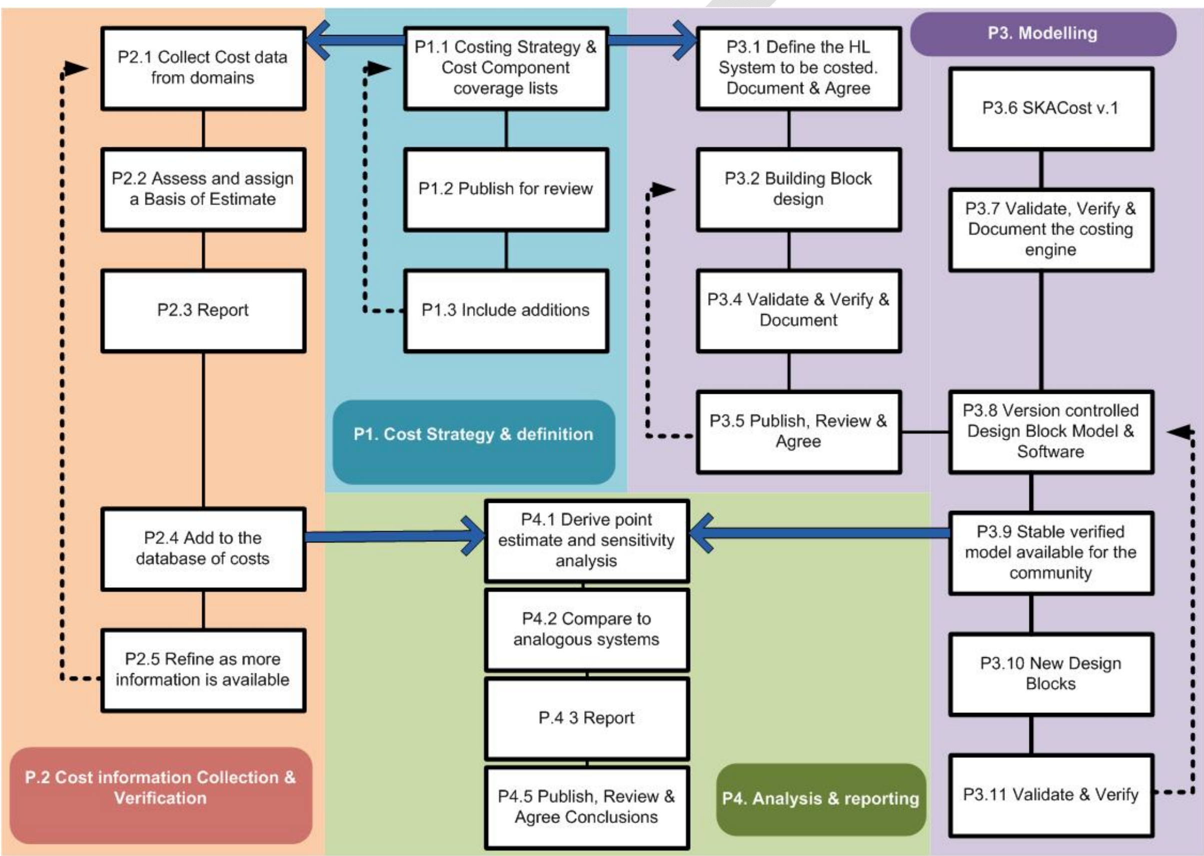

Figure 4 Process stages in the generation of an SKA costed design.

5.5 Roles and Responsibilities

The development of a costed system design for Phase 1 of the Square Kilometre Array (SKA) is a prime deliverable for PrepSKA, the EU funded SKA co-ordination project. This deliverable is due to be completed by 2013. In addition, the international community is engaged in a process of design and costing of the full SKA facility with a view to establishing funding by 2017. In this regard all those engaged in the development of SKA telescope designs have responsibilities in the process described in this costing strategy. There are those who have specific responsibilities in the tasks required to meet these goals.

The *SPDO project director* and *project engineer* have overall responsibility for the quality and content of the costed system designs developed for the SKA. The timely delivery of that costed system design is the responsibility of the project manager.

The costing strategy, communication of the strategy and co-ordination of the tasks therein is the responsibility of the *costing strategy manager* in the SPDO. The development of the SKACost model will be supported by the costing strategy manager. The Cost Strategy Manager will be the principle contact person for costing related matters.

The *domain specialists* will support the community in their efforts to implement the costing strategy process and to deliver the required information, data and documents at design reviews. In addition the SPDO domain specialists will need to familiarise themselves with the SKA costing tool and the existing design blocks, as well as support the development of new design blocks for the SKACost model.

The *design groups* will be required to deliver information in line with the content and level of quality outlined in this strategy. They will also be asked to help in the review of outputs, such as SKACost model design blocks, cost components required for full coverage of the system (and sub-system) design and analysis of the information gathered.

The UK have a lead role in the development of SKACost as the principle tool of analysis for the costing SKA designs and undertaking cost performance trade-offs.

Appendix 1. provides a contact list of those undertaking the roles described above. This list will be maintained to ensure that information is up to date.

The Responsibility, Accountability, Consult and Inform (RACI) chart shown in figure 5. provides additional details of the division of responsibilities for costing activities during the PrepSKA phase of the project.

- Responsible (R) - The entity doing the actual work
- Accountable (A) - The entity ultimately responsible for the deliverable
- Consult (C) - The entity whose expertise is sought in shaping the deliverables
- Inform (I) - The entity that requires knowledge of the deliverable

Process number	Cost Process component	Project Director	Project Engineer	Project Manager	Costing Strategy Manager	Domain Specialist	SKACost Model Lead	SKACost teams	Design Group leads	Design Grou
P1.1	Costing Strategy & Cost Component coverage lists	I	A	C	R	C	C		C	
P1.2	Publish for review	I	I	I	R	I	I	I	I	I
P1.3	Include additions	I	A	C	R	C	C	I	C	I
P2.1	Collect Cost Data from domains	I	I	A	I	A	I	I	A	R
P2.2	Assess and assign a Basis of Estimate	I	A	C	R	I	I	I	I	I
P2.3	Report	I	I	I	R	I	I	I	I	I
P2.4	Add to the database of costs	I	A	I	R	I	I	I	I	I
P2.5	Refine as more information becomes available	I	I	A	I	A	I	I	A	R
P3.1	Define HL System to be costed. Document & Agree	I	A	C	R	C	R	I	C	I
P3.2	Building Block Design		C	I	A	R	A	R	C	
P3.4	Validate, Verify & Document				I	R	A	R	I	
P3.5	Publish, Review and Agree	I	A	I	R	C	C	C	C	C
P3.6	SKACost v.1						A	R		
P3.7	Validate , Verify & Document the costing engine		I	I	I		A	R		
P3.8	Version controlled Design Block Model & Software		A		A		R	R		
P3.9	Stable verified model made available to the community	I	I	I	R	I	I	I	I	I
P3.10	New Design Blocks		C	I	A	R	A	R	C	
P3.11	Validate, Verify & Document				I	R	A	R	I	
P4.1	Derive point estimate and sensitivity analysis	I	A	I	A	C	R	R	C	
P4.3	Compare to Analagous System									
P4.5	Publish Review and Agree conclusions	I	A	I	R	C	C	C	C	C

Figure 5 RACI Diagram for Costing Activities

5.6 Bias and confidence modifiers

"Bias" in the context of cost estimates, refers to any consistent tendency based on human perspective for estimates to be lower or higher than actual cost outcomes. In an independent study of 258 large transportation projects[5] it was reported that cost underestimation occurred in 9 out of 10 of these projects, a statistical significance that cannot be accounted for by error but indicates some other effect at work.

There are many factors that will lead to the growth of costs from initial estimates, not least, any of the following:

- Omission of probable scope
- Omission of possible risks
- Unrealistic and optimistic assumptions
- Use of unrealistic escalation or inflation projections
- Cost estimates provided in base year units of cost, not for the year they are to be spent.
- Estimates prepared by those without expertise
- The reward of low estimates and the punishment of high estimates

[5] Mega Projects and Risk – An anatomy of ambition, Bent Flyvbjerg, Nils Bruzelius, and Werner Rothengatter, Cambridge University Press.

- Insufficient time to prepare good estimates
- Unanticipated external events
- Change of requirements or design.

The reward of low estimates and the punishment of high estimates is a particular pressure on those estimating costs in order to secure or maintain funding for large projects. An unidentified European Civil Servant described the problem succinctly when he said; "*You will (as a planner) know the real costs. You will realize that the budget is too low but it is difficult to pass such a message to the managers and the private actors. They know that high costs reduce the chances of funding.*"

Even NASA struggle to resist the tendency to garner project favour through optimistic cost forecasts. Mike Griffin – NASA Administrator, said "*Scientists tend to downplay costs early to convince NASA that their project is cheaper than someone else's. Later, once NASA commits and the money is being spent, more bucks are needed - so NASA spends more instead of cancelling the project.*" NASA policy makers recently concluded that "NASA *should actively pursue a course that will change our prevailing reluctance to 'tell it like it is in the cost and schedule world.'*"[6].

Studies undertaken by NASA indicate that the accuracy of an estimate has a direct relationship to the stage of development of a project. Another way of saying this is that estimates improve as development progresses. At the early stages of a project uncertainties remain that will hinder the production of an accurate cost estimate, the estimator can only be guided by existing design plans and schedules. As development proceeds, initial designs and plans are often changed. This happens because of unforeseen technical difficulties that will prevent meeting performance requirements or to opt for tradeoffs where the net effect is to increase end-product performance. Christopher Scolese – Acting NASA Administrator said "*While useful and necessary for the initial planning phase of a mission, early estimates are, at best, educated guesses made with preliminary conceptual information*."

In the studies undertaken by NASA they found that estimates for developmental projects containing only "modest technical advances" tended to be more accurate than those projects which were more ambitious - where the development threshold was pushed substantially. In these cases significant factors contributing to cost and schedule growth were over-optimism in initial designs, changes in scope over time, inherent technical difficulty of maturing technologies, and external influences.

The SKA is as susceptible to these pressures as any other project and will need to adopt methods to counter bias and deal with uncertainty in the cost estimation process. The requirement for documentary evidence associated with cost estimates and the intention to cover as many cost components as possible in the costing process are two means of reducing the affects of bias and reducing the number of unknowns in the estimate. They will not, alone, altogether overcome the uncertainties that lead to cost risk in the project. Something more will still be required to accommodate the unknown events that experience tells us will have an inflationary effect on costs.

This work acknowledges that cost overruns in projects often result from components, products and services that are missed, or unknown, as well as optimistic under-estimates of those cost

[6] NASA's Joint Confidence Level Paradox - A History of Denial, Glenn Butts, NASA Cost symposium 2009.

components that are known. Contingency allowances often come down to questions of policy. There is no attempt here to define what contingency levels should be to address 'known or unknown unknowns'. However the costing process will indicate levels of risk in cost estimates that can inform this decision.

One possible method to solve this problem is put forward by NASA who have developed the Joint Confidence Level – Probabalistic Calculator (JCL-PC) , a model for accurately estimating costs in a complex science and engineering environment. The JCL-PC is a holistic algorithm that effectively compensates for the unidentified risk events that have not yet occurred or cannot yet be acknowledged or discovered. The confidence modifiers assigned to the cost estimates are based on experience and historical evidence of how projects have performed in the past. Figure 6. provides an indication of the JCL-PC Multiplier required at each stage of the project. In order to have a 50% probability that project costs will not exceed initial cost estimates (red line), then, at the beginning of a project a confidence modifier of 1.6 is required. As the project progresses the optimism bias will decrease until when the project is 40% complete the cost estimate is assumed accurate to 50% probability. An ever decreasing amount of unknown risks, however, will still remain until the project is completed.

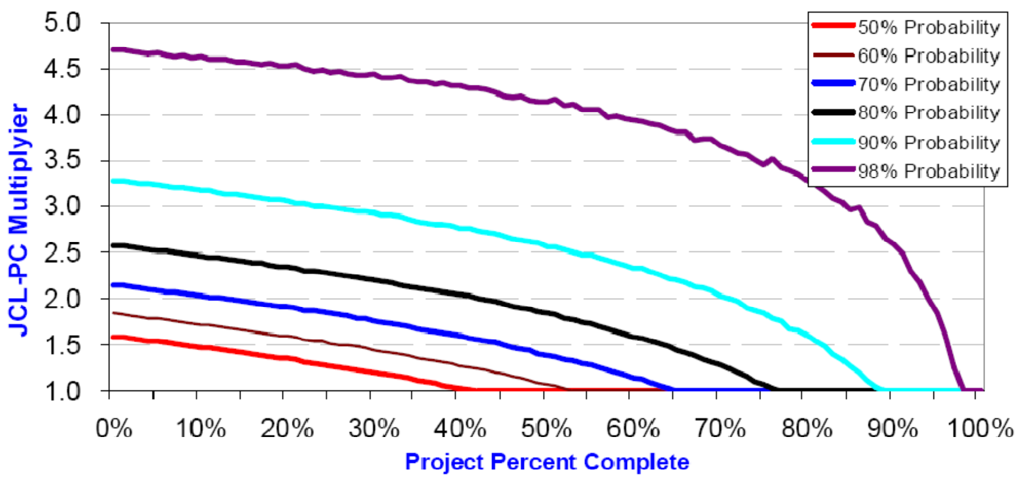

Figure 6 LCL-PC Multipliers assigned as a function of project completion

This costing strategy recommends that the work undertaken at NASA, as well as measures of BECL and cost coverage will be taken into consideration when considering the cost risk involved with an SKA system cost estimate and the levels of contingency required.

6 Methodology

6.1 Costing Policies

6.1.1 Maintenance of the Costing Strategy Documentation

The costing strategy has been developed with the aim of maintaining a pragmatic and flexible approach in the face of a complex project, whilst producing clear guidelines to ensure consistency of cost estimation practices across the project. These two goals are sometimes in conflict and for this reason the costing strategy will be kept under review in order that we can adapt to developments within WP2, WP3 and the other PrepSKA work packages, as well as to incorporate lessons learnt in our approach.

A current version of the costing strategy, including the Appendices will be published as a reference document on the SKACosting page of the SKA wiki[7]. This page will be maintained by the SKA costing strategy manager at the SPDO.

6.1.2 Cost comparisons inclusive of operations

For the purposes of cost comparisons a 10 year cost of ownership will be used in order to assess the relative costs of different solutions. This will mean costs associated with operating the telescope are not forgotten in the analysis. There may be occasions when certain technologies will pay back their initial cost over a longer timescale. In this case *in addition to* the 10 year cost of ownership an analysis demonstrating payback over a longer timescale may be submitted.

6.1.3 Scaling Laws and Inflation

Inflation rates will be derived from data obtained from Eurostat the office of statistics for the European Union[8]. The indices identified for use in SKA cost estimates are divided into three categories:

1. Product Producer Price Index (PPPI)
    - This index takes account of price data for the mining, quarrying, manufacturing and industry for the production of products.
2. Service Producer Price Index (SPPI)
    - This index takes account of the price of rendering services, such as accountancy, legal, employment, transport, consultancy etc. Data for the European Union region is only available from 2008-2009. Given the volatility of Western economies over this period and the short time frame of the statistics this data is not suitable for use as an inflation estimate for the SKA. However the UK Government has SPPI data from 1997-2009. This data has been used to establish a long term value for inflation in this sector and will be used for SKA cost estimates. Telecommunications sector data has been omitted due to the immaturity and volatile nature of this sector over the time period of interest.
3. Labour Cost Index (LCI)
    - This index takes account of the total cost of employment across the EU zone.

Cost components in Figure 11 will be inflated according to the relevant index for SKA cost estimates in PrepSKA. At the end of PrepSKA the values assigned to these indices will be revisited and updated using the Eurostat data.

Index	Value	Time period of average	Reference
PPPI	1.9%	1998-2009	Industry producer prices index - annual data - (2005=100) (NACE Rev. 2)

[7] http://wiki.skatelescope.org/bin/view/SKACosting/WebHome
[8] http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

			(sts_inpp_a)
SPPI (excl telecommunications)	2.4%	1996-2009	Service producer prices index - quarterly data - (2006=100) (NACE Rev.2) [sts_sepp_q]
LCI	3.6%	1997-2008	Labour cost index - Annual data (lc_lci_r1_a)

Figure 7 Indices of Inflation Values for cost estimation

6.1.4 Dates – Points in time for cost estimations.

Time phased costs reflect the fact that expenditure will be spread over a number of years. For example, expenditure to build some SKA stations might be in 2018, and then more in 2022. This better matches the possible spending profiles dictated by funding agencies.

The project will define three time important dates for cost estimates

- Base Year - 2007
- Phase 1 Procurement date – 2014
- Phase 1 Software delivery date - 2017
- Phase 2 Procurement date - 2017

“The base year is used as a constant dollar reference point to track program cost growth. Expressing an estimate in base year dollars removes the effects of economic inflation and allows for comparing separate estimates”[9]. The *base year* is constant across the project. The *base year* cost estimate can most usefully be given as a *present value*, with a discount rate equal to the inflation rate, as outlined later in this section.

To arrive at a *base year* estimate for SKA costing all historical or future costs will be escalated or de-escalated to the base year. For instance: A component escalated with Moore’s Law with a cost estimate of €200 (2011) would be deflated to a cost estimate of €185 (2007) using the PPPI value of 1.9%.

6.1.5 Currency of cost estimates and currency exchange

To avoid the need to consider currency conversion rates (which vary as a function of time), the cost data should be given in Euros. If the historical cost is not in Euros, prior to delivery it should be converted by the user to Euros, using the exchange rate at the year of the historical cost, provided in figure 8. For traceability, it is necessary to record the price in the original currency and the conversion rate used.

Currency	2001	2002	2003	2004	2005	2006	2007	2008	2009
Australian Dollar	1.73	1.74	1.74	1.69	1.63	1.67	1.63	1.74	1.77
Canadian Dollar	1.39	1.48	1.58	1.62	1.51	1.42	1.47	1.56	1.59
Swiss Franc	1.51	1.47	1.52	1.54	1.55	1.57	1.64	1.59	1.51

[9] Government Accountability Office, GAO Cost Estimating and assessment guide. GAO-09-3SP, March 2009. http://www.gao.gov/new.items/d093sp.pdf

Chinese Yuan renminbi	7.41	7.83	9.36	10.30	10.20	10.01	10.42	10.22	9.53
Danish Krone	7.45	7.43	7.43	7.44	7.45	7.46	7.45	7.46	7.45
Pound Sterling	0.62	0.63	0.69	0.68	0.68	0.68	0.68	0.80	0.89
Japanese Yen	108.68	118.06	130.97	134.44	136.85	146.02	161.25	152.45	130.34
Korean Won	1154.83	1175.50	1346.90	1422.62	1273.61	1198.58	1272.99	1606.09	1772.90
Norwegian Krone	8.05	7.51	8.00	8.37	8.01	8.05	8.02	8.22	8.73
New Zealand Dollar	2.13	2.04	1.94	1.87	1.77	1.94	1.86	2.08	2.21
Russian Ruble	26.15	29.70	34.67	35.82	35.19	34.11	35.02	36.42	44.14
Swedish Krona	9.26	9.16	9.12	9.12	9.28	9.25	9.25	9.62	10.62
US Dollar	0.90	0.95	1.13	1.24	1.24	1.26	1.37	1.47	1.39
South African Rand	7.69	9.91	8.53	8.01	7.92	8.53	9.66	12.06	11.67

Figure 8 Historical exchange rate figures

All future costs should be estimated in Euros. For cost estimates based on prices today or future predictions the following exchange rates should be used;

Currency	Exchange Rate (7 year average)
Australian Dollar	1.70
Canadian Dollar	1.53
Swiss Franc	1.56
Chinese Yuan renminbi	10.00
Danish Krone	7.45
Pound Sterling	0.73
Japanese Yen	141.76
Korean Won	1413.38
Norwegian Krone	8.20
New Zealand Dollar	1.95
Russian Ruble	36.48
Swedish Krona	9.47
US Dollar	1.30
South African Rand	9.48

Figure 9 Exchange Rates for use in cost estimation (based on a 7 year average)

These exchange rates are based on data from Eurostat[10] . At the end of PrepSKA the values assigned to these exchange rates will be revisited and updated using the Eurostat data.

6.1.6 Accounting for contingency

Contingency will be calculated at a project level and should not be included in estimates of hardware or software costs. Participating groups can suggest what level of contingency should be included for their particular sub-system of interest. This suggestion should be justified, based on the perceived level of risk associated with the design or cost estimate. Policy makers should take into consideration the extent of cost coverage in estimates, the assigned BECL and the optimism bias inherent in the costing of ambitious projects when assigning contingency to a cost estimate.

6.1.7 Strategy for estimating spares

[10] Euro/ECU exchange rates - Annual data (ert_bil_eur_a)

For the purposes of cost estimation the provision for 5% spares should be included. Where a lifetime purchase is justified this should be explained, documented and included in the cost estimate.

6.1.8 Strategy for estimating acquisition costs

An overhead will be assigned to costs to cover additional activities required to purchase the components or services. This will cover the costs involved with purchase such as:

- the RFT bidding process,
- financial costs related to the purchase (e.g. upfront payments),
- qualification costs and certification
- Expert fees

For the purposes of PrepSKA this fee will be an additional 10% of the purchase price unless it is clear that acquisition costs will be significant. In this case details of what is required in the process and an estimate of the costs should be prepared and included in the cost estimate.

6.1.9 Strategy for estimating transport costs

When assembling cost estimates the delivery terms should be identified. The minimum delivery requirement on the seller, based on the International Chamber of Commerce INCOterms is EX WORKS (EXW). In the majority of cases this should be specified. Other delivery agreements may be applicable in certain cases. The relevant INCOterm should be specified, along with the cost estimates, in these cases.

6.1.10 Definitions of levels of expertise and rates for estimating labour costs

For the purposes of cost estimation and comparison a standard set of skill descriptors and costs are described in figure 10. These figures should be used when estimating the cost of labour to the project. The table below in *no way* reflects the actual salaries that will be used in the SKA. The cost of labour will be dependent on the particular site selected for the SKA, the employment market at the time of employment and the local employment laws and levies. The costs shown in figure 10 do not take into account the organisational overheads, such as offices and training etc. They are comprised of nominal salaries for each skill level with a 25% overhead to cover employment taxes, pensions and employee medical insurance.

Skill descriptor	Example	Indicative educational/training level	Labour cost €k
Operative & Elementary Occupations	Cleaner, Gardener, Fabric Technician	Basic, Primary level, lower secondary	32
Administrative	Secretarial	Secondary level	32
Skilled trade, technical	Technicians	Tertiary level – academic or occupational	46
Supervisory	Office Manager, Technical supervisor	Tertiary level – academic or occupational	56
Professional	Engineer, Scientist,	Advanced	63

	Accountant	Qualifications – academic or occupational	
Senior Professional	Senior Engineer, Programme manager or Senior Scientist	Advanced Qualifications – academic or occupational	78
Senior Managerial	Lead Engineer, Lead Scientist	Advanced Qualifications – academic or occupational	105

Figure 10 Skill levels and labour costs for cost estimation.

6.2 Cost Coverage

In the first stage of the SKA project – "SKA Preparatory Phase" the costing activity will concentrate on developing a comprehensive list of cost components to deliver as complete coverage as possible of cost components. Cost estimates will be compared to this list to ensure cost estimates include as many of the required cost components as possible, or, that those cost components that have not been costed are identified. This will require a system approach to design of SKA subsystems. This approach is described in the SKA System Engineering Management Plan (SEMP).

Figure 11. provides a comprehensive list of cost components that are required when costing the SKA. SKA contributors are encouraged to review this comprehensive list with a view to providing additions if necessary. These should be sent to the SPDO costing strategy manager. This list will be published on the SKACosting wiki and updated as required.

At reviews held by contributing groups the information gathered will be compared to this list of cost components to establish the completeness of the analysis. Not all items on the list will be applicable in all cases. The contributing groups will indicate what is and is not applicable in their area of interest. This will provide information, in addition to the Basis of Estimate Confidence Level Rating, on the risk associated with cost estimates.

The System Engineering approach adopted by the project should avoid the problem of double counting. However at the assembly of the cost estimates from designs groups cross checking will be undertaken to avoid the problem of double counting. The existence of Interface Control Documentation between subsystems will help in this task.

Item	Capital	Operations	Inflation Index	Notes
Tax, customs and duty	✓	✓	Project overhead	
Bias and Confidence Modifiers	✓	✓	Project overhead	
Classic Contingency	✓	✓	Project overhead	
Acquisition costs	✓	✓	Project overhead	
Project Management	✓	✓	Project overhead	
Travel	✓	✓	Project overhead	
Training	✓	✓	Project overhead	
Transport (if EXW quoted for hardware)	✓	✓	Project overhead	
Insurance	✓	✓	Project Overhead	
Software licences	✓	✓	Project overhead	
Security	✓		Project Overhead	
System EMC	✓		Project Overhead	
System H&S	✓		Project Overhead	
System Integration, Test & Commissioning	✓		Project Overhead	
Temporary construction & integration facilities	✓		WP3	
Site operations infrastructure	✓	✓	WP3	
Construction incl Network trenching	✓		WP3	
Annual fibre costs		✓	WP3	
Antenna siting costs incl of foundations, land acquisition.	✓		WP3	
Power Infrastructure	✓	✓	WP3	
Software development	✓	✓	WP2	
Subsystem Hardware costs; Costs are incl of: • Component cost • Safe Operation • Internal M&C • Internal Power • Internal Software & licences • EMC • Integrated diagnostics • Test, Verification, Validation • Internal Integration • Spares • Repair and rework • Quality control • NRE development costs • Labour (manufacture & field installation) • Simulators • Test Equipment	✓		WP2	Subsystems are described by the system hierarchy and are inclusive of: Dish Array antennas, feeds, PAFs. AA receptors, beamformers and beam management. Channeliser and Correlator, Non Visibility Processor. Data Transmission, LO & Timing distribution. High performance computing, M&C computing & transmission.
Hardware Sub-system Operations costs incl: • Maintenance • Annual power costs • Upgrades • Labour		✓	WP2	

Figure 11 List of Cost components for comprehensive cost coverage

6.3 Industry Participation

Given the large reliance on commercially procured equipment and services, the costing strategy and process is highly dependent on effective engagement with industry.

The SKA Industry Engagement Strategy[11] describes how the SPDO/SKA Project encourages industry to engage strategically as well as contractually. Opportunities are also described for longer term industry development to encourage research and development (R&D) and specific innovation in SKA-related areas.

Industry engagement falls broadly into three areas;

- Industry Participation (contracts, jobs, industry leadership & collaboration)
- Industry Development (growth in wealth, infrastructure & human capital, industry expansion, IP generation, start-ups)
- Strategic Positioning (teaming & supply chains, market leverage, specialist placements, facility access, training, know-how exchange, industry synergies)

This last area provides avenues for active involvement in the formative stages of the SKA Project. The SPDO/SKA Project expects industry to approach engagement in a spirit of partnership to achieve a complex and demanding goal, reflecting the inspirational nature of mega-science projects, whilst achieving a return on its investment commensurate with the risk and funding capacity of a non-defence program.

Reflecting this, industry can expect;

- The SPDO/SKA project to take a 'world-view' of procurement, and to ensure that procurement policies are well researched and harmonised across the SKA Consortia regions and countries. Industry can expect dealings with the SKA Procurement Office to be professional, non-discriminatory, and efficient.
- Price enquiry processes to be impartial, diligent, and recognise actual and potential capability, and not result in early elimination of potential suppliers. Industry can expect that weightings applied as a result of any juste-retour, and capacity building policies will be applied evenly, and that due notice is taken of offerings that support strategic (win-win) collaborations, and generation of potential intellectual property.
- Offerings that include added value pathways to 'spin-off' benefits and legacy capability to be recognised.
- To be encouraged and welcomed when offering (without prejudice) price estimates, resources for teaming, knowledge sharing, lobbying, and promotion of the SKA for long-term benefits. Pre-contractual discussions concerning costs will be in a setting that avoids potential for 'lock-out'.

The SKA program's communication strategy will also include:

- Consultation (where necessary or beneficial) with industry to derive or validate pricing information.
- Provision of information and facilitation of project briefings to industry in order for local/global suppliers to have adequate time to identify and price potential opportunities.

[11] Industry Engagement Strategy – SKA Document Suite. http://www.skatelescope.org/pages/main_eng.htm

- Early release of indicative technical specifications to permit industry to begin research and development of detailed proposals.
- Regular updates to the SKA internet sites (www.skatelescope.org).
- Contribution to any SKA Forum website.
- Promotion through media releases and industry publications.
- Posting of public tenders on appropriate websites.
- Undertaking, as appropriate, company visits (to validate capability and capacity) to potential suppliers interested in tendering for major procurements as part of the overall project costing exercise.

The novel design and procurement profile of the SKA requires price testing in the market at three levels;

i) High level engagement to discover new technologies or industrial information at the concept level.

Information from industry about cutting-edge solutions, new designs and production innovation are welcomed by the SKA project. Such approaches could be initiated by the SKA Project or industry and should be covered, where appropriate, with a Non-Disclosure (Confidentiality) Agreement (NDA). Industrial technical information coming from the pathfinders/precursors is also an important input for the work of WP2 in providing a costed design.

ii) R & D contracts for prototyping & design

The project office will issue a specification for pricing (drafted by the technical domain), normally using an output specification, and encouraging innovation and emerging technologies.

iii) Global price enquiries for COTS requirements

The project office will issue a specification (drafted by the technical domain), and encourage innovation and emerging technologies. The SKA project office procurement department will manage the receiving of pricing information, liaise with the technical domain, and manage approvals.

iv) ‘In-kind’ contributions of personnel, tools, technical services, or other resources

Offers of ‘no-cost’ support from industry are generally welcomed as strategic support for the SKA project and with the goal of a win-win outcome. Such approaches must be approved by the SKA project office. All in-kind support of this nature must be transparent to all stakeholders.

6.3.1 Confidentiality considerations.

As signatories to SKA ICA-2007, the parties are (amongst other things) expected to;

maintain confidential all confidential information, whether made/developed alone or in collaboration with other Parties, or acquired through discussions (whether formal or informal) with members of the SKA community, or Third Parties where the Party is aware or should reasonably be aware that the information was obtained subject to an obligation of confidentiality. Enable non-disclosure instruments for this purpose.

Nondisclosure agreements sometimes called NDAs or confidentiality agreements are contracts intended to protect information considered to be proprietary or confidential. Parties involved in executing an NDA promise not to divulge secret or protected information disclosed during employment or other business transactions. Should one of the parties to an NDA use protected information without authorisation, a court can stop the violator from making any further disclosures and may award monetary damages.

The SKA Program Development Office (SPDO) will seek costing information from open sources, and also from suppliers and member institutions. Suppliers (and possibly SKA member institutions) may require that commercial prices and trade terms for quoted or purchased goods and services remain confidential. Similarly, an Institute may have computed costs for subsystems, possibly involving their own labour, and agree to give these data to the SPDO. In such cases, an NDA may be implemented in one of the following arrangements:

The supplier may required an NDA between themselves and the SPDO[12]

The Institute may require an NDA between themselves and the SPDO

If a member institution wishes to pass on pricing information to the SPDO, and that information is itself the subject of an NDA between that institution and the supplier, then:
The SPDO can become a signatory to that NDA, or; the NDA could permit the passing of costing information to the SPDO exclusively (possibly under strictly defined conditions).
The signing authority for NDA's on behalf of the SPDO currently constitutes the SPDO Director, and the Head of School, Jodrell bank Centre for Astrophysics, University of Manchester. Should the legal entity of the SPDO, or its successor organisation change, the signing authority will need to be reviewed, however the binding nature of NDA's means that the obligations for the signing parties are likely to remain in force for the period of the NDA.

6.4 Data Collection and Source Verification

The SEMP describes the process of design reviews. At these design reviews costing information will be presented by the design groups. The aim for cost information delivered at the design reviews is that it will be complete as possible and will be documented to provide evidence for cost estimates. Good documentation will support the credibility of cost estimates for SKA systems and sub-systems. It will aid in the analysis of changes in program cost and enable reviewers to effectively assess the cost estimate. A cost estimate should be sufficiently complete and well organized such that a cost estimating professional can use the documentation by itself to understand and assess the estimate. At the outset of the project and mainly due to uncertainties and unknowns, confidence in cost estimates might be quite low. As the project moves forward the aim should be to refine and improve confidence in costing estimates. Cost estimates to be included as part of the WP2 cost estimate will have an associated Basis of Estimate Confidence Level (BECL) rating attached to it. This should improve as the design process proceeds.

The costing analysis should include as many of the cost components described in the cost coverage list in Figure 11 as are applicable to the system in question. Not all items on the list will be applicable

[12] *SPDO means the current organisation hosted by the University of Manchester, and any subsequent legal entity established for the purpose of design, costing, prototyping, and constructing the SKA.*

in all cases. The contributing groups will indicate what is and is not applicable in their area of interest. This will provide information, in addition to the Basis of Estimate Confidence Level Rating, on the confidence associated with cost estimates. The cost estimates provided as part of the design process in the SKA will be closely examined for their comprehensive coverage of cost components, quality of supporting documentary evidence and, as a result, their credibility. The process of verification of cost estimates will be undertaken in an objective manner. The existence of the processes defined in this strategy will support this approach.

6.4.1 Basis of Estimate Confidence Levels (BECL)

There will be 5 levels of confidence defined as part of the basis of estimate, with the level having the least confident estimation basis being 5 and the level with the most confidence being 1. The expected range of actual cost outcomes compared with estimated costs will reduce with each order of basis of estimate confidence level. The costing strategy manager at the SPDO will administer the basis of estimate system.

Upon receipt of costing estimates from contributing groups the domain specialist, in consultation with the costing strategy manager and project engineer, will assign a BECL value based on the associated levels of documentation required for each level. This rating will rely heavily on the supporting information and documentation underpinning the particular cost estimate. Figure 12. provides details of the BECL ratings .

Where a scaling factor has been used to extrapolate between a known price and an estimated price the suffix F will be added to the BECL rating as in indicator. This might happen, for instance when using small quantity pricing to estimate large quantity pricing or in order to estimate future prices based on historical price performance. When scaling has been used a description of the scaling and justification of its use should be included in the accompanying documentation. Examples of such documentation might be technology roadmaps supplied by technology companies.

The accuracy of a cost estimate for the SKA will be dependent upon both the estimate of cost per item and the number of items required. The BECL rating will also therefore depend upon the maturity of the overall system and sub-system design. As the project progresses design reviews will be undertaken in order to peer review SKA plans. As these reviews are passed, so the confidence in the design will grow and the risk associated with estimated quantities will diminish, as will the BECL.

Figure 12 Description of the Basis of Estimate Ratings

BE #	Description	Documentary Evidence	Minimum requirement for confidence in quantities.
BECL5 (F)	Lowest BE rating. Costs based on anecdotal evidence and best guess scenarios. Undeveloped specifications and technology under design.	Expert opinion,vendor target prices or historical prices from analogous projects. Description of scaling laws used in estimates.	Concept Design Phase. System and Domain Conceptual Design Review undertaken. (CoDR)
BECL4 (F)	Technical specifications in rough draft stage. Costs either anecdotal or best guess. Quantities reasonably well known. All aspects speculative but at a mature stage of discussion within the group. Schedules, contracts, risk plans all in progress. Relationships with potential suppliers under development.	Vendor written estimates,quotes requested without competitive tender or historical prices from analogous projects. Description of scaling laws used in estimates.	Definition Design Phase. System and Domain Requirements Review Undertaken. (SRR)
BECL3 (F)	Technical specifications under peer review. Costs obtained from reliable sources and reiterated several times. Quantities known to high degree. Designs finalized and agreement reached on implementation modes. Costs and methodologies accepted throughout the group. Risk mitigation plan in place awaiting approval.	Quotes requested without competitive tender, catalog prices or historical prices from analogous projects. Description of scaling laws used in estimates.	Preliminary Design Phase. System and Domain Critical Design review undertaken. (CDR)
BECL2	Technical Specifications finalized. Schedule of delivery finalized. Quantities finalized. Contractual arrangements being concluded. Variations unlikely. Integration into system known, documented and costed. Associated labour costs known. Logistics of supply and delivery known and costed. Costs Corroborated by at least one other peer in the group. Risk mitigation plan approved	Quotes for supply under competitive tender. The use of scaling laws to estimate costs is not acceptable at this stage.	Detailed Design Phase. Domain Pre-production design review undertaken. (PR) System Critical Design review undertaken. (CDR)
BECL1	Highest BE rating. Meets all of the requirements for BE2. Corroborative evidence from actual costs incurred elsewhere (Precursor) .Supply contract firm. Variation possibilities very limited or Zero. Labour rates firm for 12 months. Schedule and Risk quantified.	Contract signed. The use of scaling laws to estimate costs is not acceptable at this stage.	Fabrication & assembly Phase. Contract tender quantity.

6.5 Analogous Costing

Analogous costing exercises are an important source of information for cost estimates. Analogous costing can be used to substantiate hardware cost estimates based on historical prices obtained from previous or analogous projects. The use of analogous costing information is particularly important when considering project overhead costs. It may not be possible to obtain estimates of project overhead costs from by any other method

Whilst it may not be possible to obtain a full range of analogous costing information from SKA precursor and pathfinder projects during PrepSKA as much work in the area as possible will be undertaken with the available resources. In the subsequent phases of the project the collection and analysis of analogous costing data will continue.

6.6 Software Development Cost Estimation

The estimation of software development costs differs from the estimation of hardware, infrastructure and services costs in some fundamental ways and therefore deserves a special mention. Software development is mainly labour intensive, and all the tasks associated with developing it are nonrecurring—there is no production phase. That is, once the software is developed, it is relatively simple to produce a copy of it. To a first order analysis the cost to develop software depends on a few basic elements—the nature of the software to be developed, the development effort to accomplish it and the schedule for delivery.

Software development technologies change constantly, making it difficult to collect good data for cost estimating. The software industry does not have a long history of successful cost estimation. Never the less a credible estimate of software costs for the SKA is required. The first steps in this process are the definition and scope of the requirements for SKA software. Project teams in the domain of software and computing are engaged in defining these requirements and a WBS[13] for this area has been established. As in other domains, as the software design matures so will the cost estimates.

Software development costs for the SKA will be estimated by first estimating the size and complexity of the problem space. Once a set of requirements have been defined then software cost estimation models can be applied in order to estimate labour costs, based on these requirements. A minimum of two models should be applied to the problem. This reflects the fact that no two models will produce exactly the same answer for the same problem. There is therefore a need to obtain a number of sources of cost estimates based on the definition of the requirements and the data available to the cost estimator. In addition, any costs of tools, software licence fees, third party resources, hardware required for pre-production work and so on will be included. However, in almost all cases the cost of labour will predominate over these other costs.

There are a number of models and methods available for estimating the costs of software development. Which model is applicable in each case will depend on the information available to estimators and their prior experience in cost estimation of this type. A document "Cost Estimation for Software"[14] has been published which describes in detail the background to this work. The first

[13] WBS Software and Computing - WP2.6_WBS_07
http://wiki.skatelescope.org/pub/SoftwareComputing/WebHome/20100322_WP2.6_WBS_07.pdf
[14] Cost estimation for software -
http://wiki.skatelescope.org/pub/SoftwareComputing/WebHome/20100416_Cost_estimation_for_software_RevB.pdf

approaches that come to mind when speaking about software cost estimation are the parametric models, which emerged in the 1980s and before, such as the Constructive Cost Model (COCOMO) or the Software Lifecycle Management (SLIM). These models take into account factors or cost drivers related to the domain, the environment, and the constraints of a project to transform an estimate of size into an estimate of person-months, or team size and duration, hence leading to cost. These models are calibrated using data collected across ranges of projects.
Recognising that models already exist to model the software development costs, such as COCOMO and SLIM. Software development costs will not be included in SKACost. The responsibility of providing these costs into the overall system cost will reside with the domain specialist for software. The responsibility to ensure both SKACost and software development cost modelling deliver costs to the same telescope description resides with the system. Consistent mechanisms for the description of telescope scenarios and robust processes are needed at the system level in order to ensure that, models generating software development costs and those in SKACost generating hardware costs, remain consistent with one another in both the timing of delivery and the description of the system they are modelling.

The values used within the models should be defined and justified, along with the cost estimate. In particular a description of the source of any historical data used and the values of productivity assumed in assembling the cost estimate should be stated. For the purposes of cost estimation of software, for Phase 1 SKA, a delivery date of 2017 should be used.

7 SKACost and Cost Modelling

7.1 Introduction

A model for the SKA will be established in conjunction with the SPDO and developed into a telescope model using SKACost. The design blocks included in the model will include cost scaling laws developed by the design groups in conjunction with the domain specialists at the SKA Programme Development Office (SPDO). Modelling of this kind has been shown necessary for costing the SKA. Other methods of developing system costs, such as spreadsheets, have been shown unsatisfactory for parametric modelling of a system of this level of complexity. Spreadsheets will support the generation of point estimates and the identification of large component costs. Following the design process SKACost modelling will iteratively refine the model of the SKA, starting at a high level at first and gradually increasing in detail and complexity. SKACost has the ability to model to the component level. The aim in PrepSKA is to develop a controlled model to sub-system level and to subject this model to peer review from community experts. In this way at the end of PrepSKA users will have confidence in the tool, the model and the scaling laws therein. In conjunction with the collection of cost estimates from the design groups this tool will provide the means to analyse the costs of the SKA. In addition, the modelling work undertaken in PrepSKA will provide the groundwork for subsequent cost performance tradeoffs to be undertaken in refining a design for the full SKA, as well as for examining the cost effects of design or requirement changes.

Software development costs will not be included in SKACost. This reflects the fact that models already exist to model the software development costs, such as COCOMO and SLIM. The responsibility of providing these costs into the overall system cost will reside with the domain specialist for software. The responsibility to ensure both SKACost and software development cost modelling deliver costs to the same telescope description resides with the system. Consistent mechanisms for the description of telescope scenarios and robust processes are needed at the system level in order to ensure that, models generating software development costs and those in SKACost generating hardware costs, remain consistent with one another in both the timing of delivery and the description of the system they are modelling.

7.2 Objectives

SKACost model consists of two parts. 'The Engine', which is the software upon which the model is based and 'The Model', which is the design blocks and cost scaling that define the telescope.

SKAcost model will deliver a qualified telescope model at the end of PrepSKA. The model will be used by expert users at the SPDO to cost Phase1 SKA, as a priority. Furthermore it will enable the costing of changes, upgrade paths and future Phase 2 telescope designs. This model will encapsulate technical designs, including upgrade paths. It will have a verified and validated engine and design blocks. It will be fully documented and the process of verification and validation will be logged.

7.3 Approach

The SKACost development will be broken down into 3 parts;

- Part 1. Preparation
  - *The Engine:* SKACost v.1 software will be validated and documented.
  - *The Model:* Top Level design block models will be defined. Building blocks will be developed based on the System hierarchy described in the SEMP, concentrating on full coverage of cost components. These building blocks will be documented and verified.
- Part2. SKACost design for Phase 1.
  - *Engine:* On-going support and bug fixes
  - *Model:* Building blocks will be developed based on Phase 1 SKA design. Concentrating on full coverage of cost components. These building blocks will be documented and verified.
- Part 3. SKACost representative design for Phase 2
  - *Engine:* On-going support and bug fixes
  - *Model:* Building blocks will be developed based on all options for a Phase 2 SKA design. Concentrating on full coverage of cost components. These building blocks will be documented and verified.

Each project part will culminate in a review, a documented model and a report or cost analysis of a system built within the model. The cost estimates used within the model will be generated and collected externally and will be an input to the modelling work. This process is illustrated in Figure 13.

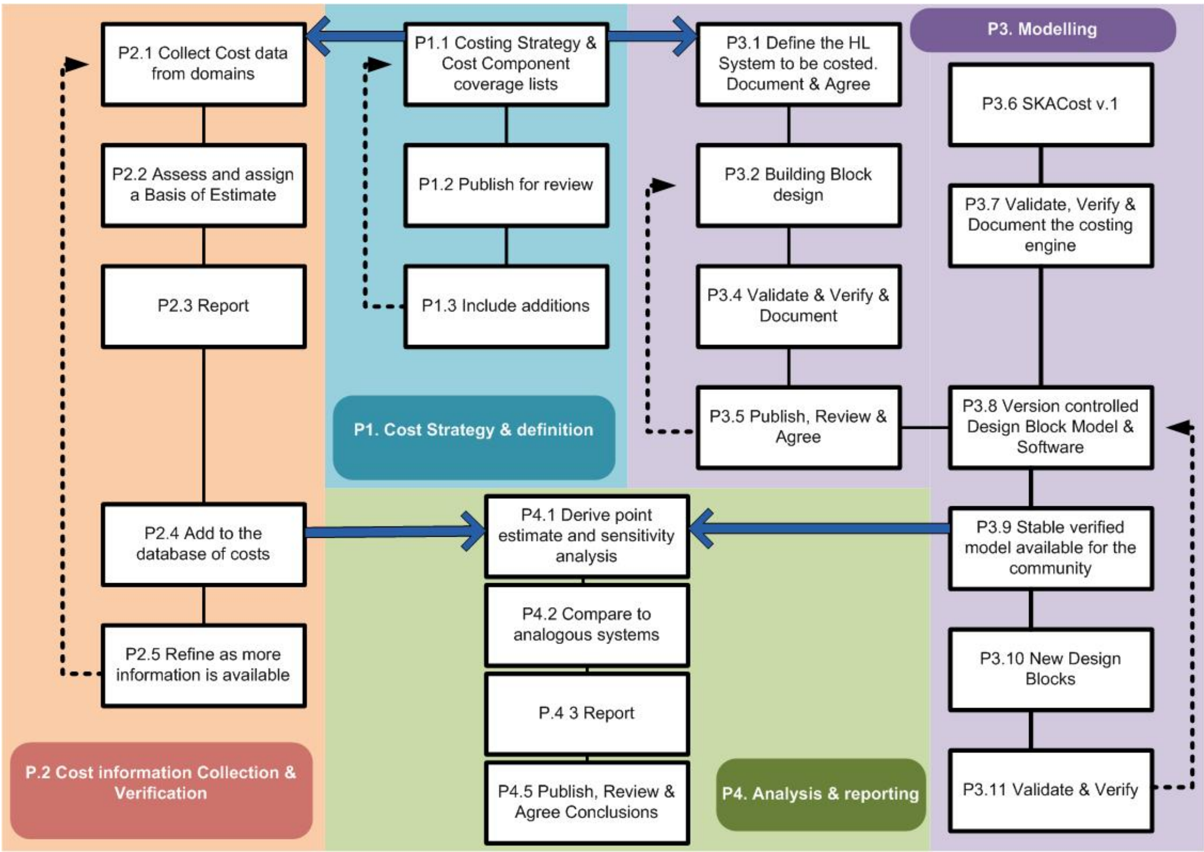

Figure 13 Cost Strategy Process.

The SKA Cost Modelling work is highlighted in purple in section 'P3. Modelling'.

The SKACost telescope models will be made available to the SKA community for use. However, only the SPDO model will be under formal review and control. For this reason it will be necessary to differentiate between cost analysis undertaken using the controlled model and analysis using an uncontrolled version of the software. The SKAcost models will be described as either:

- **SPDO models**: a model which has been through the documentation, verification and validation process.
- **Local models**: a model that an external contributor has developed. For the purposes of the project it is considered uncontrolled. Local models can feed into the SPDO model once it has been documented, verified and validated.

7.4 Plan, Roles and Responsibilities.

The project plan for SKACost Modelling work is shown in Appendix 2. Figure 14. provides a description of the tasks involved in the project plan and the responsibility for the delivery of those tasks.

Gant chart ID	Description	Inclusive tasks	Responsibility
2	SKA Cost requirements review	Review existing documentation Can a 10 year cost of ownership be included? Expand if necessary Complete requirements documentation	UCAM

3	SKA Cost Model requirements review	Review existing document sources Plan high level model based on SKA system Include how to include full cost coverage Can a 10 year cost of ownership be included? Document SKACost Model	SPDO
4	SKA Cost Process review	Review existing documentation Expand if necessary Complete Process documentation	SPDO
5	SKA Cost Project review	Agree Objectives Agree Plans & timescales Agree Responsibilities	SPDO
8	SKACost Engine	Engine - verification Engine - validation Engine - documentation Engine - publish documentation on SKAwiki	UCAM
9	SKA Cost Model	Model - build blocks Model - verify blocks Model - validate blocks Model - document blocks Model - publish blocks documents SKAwiki	UCAM
10	SKA Cost support	Model- validate blocks	SPDO
13	Obtain Phase 1 System design		SPDO
14	SKA Cost Phase 1 Model	Plan blocks for implementation Instigate cost estimation process Model - build blocks Model - verify blocks Model - validate blocks Model - document blocks Model - publish blocks documents SKAwiki	UCAM
15	SKA Cost Model Support	Model- Validate Blocks	SPDO
16	Accumulate cost information and assess	Accumulate cost estimates Assess cost estimates	SPDO
17	Input costing info into model	Input into the model SKA Phase 1 Cost analysis Document SKA Phase 1 Cost analysis	UCAM
18	Support analysis & documentation	SKA Phase 1 Cost analysis Document SKA Phase 1 Cost analysis	SPDO
21	Obtain 'maximal' system design		SPDO
22	SKA Cost Phase 2 Model	Plan blocks for implementation Instigate cost estimation process Model - build blocks Model - verify blocks Model - validate blocks Model - document blocks Model - publish blocks documents SKAwiki	UCAM
23	SKA Cost Model Support	Model- Validate Blocks	SPDO
24	Accumulate cost information and assess	Accumulate cost estimates Assess cost estimates	SPDO
25	Input costing info into model	Input into the model SKA Phase 1 Cost analysis	UCAM

		Document SKA Phase 1 Cost analysis	
26	Support analysis & documentation	SKA Phase 1 Cost analysis Document SKA Phase 1 Cost analysis	SPDO

Figure 14 SKA Cost modelling task list and responsibilities.

There are a number of users contributing to the modelling of telescope designs:

- *Cost Strategy Manager:* Prime contact for cost related matters at the SPDO.
- *Domain Specialists*: Who will develop the design blocks.
- *SKACost Model Lead*: Prime contact for SKACost Model related matters in the lead institution.
- *SKACost Model team:* Expert users who will support the domain specialists to develop design blocks.
- *External contributors*: these are people outside of the SPDO who build telescope designs using SKAcost, and wish to contribute these models to the SPDO. Currently, Cambridge and ICRAR are the only such contributors.

Appendix 1. provides a contact list of those undertaking the roles described above. This list will be maintained to ensure that information is up to date.

7.5 Communications and Reporting

Those involved in developing the SKACost engine and the telescope models will be invited to a monthly teleconference. There will be face to face meetings on a 6 monthly basis and review meetings, as described in the project plan in Appendix 2.

The aim in PrepSKA is to develop a controlled model to sub-system level and to subject this model to peer review from community experts. In this way at the end of PrepSKA users will have confidence in the tool, the model and the scaling laws therein. An SKA wiki site 'SKACosting' has been set up in order to provide a repository for SKACost model documentation available for review. SKACosting[15] is available to all those users who have access to the SKAwiki. The SKACost Model team have a site for internal project discussion documentation – SKACostingInternal[16].

7.6 The SKACost Engine and the SKACost telescope model

SKACost, described in detail in SKA Memo 120, provides a framework in which hierarchical telescope designs can be systematically encoded and costs, power, data flow, and other resource requirements can be calculated.

Within the tool, a sharp division is maintained between the costing engine - the software used to calculate the numbers of components needed to build an SKA to a particular specification - and the telescope designs which it acts upon. This separation ensures that cost calculations are performed in a homogeneous way between all design blocks, since they must all use the same costing routines. The accuracy of any costs calculated by the tool will depend primarily on uncertainties in the models used, rather than on the engine itself.

Within the hierarchical telescope designs that the tool acts upon, large design blocks (for example, the whole SKA) subdivided into smaller units (for example, SKA AA Stations) until eventually the

[15] SKACosting wiki page @ http://wiki.skatelescope.org/bin/view/SKACosting/WebHome
[16] SKACostingInternal wiki page @ http://wiki.skatelescope.org/bin/view/SKACostingInternal/WebHome.

hierarchy reaches indivisible atomic units which referred to as components. This hierarchy can have an arbitrarily large number of intermediate levels, and the number is likely to increase as models are refined and increasing levels of detail are added to initially simple models. Each design block acts as a black box, taking some inputs that are used to calculate relevant quantities, to order sub-blocks or components of an appropriate type and number and to pass further inputs to “child” blocks further down the hierarchy. The calculations within each design block may be as simple or complicated as required and the black box approach means that design blocks can be easily replaced with more sophisticated, or more accurate models as these are developed. Similarly, at the component level, it is trivial to switch from using one component to another in order to compare the cost and power requirements, and to update costs and BECLs as these mature. Design blocks can be reused in multiple places in the hierarchy, and can be called with different inputs each time.

A key feature of SKAcost is that these hierarchical telescope designs are scalable; they do not merely represent a single telescope built to a particular specification, but rather take a wide range of input parameters, and within reasonable limits, can estimate what components would be required to build a telescope to any requested specification.

7.7 The SKA Model

SKACost will be used in the SKA cost modelling work, and therefore the appropriate models must be generated. These hierarchical structures mapping to the SEMP hierarchy and more detailed sub-structures will be developed in conjunction with the SPDO. The models will be based on the system hierarchy shown in figure 15. The SKACost model team will then translate these data into a model that SKACost can interpret. In order that the SKACost model and system hierarchy track each other, the SKACost telescope model will adopt the same version number as the SEMP hierarchy.

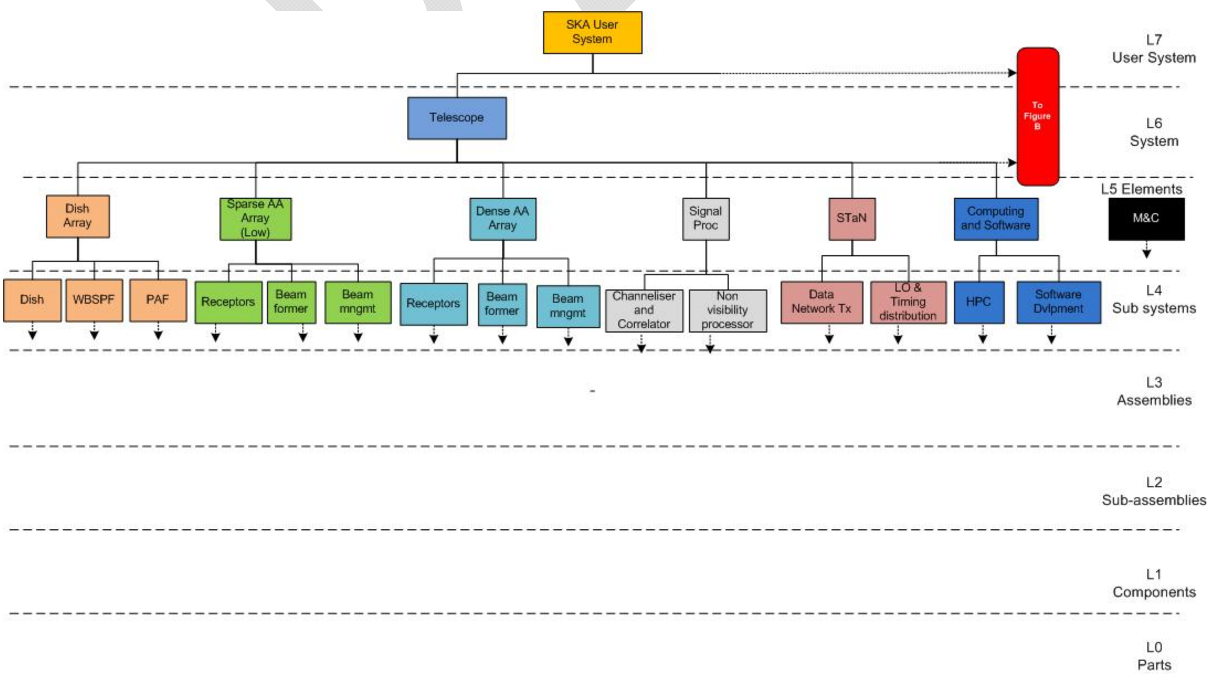

Figure 15 System hierarchy block diagram for use in the generation of design blocks

7.8 Analysis and Output

When analysis derived from SKACost is published the telescope model used should be identified as either, **SPDO models**: a model which has been through the documentation, verification and validation process or **Local models**: a model that an external contributor has developed. For the purposes of the project it is considered uncontrolled.

The ambition is that regular updates of costing work will be published on the SKACosting wiki page and that costing work will be presented at most of the SKA international meetings.

8 Analysis and Output.

1. Communications

An SKACosting wiki page has been set up as a repository for news and reference documentation for costing. This SKACosting page is available to every user of the SKA wiki[17].

Costing related inquiries can be made through the SPDO costing Strategy Manager who will be the point of contact for costing related matters.

Costing related presentations will be scheduled as part of most of the main SKA PrepSKA international meetings, such as the annual WP2 meeting.

2. Requests for costing

Requests for costing should be made to the SPDO Costing Strategy Manager in writing.

9 Authors

This document has been written by Roshene McCool with contributions from Phil Crosby, Duncan Hall, Tim Colegate, Rosie Bolton and Dominic Ford.

10 Appendices

10.1 Contact Details of Persons Responsible for Cost Estimation Tasks

Role	Name	Organisation	email
Project Director	Richard Schilizzi	SPDO	schilizzi@skatelescope.org
Project Engineer	Peter Dewdney	SPDO	dewdney@skatelescope.org
Project Manager	Kobus Cloete	SPDO	cloete@skatelescope.org
Domain Specialist – Receptors	Neil Roddis	SPDO	roddis@skatelescope.org
Specialist – AA-lo	Jan Geralt bij de Vaate	ASTRON	vaate@astron.nl
Domain Specialist – Signal Transport and Networks	Roshene McCool	SPDO	mccool@skatelescope.org

[17] http://wiki.skatelescope.org/bin/view/SKACosting/WebHome

Domain Specialist – Digital Signal Processing	Wallace Turner	SPDO	turner@skatelescope.org
Domain Specialist – Computing and Software	Duncan Hall	SPDO	dhall@skatelescope.org
Specialist - Power	Peter Hall	ICRAR	peter.hall@icrar.org
Costing Strategy Manager	Roshene McCool	SPDO	mccool@skatelescope.org
SKACost Model Lead	Rosie Bolton	UCAM	rosie@mrao.cam.ac.uk
SKACost Model Team members	Dominic Ford Tim Colegate Gabriel Grigorescu	UCAM ICRAR UCAM	dcf21@mrao.cam.ac.uk tcolegate@ivec.org gabriel@mrao.cam.ac.uk
SPDO Site Engineer	Rob Millenaar	SPDO	millenaar@skatelescope.org
SPDO Manager - Industry Participation Strategy	Phil Crosby	SPDO	crosby@skatelescope.org

10.2 SKACost development project plan

ID		Task Name
1		**Project set-up - Getting organised**
2		SKACost requirements review - UCAM
3		SKACost Model requirements review - UCAM
4		SKACost Process review - SPDO
5		SKACost Project review - SPDO
6		Internal project review
7		**SKACost Project Part 1**
8		SKACost Engine - UCAM
9		SKACost Model - UCAM
10		SKACost Model support - validate blocks - SPDO
11		Project level Review Part 1. progress and outputs WP2 2010?
12		**SKACost Project Part 2.**
13		Obtain Phase 1 system design - SPDO
14		SKACost Phase 1 Model -UCAM
15		SKACost Model support - validate blocks - SPDO
16		Accumulate cost information & assess - SPDO
17		Input costing info into the model, analyse & document -UCAM
18		Support analysis & documentation -SPDO
19		Project level review Part 2.
20		**SKA Cost Project Part 3.**
21		Obtain 'maximal' system design (System CoDR HLD is current sc
22		SKACost Phase 2 Model -UCAM
23		SKACost Model support - validate blocks - SPDO
24		Accumulate cost information & assess - SPDO
25		Input costing info into the model, analyse & document -UCAM
26		Support analysis & documentation -SPDO
27		Project level review Part 3.
28		**6 monthly meeting**
32		**Teleconference**