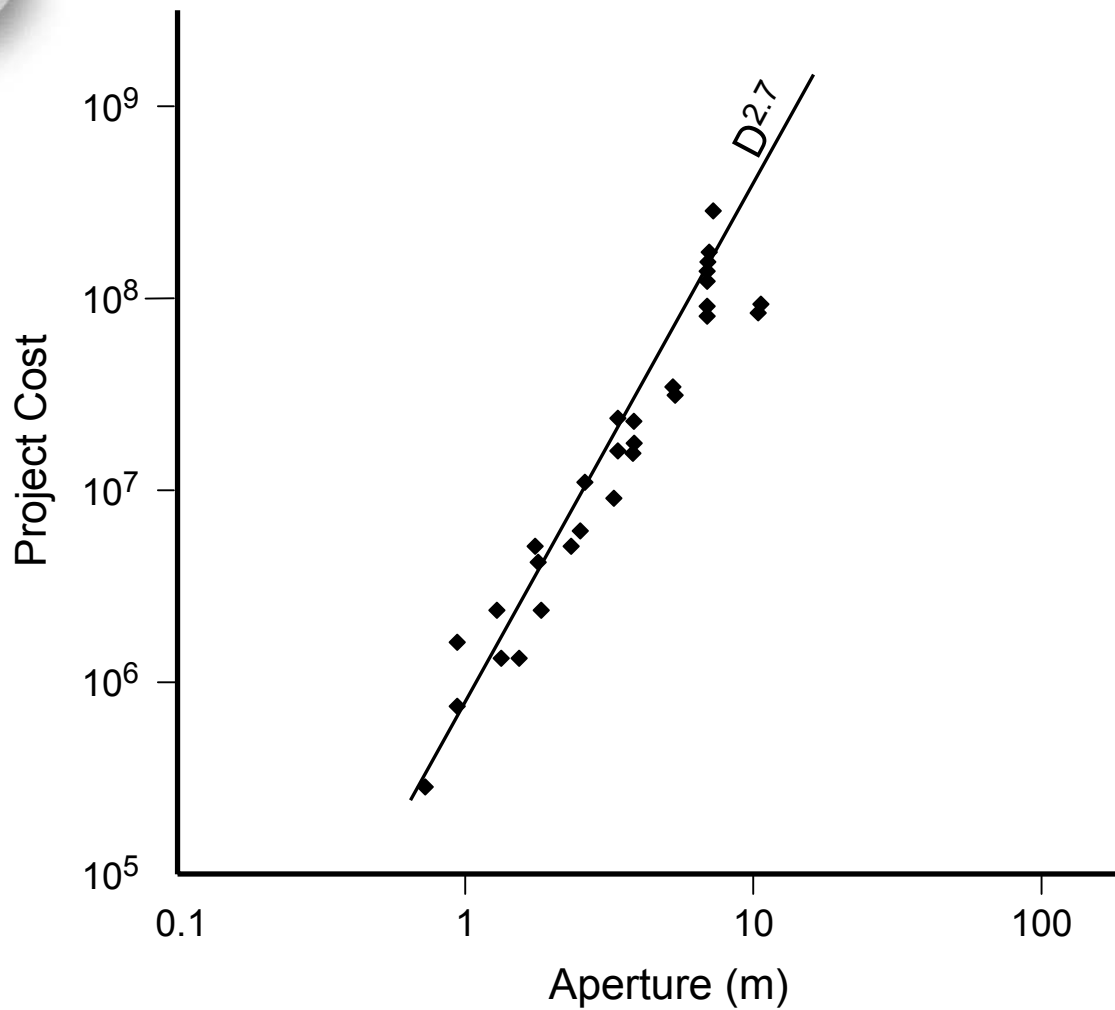


# Estimating the Costs of Extremely Large Telescopes

Larry Stepp, Larry Daggert and Paul Gillett

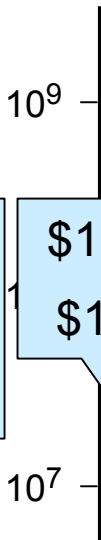
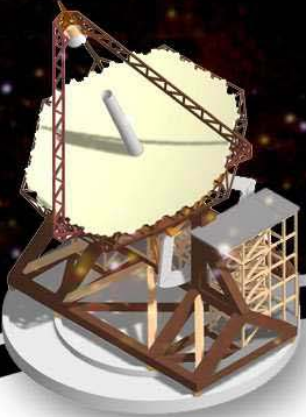
# Scaling Laws

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# Scaling Laws

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\$10.6 M -- 1973  
\$33.7 M -- 1992  
10m ~ \$400 M

\$110 M -- 1992  
\$141 M -- 2002



350 tonnes



270 tonnes



~~\$2.5 B -- 2002~~

# Life-cycle Costs

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Typical yearly expenditures of large observatories:

- Operations: 3% - 6% of construction cost
- Upgrades: 3% - 5% of construction cost
  - New instruments
  - Adaptive optics
  - Etc.

Over ~ 30-year lifetime, = 2 to 3 times construction cost

# Cost Control

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Control of life-cycle cost is the most important factor in success of an ELT

- But, we need to control costs in a manner that *maximizes scientific performance*
- Best way to do this is Design to Cost

# Design to Cost

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- Cost is considered a design variable in the trade space that includes performance and schedule
  - “Cost As an Independent Variable” (CAIV)
- Value Engineering
  - Discipline of reducing LCC while preserving essential performance
    - Emphasize primary functions
    - Consider many alternative designs
    - Simplify designs and operational modes
  - Requires understanding of what constitutes value to the customer



# Quantitative Measures of Performance and Cost

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1. Need to quantify science value:
  - *Scientific merit functions*
2. Need to predict telescope performance in presence of disturbances:
  - *Integrated modeling*
3. Need way to predict cost of multiple design options:
  - ?



# Scientific Merit Functions

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- Traditional approach to defining science requirements:
  - Performance requirements for each observing mode are set in wish-list manner
  - Requirements are collected from all the observing modes
  - Specifications are based on most demanding requirements
- This is essentially a “contractual” approach; descoping takes semi-formal approval
- This doesn't lend itself to the performance/cost trades of Design to Cost approach



# Scientific Merit Functions

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- To evaluate design trades in terms of performance/cost requires a quantitative expression of scientific value
- For each observing mode / instrument capability define a scientific merit function (SMF), based on:
  - SNR
  - Multiplexing
  - Timeliness
  - etc.
- Scientific value is summation of SMFs x weighting functions x time allocation:

$$\text{Scientific value} = \sum W_i * T_i * \text{SMF}_i$$



# Integrated Modeling

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- The distinguishing feature of “integrated” modeling is that it incorporates active control
  - Can include:
    - Structural models
    - Optical models
    - Thermal models
    - Fluid dynamics models
  - Incorporates:
    - Actuators
    - Feedback sensors
    - Disturbances

# Integrated Modeling

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- Used to predict the performance of a given design in the presence of disturbances
  - Performance can be evaluated statistically, in terms of probability of occurrence
- Each SMF is evaluated based on the calculated system performance
- The effect of a design trade on the SMFs can then be determined

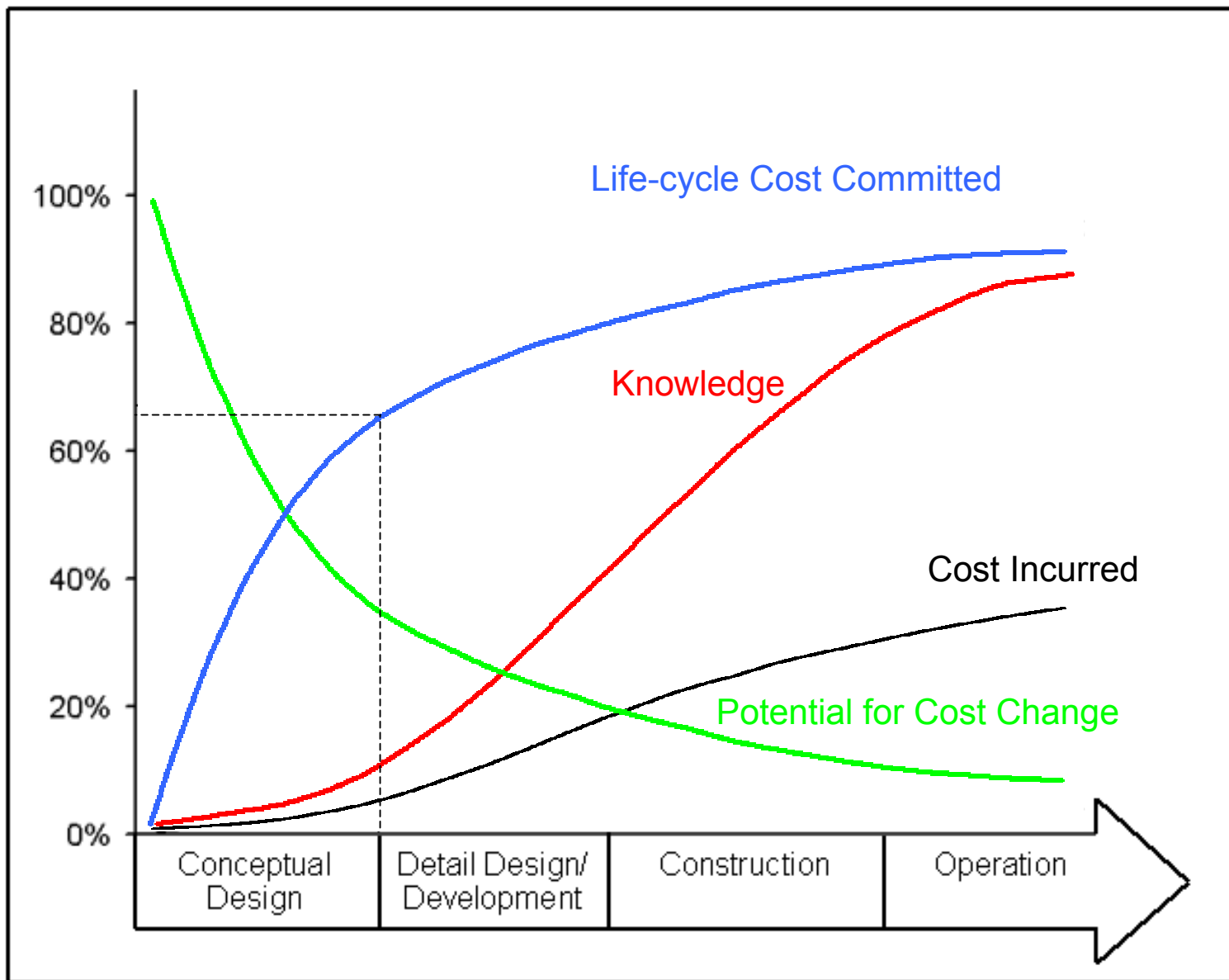
# Applying Design to Cost

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Need to implement Design to Cost as early as possible



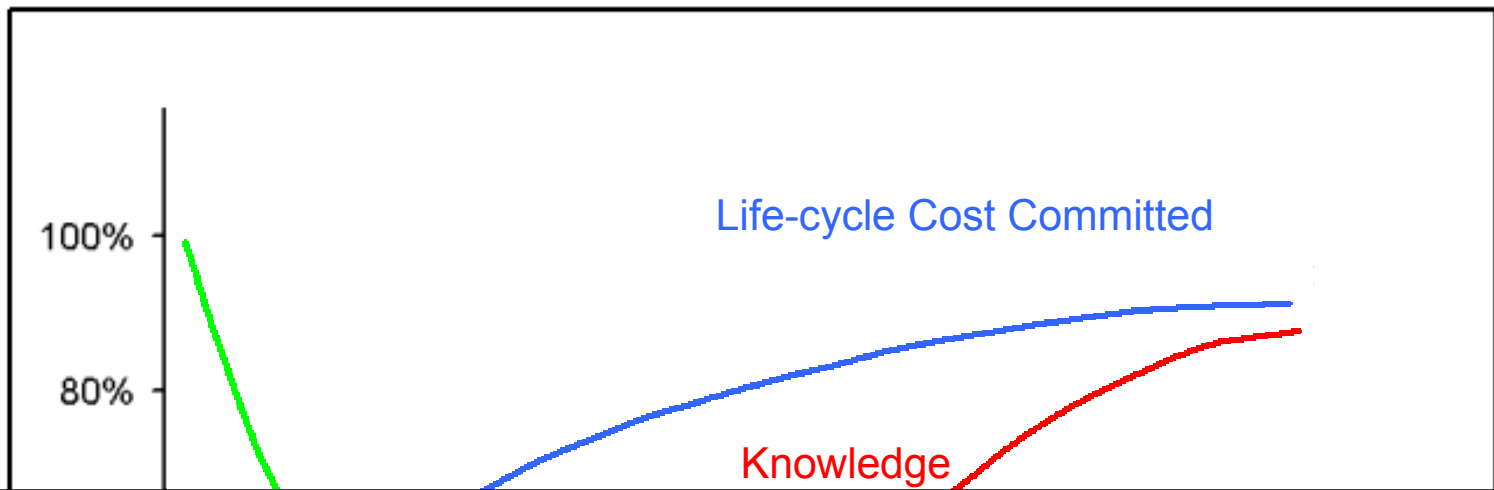
# Applying Design to Cost



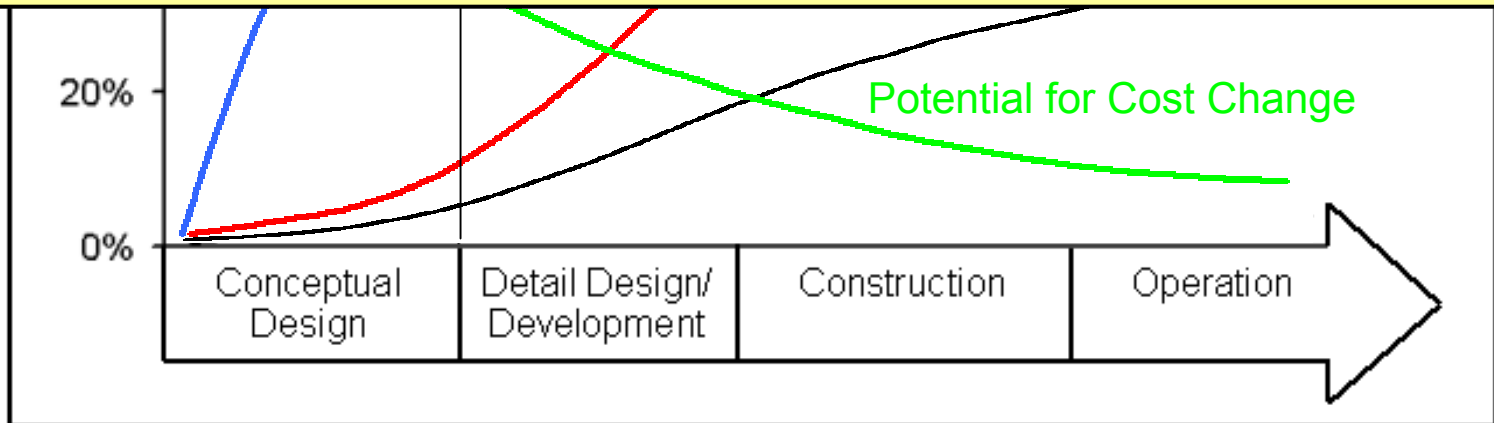
Adapted from presentation by Joseph Hamaker



# Applying Design to Cost



Applying Design to Cost requires more effort in the conceptual design phase (typically ~ 20%) but since D&D phase is typically ~ 5% of LCC, the increase in total cost is ~ 1%, while the savings can be large



Adapted from presentation by Joseph Hamaker



# Dilemma:

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How do you make key Design-to-Cost decisions early in the project, before you have detailed designs on which to base cost estimates?

# Cost-Estimating Methods

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## Top-down methods

- Expert opinion
- Analogy
- Parametric

- Also called a WAG
- Used when no other method is available
- Credibility depends on experience and independence of expert

## Bottom-up methods

- Industrial Engineering
- Parametric

# Cost-Estimating Methods

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## Top-down methods

- Expert opinion
- Analogy
- Parametric

- Based on actual cost of similar programs
- Usually require some adjustment
- Accuracy depends on similarity between programs

## Bottom-up methods

- Industrial Engineering
- Parametric



# Cost-Estimating Methods

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## Top-down methods

- Expert opinion
- Analogy
- Parametric

## Bottom-up methods

- Industrial Engineering
- Parametric

- Based on historical data
- Relationships between cost and measurable parameters are determined by regression analysis
- Can estimate project cost based on key parameters



# Cost-Estimating Methods

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## Top-down methods

- Expert opinion
- Analogy
- Parametric

## Bottom-up methods

- Industrial Engineering
- Parametric

- Based on detailed design:
  - Catalog prices
  - Vendor quotes
  - Material costs
- Accurate but time-consuming

# Cost-Estimating Methods

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## Top-down methods

- Expert opinion
- Analogy
- Parametric

## Bottom-up methods

- Industrial Engineering
- Parametric

- Can also be used to estimate cost of main component systems
- Well suited to evaluate effects of design changes

# Instruments

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- Facility-class instruments for 8-10 m telescopes have had problems with cost and schedule -- Adrian Russell study:
  - Average cost overrun 100%
  - Average schedule overrun 160%
- Instruments 10% - 20% of telescope construction costs
- Instrument upgrades ~ 3% of TCC per year
- Need improved project management techniques
  - Instrument-building organizations are collecting historical data to improve cost estimating

**Paper describes instrument cost-estimating lessons learned and bottom-up parametric estimating methods**



# Quantitative Measures of Performance and Cost

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1. Need to quantify science value:
  - *Scientific merit functions*
2. Need to predict telescope performance in presence of disturbances:
  - *Integrated modeling*
3. Need way to predict cost of multiple design options:

*Parametric Cost Estimating*  
**To assess the performance and cost impact of the design trades without delaying the project, these analytical tools need to be developed in advance.**



# Cost-Estimating Capability

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- Design to Cost must be a key part of systems engineering for any ELT project
- We are entering a new regime, where *auditable* cost estimates will be required to attract funding
  - Aerospace companies, DoD and NASA have full-time cost estimating staffs
  - Ground-based astronomy has none
- We need to develop our cost estimating capability
  - Train / recruit staff
  - Collect historical data
  - Develop CERs

# Collaboration

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This is an excellent area for community-wide collaboration.