13 Reasons a Cost Estimate during a Concurrent Engineering Study could go wrong

Processes & Best Practices Track (PB02)
2020 ICEAA Professional Development & Training Workshop
via Webinar, 3 June 2020

Andy Braukhane
Outline

Part I: Introduction

- Short Biography
- What is DLR?
- Concurrent Engineering (CE)
  - Process
  - Definitions
  - Other facilities
  - Our process
- CE Centers
- Cost Engineering in CE

Part II: 13 reasons...

1. Wrong expectations
2. Team
3. Tools
4. Specific cost
5. Use of margins
6. Heritage & complexity
7. Lack of time
8. Lack of data
9. Rapid data changes
10. Data disconnection
11. Bottom up
12. Optimizing wrong place
13. Relevance / acceptance

Part III: Summary & Conclusion
Who is that person talking to you?  
What has he done (or not) so far?

- By education
  - Aerospace & Systems Engineer

- Working in the DLR CEF “for ages”,
  - as Systems Engineer,
  - Study Team Leader,
  - Cost Estimator/Analyst.

- Involved in projects such as:
  - DLR MASCOT Lander
  - DLR Compact Satellite
  - DLR Post-ISS study
  - ESA Science mission studies

- Interested in processes & human aspects

CEF = Concurrent Engineering Facility
German Aerospace Center (DLR)

CEF = Concurrent Engineering Facility

Institute of Space Systems

CEF

AI Sat
Eu: Cropis
MASCOT
Concurrent Engineering (CE)?

What is CE (in space)?
- systematic (& guided) process,
- parallel and iterative work,
- clear share of responsibilities
- very suitable for early project phases

Why?
- To design and develop complex and/or “one-of-a-kind” systems
- To involve everyone by structured communication “from Day 1”
- To converge fast & efficiently during the product development process

BENEFITS of CE
- Reduces time & cost
- Increases consistency
- Decreases mistakes
- Mutual education

Source: e.g. TSTI

Adapted from: ESA
Concurrent Engineering (CE) at DLR

How?

• By making best use of:
  ✓ People/Team
  ✓ Process
  ✓ Infrastructure
  ✓ Data Model
Concurrent Engineering/Design Centers

Source: Martelo Gomez, A., Quantius, D., Engineering Facility - CE facility and process at DLR, 2019
Concurrent Engineering approaches

@ DLR - CEF

@ ESA - CDF

@ NASA - Team X

~1 week

end of activity / major review

CE session

quite dense

very efficient
Cost Estimation in (DLR) CE-Environment

• **Goal:**
  - To provide a realistic and robust cost estimate considering all programmatic and technical options and constraints.

• **Working Rules** (for all domains)
  - Start simple, iterate, detail, improve
  - Communicate, understand, educate

• **Design model for data exchange**
  - DLR’s “Virtual Satellite”

• **Cost Estimator tool box includes:**
  - Small Satellite Cost Model (SSCM)
  - TransCost 8
  - CERs & factors (formerly used) from
    - SMAD, New SMAD, USCM, QuickCost, AMCM, SVLCM
  - T1/Flight unit equivalent approach
  - Lately also:
    - NASA PCEC, MOCET (xls-based)
    - SEER for Space (commercial)
    - WBS-based “bottom-up” templates

Me (again..), trying to figure out the cost of a new, lean, low-Earth orbit „space station“

(DLR Orbital Hub)
Wrong Expectations (#1)
International and multi-disciplinary team (#2)
Tools not available or applicable (#3)
Specific / ROM cost (#4)
Use of margins and contingencies (#5)
Heritage & Complexity (#6)
Lack of time (#7)
Lack of data (#8)
Rapid data changes (#9)
Disconnection to central data model (#10)
Bottom-up estimates during CE-study (#11)
Optimizing in the wrong place (#12)
Lack of acceptance or relevance (#13)
Wrong Expectations (#1)

- **Different views:**
  - Customer
  - Managers
  - Scientists
  - Engineers
  - Cost Estimator
  - …

- **Expected cost results:**
  - ‘Golden Number’
  - Segment level
  - S/S level
  - NRE / RE share
  - or detailed (!) labour, materials, facilities and investment cost breakdown
  - …

- Discuss, iterate, clarify expected results as early as possible → tailor!
- Early phase uncertainties and detail, limited resources → clarify/agree!

Source: adapted from NASA Cost Estimating Handbook (CEH), v4.0 (example)
International and multi-disciplinary team (#2)

- Know who is involved
- Be aware of cultures
- Check impact of salary differences (sensitivity)
- "Geo return" issues

Source: https://cheops.unibe.ch/aboutus/cheops-mission-organization/
Tools not available or applicable (#3)

- Variety of space systems
  - Large S/C
  - Small S/C
  - CubeSats
  - Space Infrastructures
  - Lander
  - Rover
  - ...

- Economic considerations

- Tool available / accessible?
- Tool applicable?

- Tool adjustments needed 'a priori'
  - "Amalgamation", "benchmarking", use cost estimate building blocks

DLR Orbital Hub

Trojan Lander

MASCOT

DLR.de • Chart 13
What is it for?
• Quick initial reference,
• Rates as a starting point,
..drawn from literature, experience

Problems
• ‘Experiences’ are different
• May be argued against
• Not well documented in source

Different specific cost „interpretations“

<table>
<thead>
<tr>
<th>In [K€/kg] (e.g. FY2020)</th>
<th>S/C bus cost [k€]</th>
<th>Full project cost [k€]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S/C dry mass [kg]</th>
<th>250</th>
<th>200</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/C launch mass [kg]</td>
<td>350</td>
<td>143</td>
<td>286</td>
</tr>
</tbody>
</table>

- Assume the worst
- Again: clarify expectations (see #1), collect opinions
- Check, agree on Fiscal Year & proper interpretation, communicate to team

ROM = Rough order of Magnitude
Use of margins and contingencies (#5)

It is about:
- Standards
- Parameter
- Pile ups
- Early vs. actuals
- Tools to use

- Identify how the tools / models use them
- Use values close to actuals, or the w/c
- Question unnecessary margin pile-ups

Source: snapshot from SEER-Space
Difficult to assess (in Phase 0/A)
Subjective
Based on,
- Mass?
- Parts?
- S/W?
- Mission?

Heritage & Complexity (#6)

Within tool? And how?

- Know CER assumptions (e.g. „n/a“, „new“, „average“)
- Be aware of sensitivity (factors, linear CERs vary a lot)
- Account for it as late as possible during CE-study

DLR small satellite bus development timeline

Lack of time (#7)

- Self-made problem, the ‘price you pay’ for the condensed approach.
- Central reason, affecting/creating some of the other problem areas

<table>
<thead>
<tr>
<th>Technical Parameter</th>
<th>Units</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiscal Year for Estimate</td>
<td>YYYY</td>
<td>2019</td>
<td>This year</td>
</tr>
<tr>
<td>Inflaton Methodology</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Development Time</td>
<td>months</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>Calendar Year for Phase &amp; Start</td>
<td>YYYY</td>
<td>2031</td>
<td></td>
</tr>
<tr>
<td>Design Life</td>
<td>months</td>
<td>32.0</td>
<td>1 year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System</th>
<th>Destination</th>
<th>Earth Orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Wet Mass</td>
<td>kg</td>
<td>421.5</td>
</tr>
<tr>
<td>Spacecraft Wet Dry Mass</td>
<td>kg</td>
<td>368.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power</th>
<th>Solar Array Mounting Type</th>
<th>Deployed</th>
<th>Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Cell Type</td>
<td>-</td>
<td>Silicon Inverted</td>
<td></td>
</tr>
<tr>
<td>Power Subsystem Mass</td>
<td>kg</td>
<td>57.8</td>
<td>Virtuel mass budget (incl. Sys-margin portion)</td>
</tr>
<tr>
<td>BOL</td>
<td>W</td>
<td>3899.0</td>
<td></td>
</tr>
<tr>
<td>Solar Array Area</td>
<td>m²2</td>
<td>4.76</td>
<td>net cell area (o panel - 15%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure</th>
<th>Primary Structure Material</th>
<th>Composite</th>
<th>mainly (CPE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure Subsystem Mass</td>
<td>kg</td>
<td>100.0</td>
<td>Virtuel mass budget (incl. Sys-margin portion)</td>
</tr>
</tbody>
</table>

- Be prepared
- Be fast
- Tailor
- Go top-down
- Reduce / avoid experimenting
- Implement means for reducing errors (automatise, cross-check)

Source: Input sheet from Excel-based Small Satellite Cost Model (SSCM) 2014, adapted for DLR needs
Lack of data (#8)

Early phase studies:
• Very immature technical understanding
  • few technical data
  • few cost data

Company-related issues
• No access to cost data…
• Not many (or zero) space systems built..

Not CE-study but early phase specific

Collect potential similar mission examples during preparation phase
Know the unknowns, document them, **substitute** bad with good data
Find (and adapt) a parametric tool or set of CERs to get started…
Rapid data changes (#9)

- Know which cost drivers to „follow“ & which to „forget“
- Prepare good forecasts
- Know sensitivities
- Prepare tools & models
Disconnection to central data model (#10)

Included in DLR Virtual Satellite Model, e.g.:
- Mass Budget, Power Budget, Modes, Distributed CAD,
- Functional Diagrams, Temperature ranges, Margins, ..

Excluded, e.g.:
- Trajectories, Power profiles,
- Risk matrices, **Cost estimate**

- Link, extract, subscribe to most relevant outputs (for your own inputs),
- Robust assumptions up front → **Cost @ MBSE is still underestimated!**
Bottom-up estimates during CE-study (#11)

- **WANTED** by several customers! → Although better suitable for later phases...

### Equipment cost [k€]

<table>
<thead>
<tr>
<th>Equipment</th>
<th>COST</th>
<th>Labour per PHASE [FTE]</th>
<th>Labour</th>
<th>Labour</th>
<th>GRAND TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24</td>
<td>18</td>
<td>15</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1054.4</td>
<td>15.4</td>
<td>33.1</td>
<td>36.1</td>
<td>36.2</td>
</tr>
</tbody>
</table>

#### Architecture / Mission

<table>
<thead>
<tr>
<th>Equipment</th>
<th>COST</th>
<th>Labour per PHASE [FTE]</th>
<th>Labour</th>
<th>Labour</th>
<th>GRAND TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20940.4</td>
<td>15.4</td>
<td>33.1</td>
<td>36.1</td>
<td>36.2</td>
</tr>
</tbody>
</table>

#### Satellite

- **incl. margin contract** 20%

<table>
<thead>
<tr>
<th>Equipment</th>
<th>COST</th>
<th>Labour per PHASE [FTE]</th>
<th>Labour</th>
<th>Labour</th>
<th>GRAND TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17404.5</td>
<td>16.2</td>
<td>27.0</td>
<td>33.0</td>
<td>35.0</td>
</tr>
</tbody>
</table>

#### Subsystems

- **ADS/CNC**
- **Propulsion**
- **TT&C/Comm.**
- **DMS/DRMS**
- **Software**
- **Power**
- **Thermal**

**Source:** Excerpt from internal engineering build-up cost estimation template

- Harmonize assumptions of contributing people (unify!)
- Prepare cost share on e.g. S/S level using parametrics
- Perform sanity checks,
- Be aware of gaps (fill them)
- Know desired breakdown!
Optimizing in the wrong place (#12)

- NASA WBS (Level 2), with assessment on (early) cost estimation focus

- Understand driver
- Set focus properly
- Do not over-detail
- Know your CER sensitivity & slopes

Source: NASA Cost Estimation Handbook (CEH) v4.0
Lack of acceptance or perceived relevance (#13)

- “What is this CER thing? Parametric?”
- “Why don’t you use the cost from XYZ mission?”
  - (Desire for bottom-up, remember?)
- “Fiscal Year what?”
- “How much does it cost?”
  - (not explaining what “it” is)
- “This should cost much less!”

...or do you recall these ones?:

- “First we need to know if this (technically) works.”
- “The cost (and risk) assessment is not yet relevant.”
- “I need to focus on my design.”
- “I don’t know what it costs.”

Explain, educate, raise awareness, wake them up, clarify stage of project, & ..just take it easy..
Mutual impacts of the 13 issues/problems

1. Wrong expectations (#1)
2. International & multi-disciplinary team (#2)
3. Tool availability & applicability (#3)
4. Specific / ROM cost (#4)
5. Margins & Contingencies (#5)
6. Heritage & Complexity (#6)
7. Lack of time (#7)
8. Lack of data (#8)
9. Rapid data changes (#9)
10. Disconnection to data model (#10)
11. Bottom-up estimates (#11)
12. Optimizing in wrong place (#12)
13. Acceptance or relevance (#13)

In general

CE-specific
In Summary...

Concurrent Engineering (CE)
- Very suitable in early phases
- Increases quality, consistency
- Reduces time, cost, errors
- Different approaches possible

Enjoy a focused, available team

Cost Estimation in CE is facing:
- Low design maturity, few data
- Tough schedule
- Many technical people
- Different cultures, expectations

Good, intense, iterative estimation

Ideas, Recommendations, Lessons Learnt

→ „imPACD“

ideally maximum..

- Preparation > data, tools, methods, adjustments, tailoring
- Awareness > all stakeholders, team, problem areas, desires
- Communication > carify, harmonize, explain and even educate
- Documentation > Agree, list/show assumptions, input to data base
Are there any

Thank you

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If you want to know more about the DLR CEF, then please click:
https://www.dlr.de/irs/PortalData/46/Resources/videos/CEF-Video_Version_9_.mp4
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