Colombia mar 2019

VI CONGRESO INTERNACIONAL DE DISEÑO E INGENIERÍA NAVAL

COPINAVAL
CARTAGENA DE INDIAS - COLOMBIA

XXVI CONGRESO PANAMERICANO DE INGENIERÍA NAVAL, TRANSPORTE MARÍTIMO E INGENIERÍA PORTUARIA

Organizan:

COTECMAR

ESCUELA NAVAL ALMIRANTE PADILLA

ARMADA DE COLOMBIA

INSTITUTO PANAMERICANO DE INGENIERÍA NAVAL

A practical approach for decision-making on preliminary naval ship cost estimating using multiple cost estimation methods

About me

Kevin Patrón Hernández

- Mechanical Engineer (Universidad Tecnológica de Bolívar, 2013)
- Adjunct professor at Universidad Tecnólogica de Bolivar (2013 - 2015)
- Naval Architecture Designer at Cotecmar's Design and Engineering office (2015 – Current date)
- Areas of development and research at Cotecmar:
  - Analysis and design of ship structures
  - Mathematical modelling for ship design

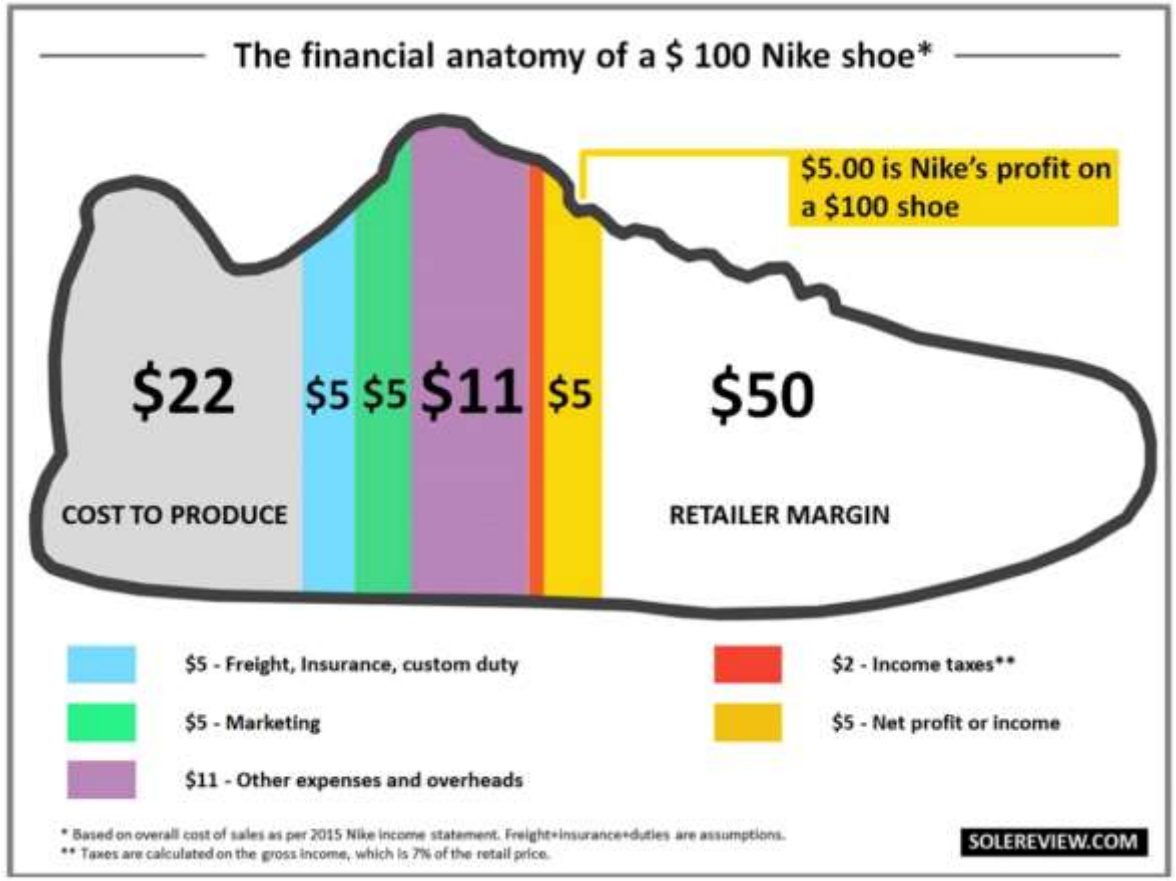
Agenda

1. **Introduction to naval ship cost estimating**
2. Motivation for a decision-making approach on preliminary naval ship cost estimating
3. The proposed approach
4. Example of usage
5. Concluding remarks

Cost vs. Price

"**Cost** : **amount of money needed to actually produce an item**.

Price: **what you and I must pay for that item** in the marketplace."



https://www.solereview.com/what-does-it-cost-to-make-a-running-shoe/

Mislick, G., Nussbaum, D. (2015) Cost Estimation: Methods and Tools. John Wiley & Sons, Wiley Series in Operations Research and Management Science

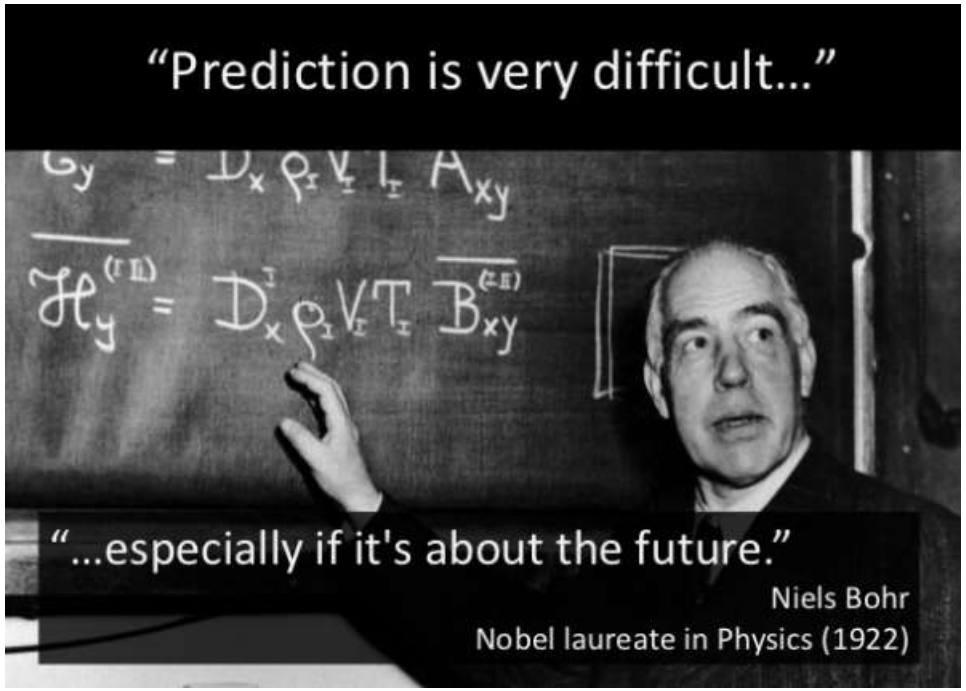
Cost estimating

Cost estimating is **a process**:

- collect and analyze historical data
- apply quantitative models, techniques and tools

…**to predict an estimate of the future cost** of :

- an item
- product
- program
- …or task

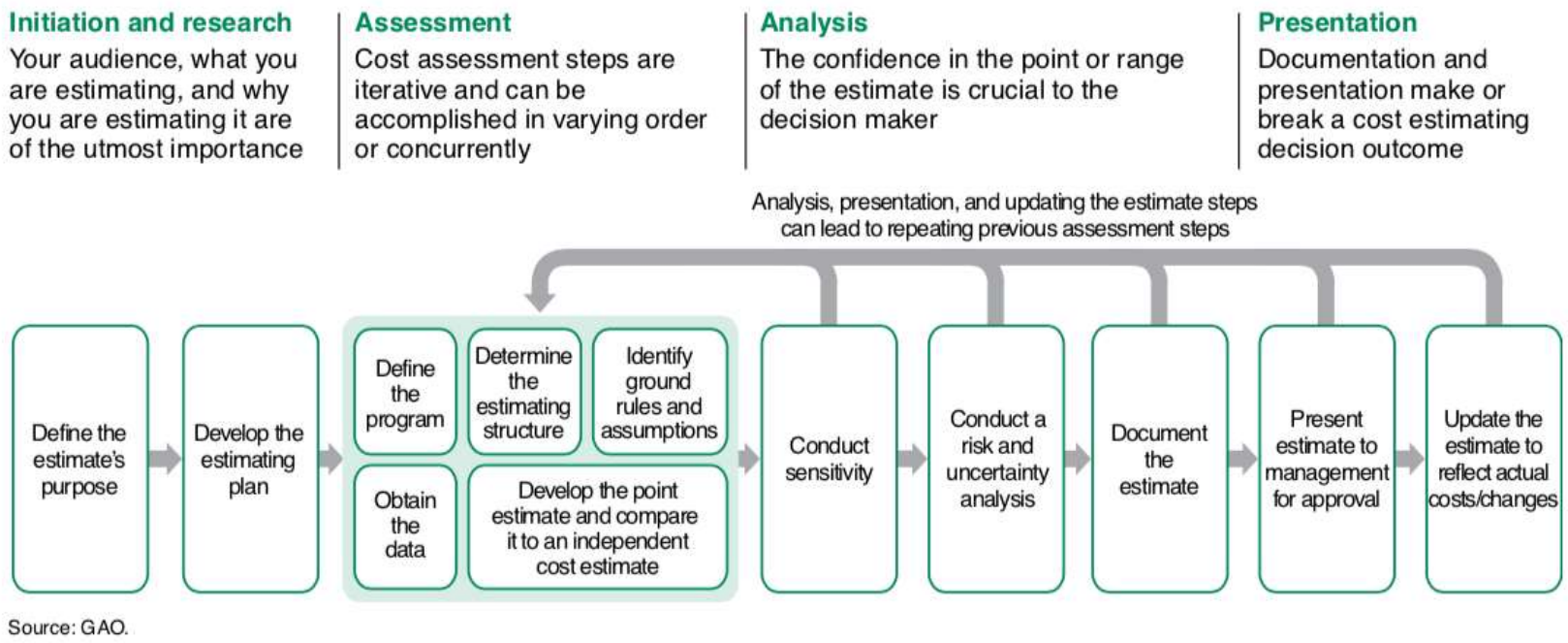


https://www.slideshare.net/mti2/commercial-success-from-innovation

Mislick, G., Nussbaum, D. (2015) Cost Estimation: Methods and Tools. John Wiley & Sons, Wiley Series in Operations Research and Management Science

Cost estimating process

"Cost estimating is the application of the art and the technology of approximating the probable worth (or cost), extent, or character of something **based on information available at the time**"

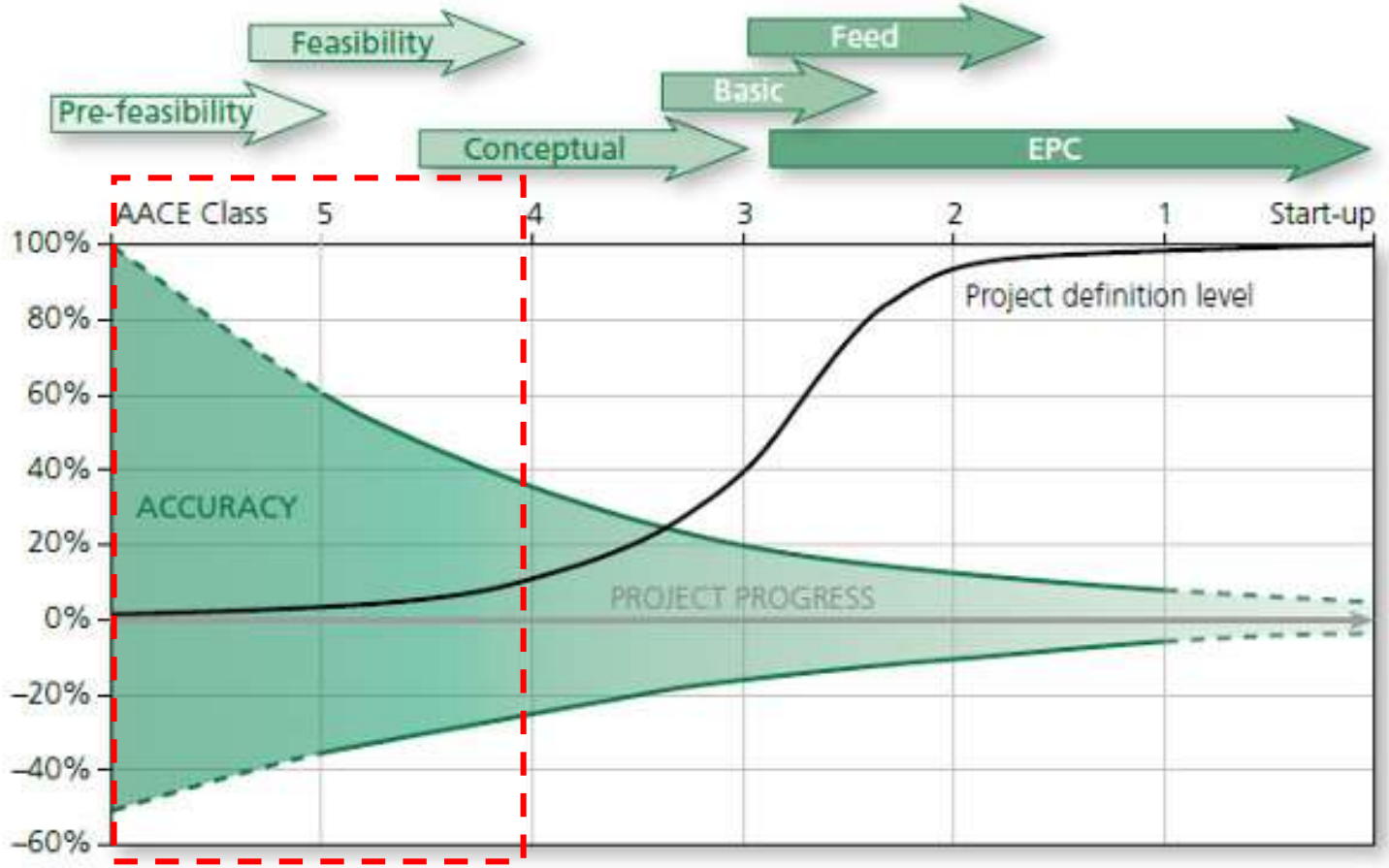


Source: GAO.

Mislick, G., Nussbaum, D. (2015) Cost Estimation: Methods and Tools. John Wiley & Sons, Wiley Series in Operations Research and Management Science

US GAO (2005) GAO Cost Estimating and Assessment Guide

Uncertainty in cost estimating



Our area of interest

Cost estimating methods

Analogy

cost of **similar programs** is used to estimate a new one and adjusts for differences

$$\text{New program cost} = (\text{scaling factor}) \times (\text{historical program cost})$$

Parameter	Existing system	New system	Cost of new system (assuming a linear relationship)
Engine	F-100	F-200	
Thrust	12,000 lbs	16,000 lbs	
Cost	$5.2 million	X	(16,000/12,000) x $5.2 million = $6.9 million

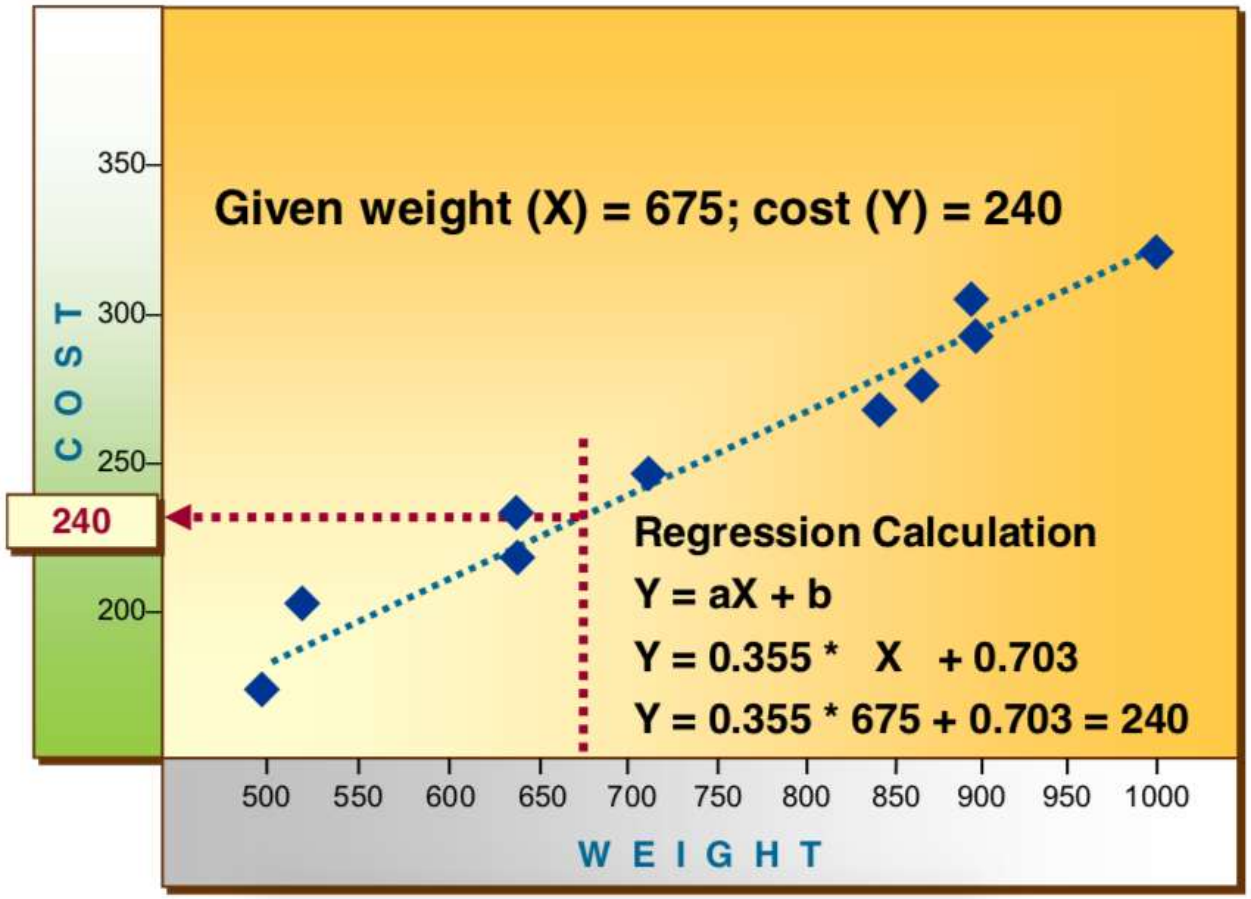
Source: © 2003, Society of Cost Estimating and Analysis (SCEA), "Costing Techniques."

US GAO (2005) GAO Cost Estimating and Assessment Guide

Cost estimating methods

Parametric

cost is related to one or more technical, performance, cost **program parameters**, using **statistical relationships**

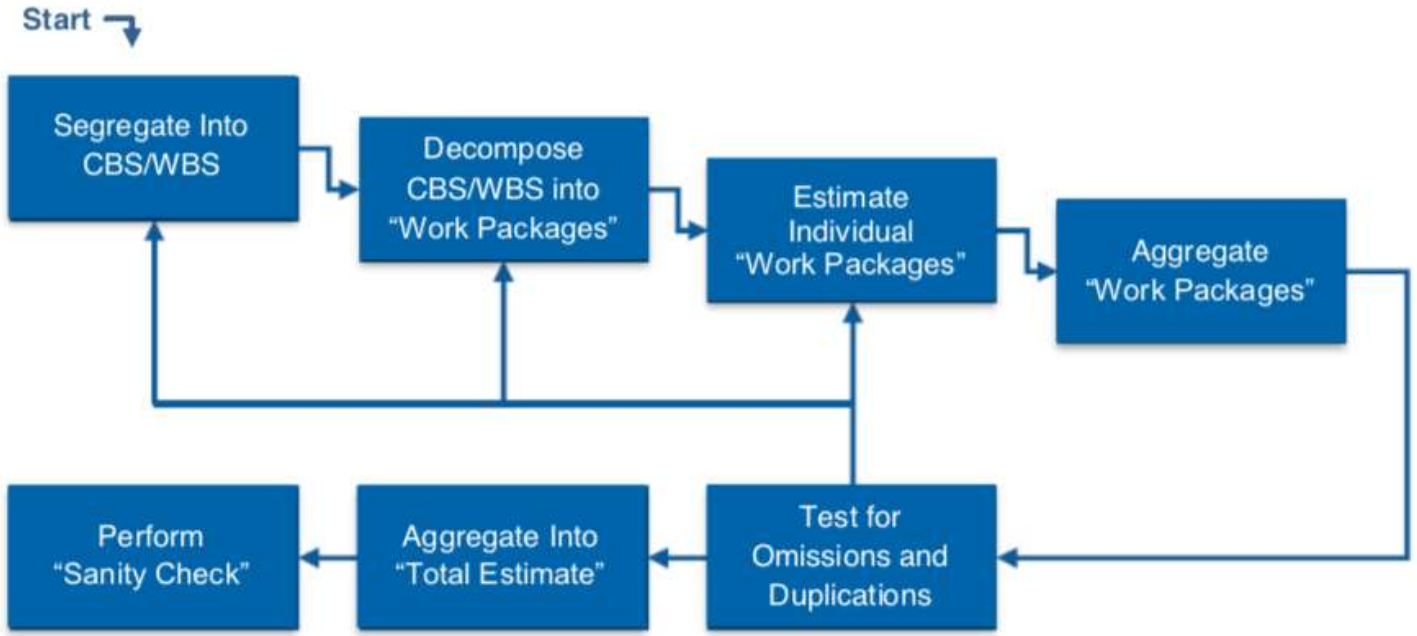


US GAO (2005) GAO Cost Estimating and Assessment Guide
NASA Cost Estimating Handbook Version 4.0

Cost estimating methods

Engineering build-up

cost estimate developed at the lowest level of the **WBS:** the sum of the pieces becomes the estimate



US GAO (2005) GAO Cost Estimating and Assessment Guide
NASA Cost Estimating Handbook Version 4.0

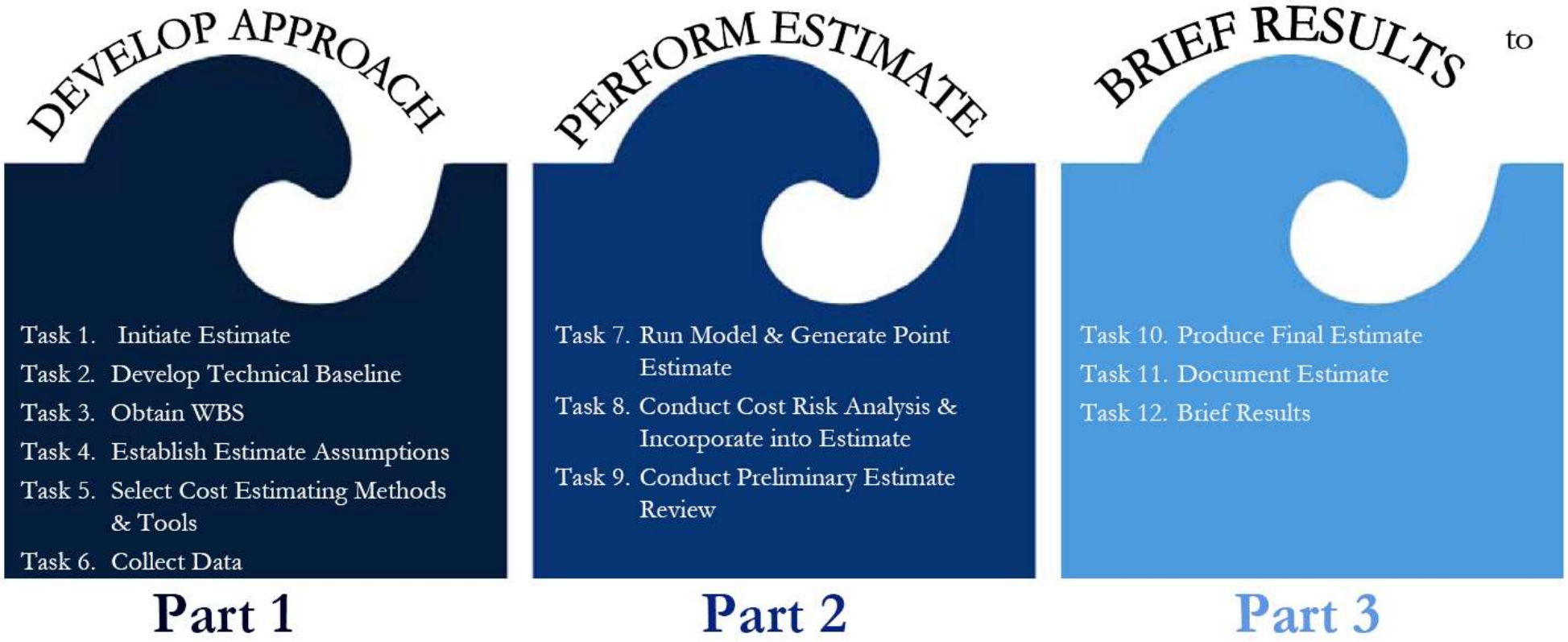
Naval ship cost estimating

ESWBS Names and Group Descriptions

Group #	ESWBS Name	Group Description
100	Hull Structure	Includes shell plating, decks, bulkheads, framing, superstructure, pressure hulls, and foundations
200	Propulsion Plant	Includes boilers, reactors, turbines, gears, shafting, propellers, steam piping, lube oil piping, and radiation shielding
300	Electric Plant	Includes ship service power generation equipment, power cable, lighting systems, and emergency electrical power systems.
400	Command and Surveillance	Includes navigation systems, interior communications systems, fire control systems, radars, sonars, radios, teletype equipment, telephones, and command and control systems.
500	Auxiliary Systems	Includes air conditioning, ventilation, refrigeration, replenishment-at-sea systems, anchor handling, elevators, fire extinguishing systems, distilling plants, cargo piping, steering systems, and aircraft launch and recovery systems
600	Outfit and Furnishings	Includes hull fittings, painting, insulation, berthing, sanitary spaces, offices, medical spaces, ladders, storerooms, laundry, and workshops
700	Armament	Includes guns, missile launchers, ammunition handling and stowage, torpedo tubes, depth charges, mine handling and stowage, and small arms.
800	Integration/Engineering	Includes all engineering effort, both recurring and nonrecurring. Nonrecurring engineering is generally recorded on the Construction Plans category line of the end cost estimate while recurring engineering is recorded in Group 800 of the Basic Construction category.
900	Ship Assembly and Support Services	Includes staging, scaffolding, and cribbing; launching; trials; temporary utilities and services; materials handling and removal; and cleaning services

USA DoD (2005), NAVSEA Cost Estimating Handbook

Naval ship cost estimating

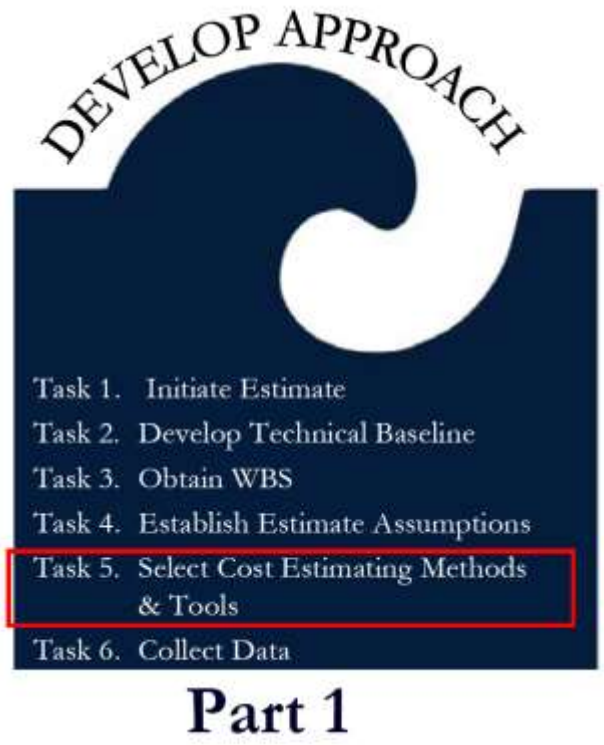


USA DoD (2005), NAVSEA Cost Estimating Handbook

Agenda

1. Introduction to naval ship cost estimating
2. **Motivation for a decision-making approach on preliminary naval ship cost estimating**
3. The proposed approach
4. Example of usage
5. Concluding remarks

Motivation



Methods and tool selection decisions are influenced by:

- ✓ the level of the program definition
- ✓ the purpose of the estimate
- ✓ the **availability** of cost, technical, or economic data
- ✓ the **quality** of the cost, technical or economic data
- ✓ and time constraints

USA DoD (2005), NAVSEA Cost Estimating Handbook

Motivation

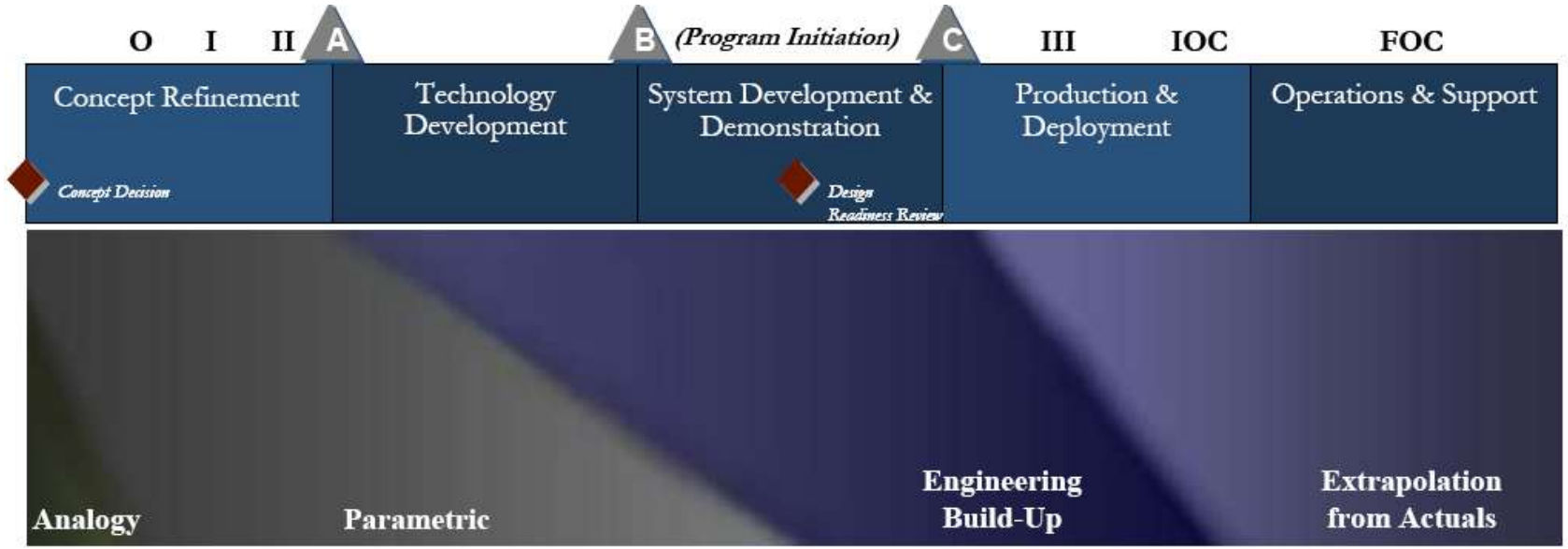
Cost Estimating Methodology by Program Life Cycle Phase

	Concept Refinement	Technology Development	System Development & Demonstration	Production & Development	Operations & Support
Analogy	●	●	◑	◑	◑
Parametric	●	●	◑	◑	●
Engineering Build-Up	◑	●	●	●	◑
Legend	○ *Not Applicable*	◑ *Sometimes Applicable*		● *Applicable*	

USA DoD (2005), NAVSEA Cost Estimating Handbook

Motivation

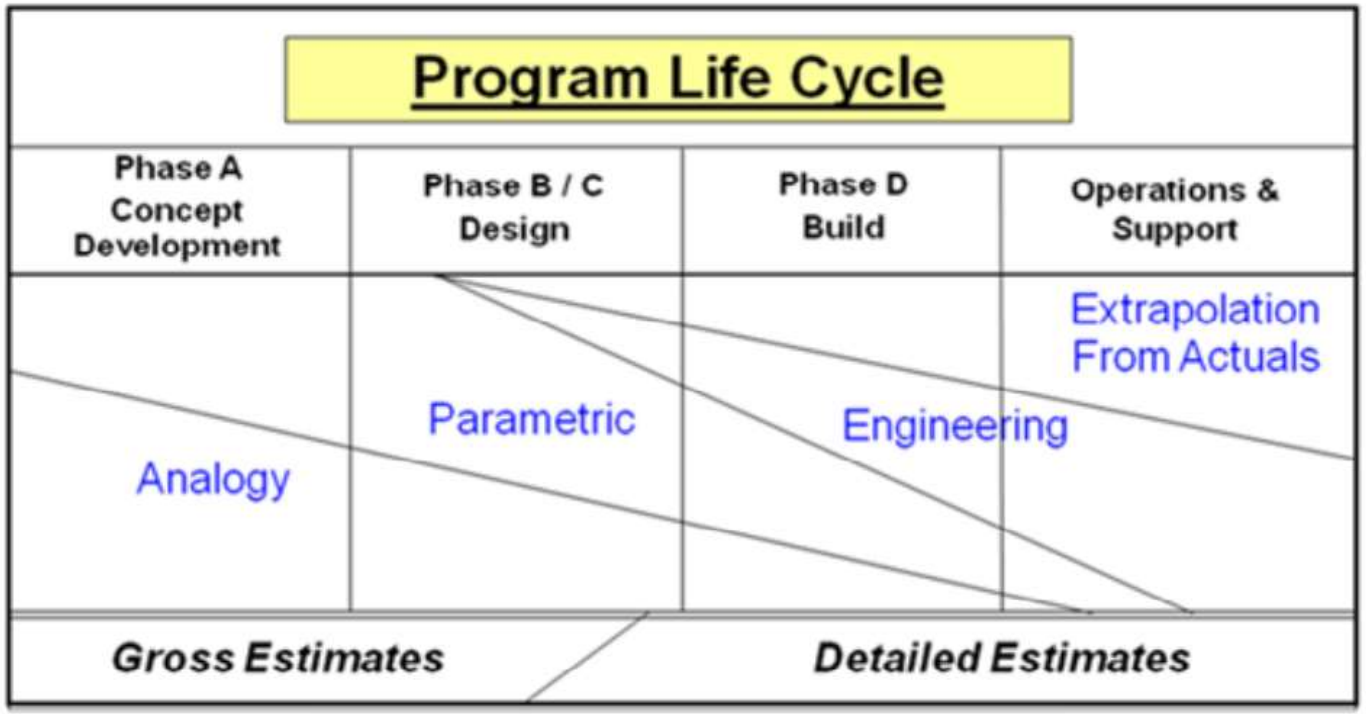
Common Estimating Methods by Life Cycle Phase



USA DoD (2005), NAVSEA Cost Estimating Handbook

Motivation

Common Estimating Methods by Life Cycle Phase



NASA Cost Estimating Handbook Version 4.0

Motivation

If …

…the applied cost estimation methods are **equally valid and applicable** for conceptual design
…each method leads to (slightly different) **reliable results,** based on different base information
…each method provides with **relevant information to the decision makers**

Then …

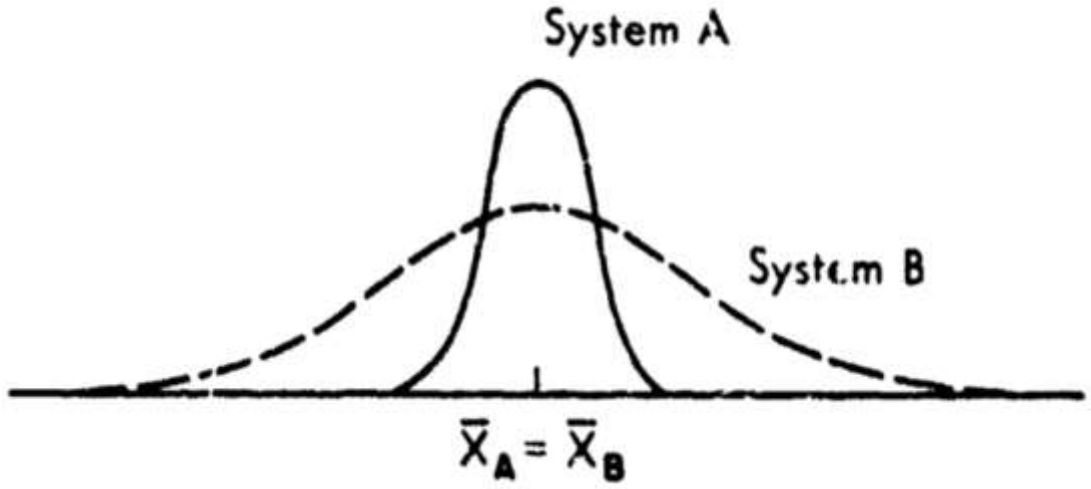
it becomes necessary to have an additional rational method that facilitates the decision-making process for the obtention of a single resultant result !

Agenda

1. Introduction to naval ship cost estimating
2. Motivation for a decision-making approach on preliminary naval ship cost estimating
3. **The proposed approach**
4. Example of usage
5. Concluding remarks

The proposed approach

"Cost estimates are expressed as **probability distributions** to reflect the actual, though perhaps unmeasurable, **uncertainty** surrounding each estimate."



Relative likelihood of ocurrence vs. Cost

Dienemann, P. (1966) Estimating cost uncertainty using Monte Carlo techniques

The proposed approach

- "Different decision-makers inherently have different judgments or opinions on a decision target"
- Aggregation of those different opinions is formed by a consensus
- "The decision-maker's opinion can be represented by a probability distribution function" (PDF)
- The problem reduces to the **aggregation** of a set of distributions to an ***aggregated or consensus distribution***.

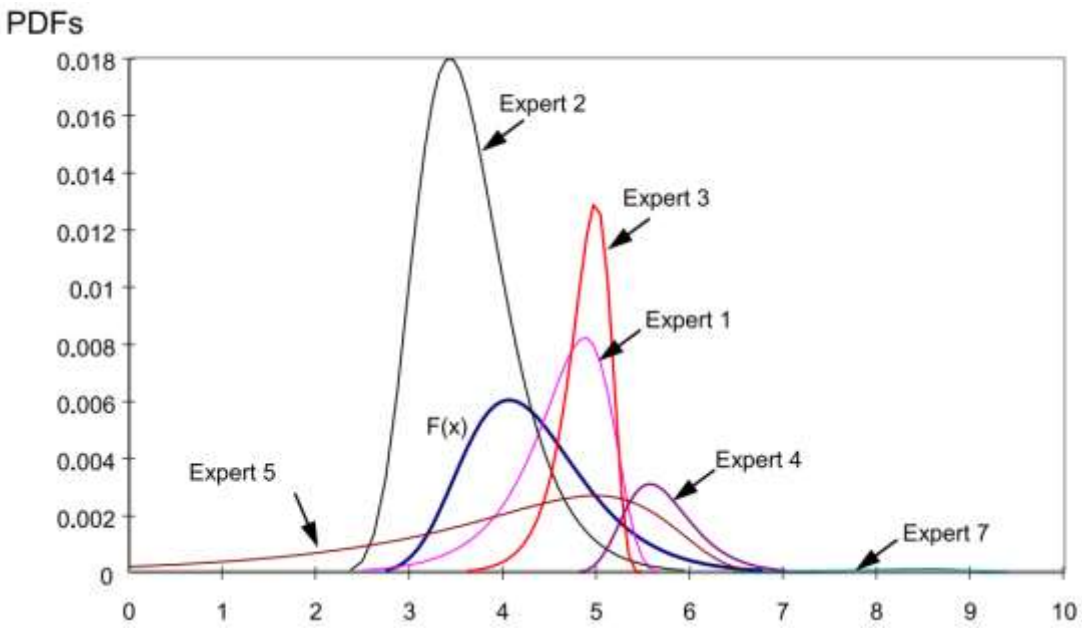
X. Liu, A. Ghorpade, Y. L. Tu, and W. J. Zhang, "A novel approach to probability distribution aggregation," *Inf. Sci.*, vol. 188, pp. 269–275, Apr. 2012

The proposed approach

- Aggregated PDF* $f(x)$

$$f(x) = \sum_{i=1}^{m} w_i \, f_i(x)$$

Linear combination of individual cost estimation PDFs



$$0 \le w_i \le 1, \quad \sum_{i=1}^{m} w_i = 1$$

PDF* : Probability Distribution Function

X. Liu, A. Ghorpade, Y. L. Tu, and W. J. Zhang, “A novel approach to probability distribution aggregation,” *Inf. Sci.*, vol. 188, pp. 269–275, Apr. 2012

The proposed approach

1. "What should be criterion applied to evaluate decision-makers?"

2. "How should weight be assigned to decision-makers?"

Methods

- Ranking of decision-makers
- Delphi method
- Analytic Hierarchy Process
- …etc

$$w_i = \frac{r_i}{\sum_{i=1}^{m} r_i}.$$

X. Liu, A. Ghorpade, Y. L. Tu, and W. J. Zhang, "A novel approach to probability distribution aggregation," *Inf. Sci.*, vol. 188, pp. 269–275, Apr. 2012

The proposed approach

Objective:

Maximum consensus or minimum difference among cost estimation results

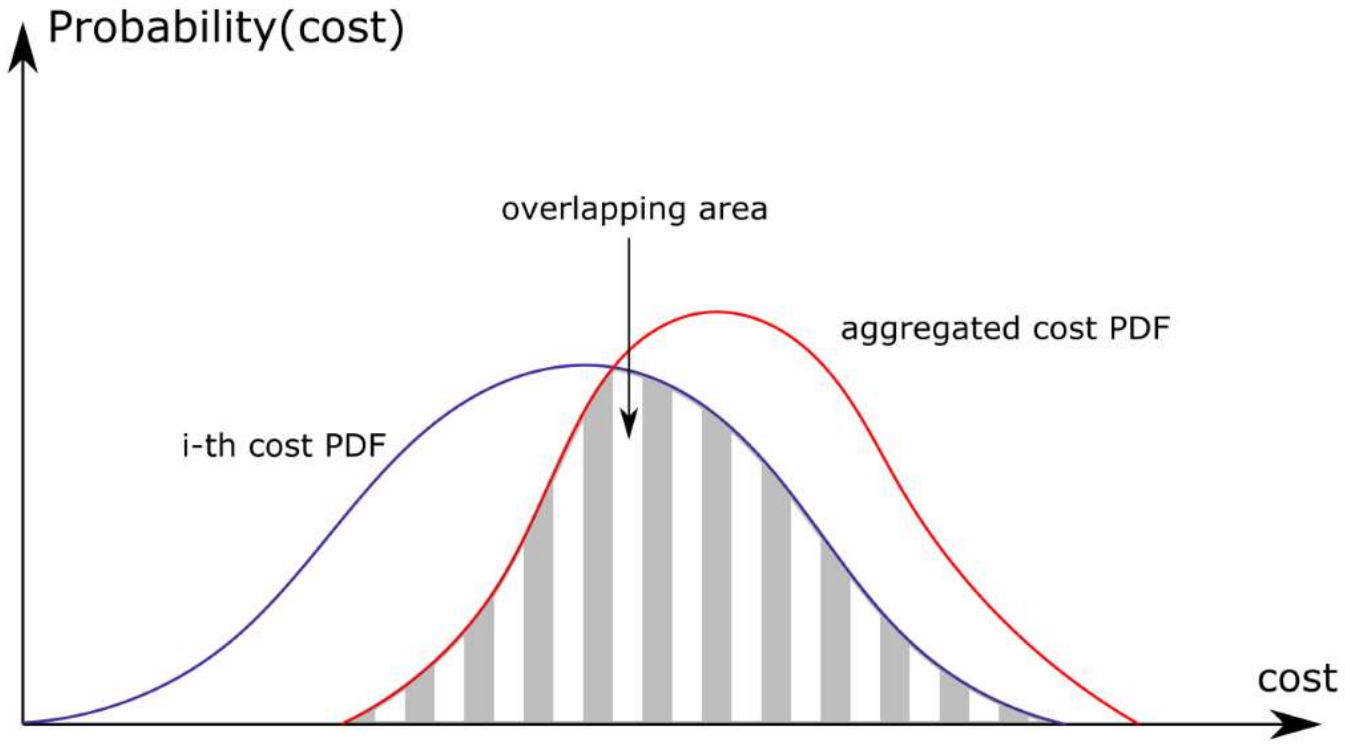
Keypoints:

- The *expertise* of a cost estimation method is represented by the *overlapping area between its distribution and the aggregated distribution.*

- The weight of a cost estimation model is given in proportion to the corresponding overlapping area.

X. Liu, A. Ghorpade, Y. L. Tu, and W. J. Zhang, "A novel approach to probability distribution aggregation," *Inf. Sci.*, vol. 188, pp. 269–275, Apr. 2012

The proposed approach



$$W_i = \frac{A_i}{\sum_{i=1}^{m} A_i}$$

X. Liu, A. Ghorpade, Y. L. Tu, and W. J. Zhang, “A novel approach to probability distribution aggregation,” *Inf. Sci.*, vol. 188, pp. 269–275, Apr. 2012

The proposed approach

Goal:

Maximize the sum of the overlapping areas for all cost estimation methods (i.e., total overlapping area)

→ find the weights that maximize this sum of overlapping areas

$$\max A_{tot} = \sum_{i=1}^{m} A_j \qquad s.t \quad 0 \le w_i \le 1, \quad \sum_{i=1}^{m} w_i = 1$$

An optimization technique is employed to determine the weights.

X. Liu, A. Ghorpade, Y. L. Tu, and W. J. Zhang, "A novel approach to probability distribution aggregation," *Inf. Sci.*, vol. 188, pp. 269–275, Apr. 2012

Agenda

1. Introduction to naval ship cost estimating
2. Motivation for a decision-making approach on preliminary naval ship cost estimating
3. The proposed approach
4. **Example of usage**
5. Concluding remarks

Example

Estimate the shipbuilding cost of a given naval ship , based on the following results obtained from different cost estimation methods

Cost estimation method	Minimum cost (USD)	Expected cost (USD)	Maximum cost (USD)
Carreyette	62,048,269	68,942,521	75,836,773
Lamb	62,304,721	73,299,672	84,294,622
CGT	68,546,855	78,957,125	89,293,750
Multiple regression	72,844,500	90,443,000	108,041,000

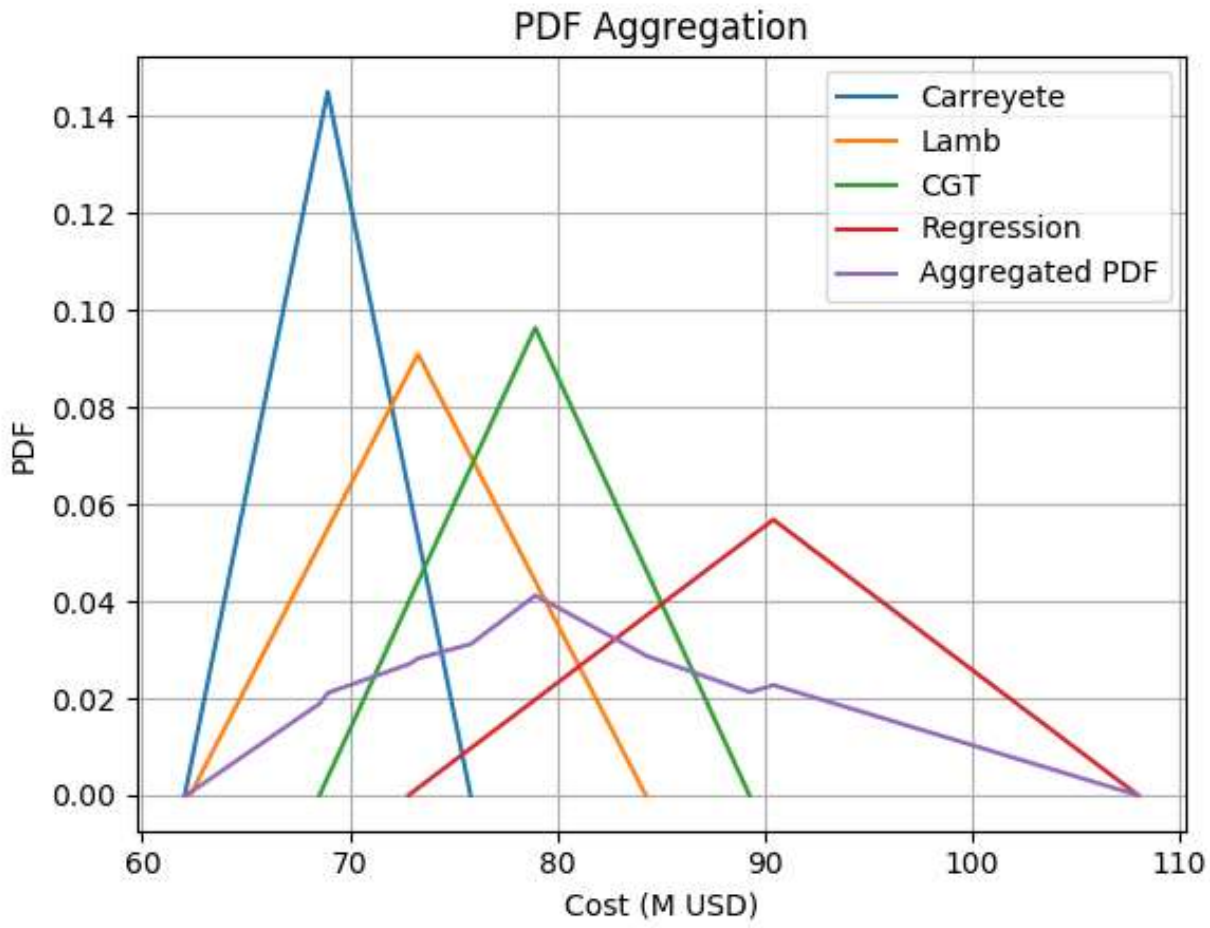
Example

Cost estimation method	Minimum cost (USD)	Expected cost (USD)	Maximum cost (USD)
Carreyette	62,048,269	68,942,521	75,836,773
Lamb	62,304,721	73,299,672	84,294,622
CGT	68,546,855	78,957,125	89,293,750
Multiple regression	72,844,500	90,443,000	108,041,000

Cost estimation method	Weight (w)
Carreyette	0.1
Lamb	0.1
CGT	0.3
Regresión múltiple	0.4

Sum of overlapping areas = 0,89

Non-optimal (arbitrary) weights



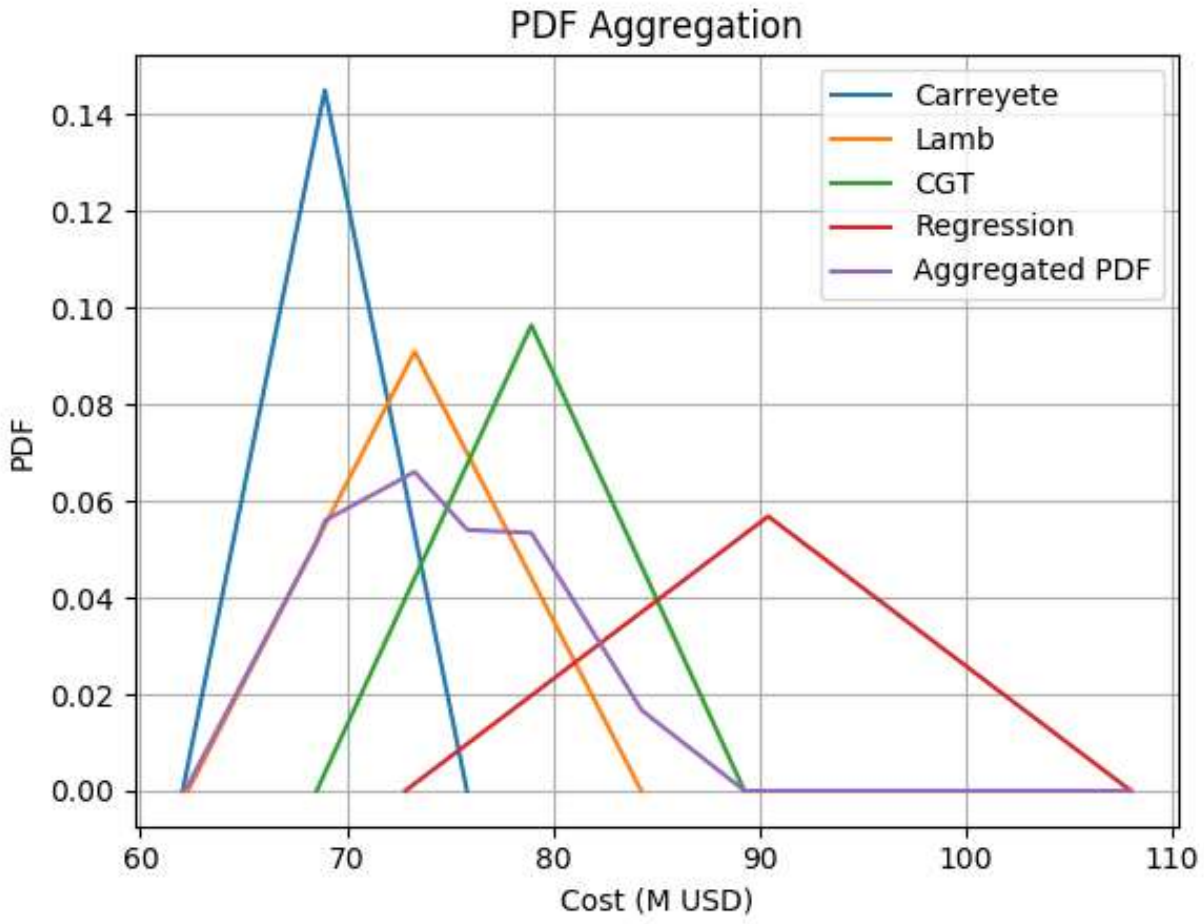
Example

Cost estimation method	Minimum cost (USD)	Expected cost (USD)	Maximum cost (USD)
Carreyette	62,048,269	68,942,521	75,836,773
Lamb	62,304,721	73,299,672	84,294,622
CGT	68,546,855	78,957,125	89,293,750
Multiple regression	72,844,500	90,443,000	108,041,000

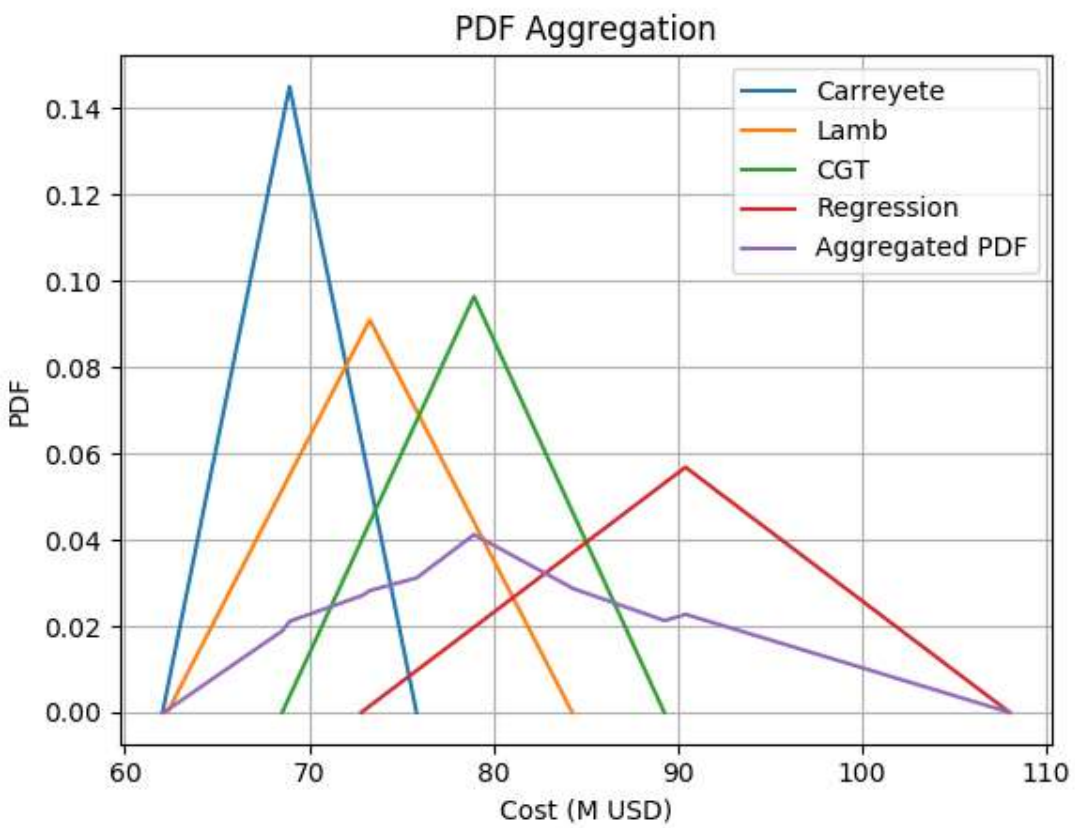
Cost estimation method	Weight (w)
Carreyette	0.215
Lamb	0.425
CGT	0.358
Regresión múltiple	0.000

Sum of overlapping areas = 1.0

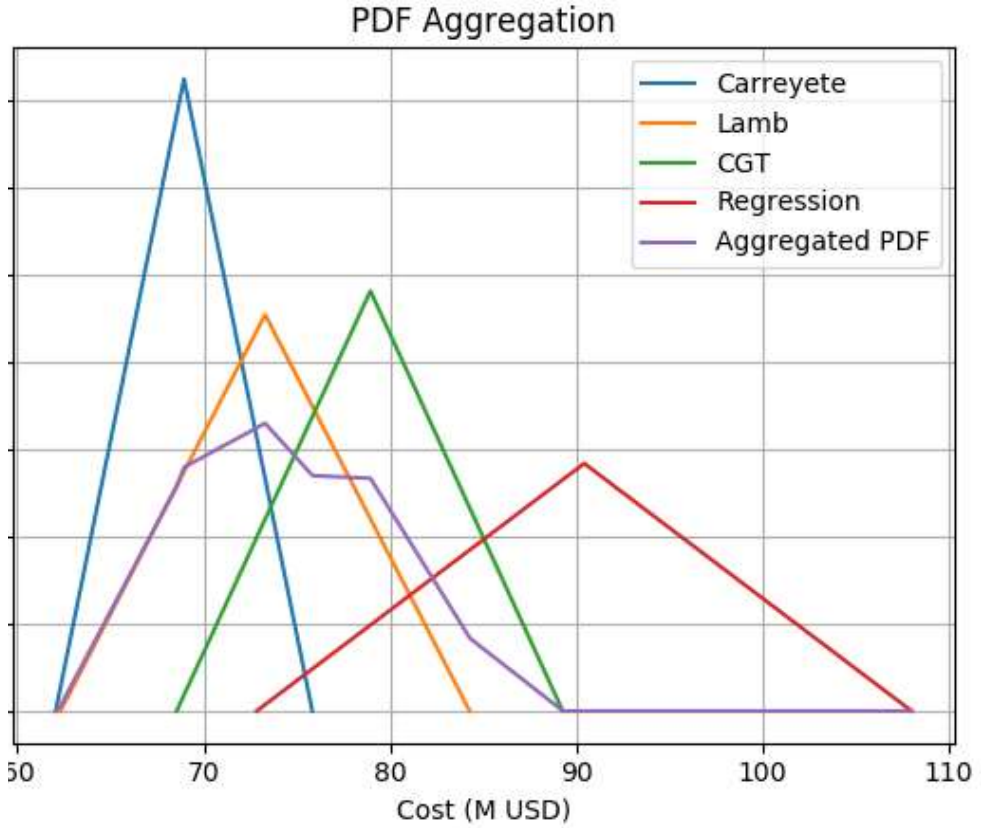
Optimal weights



Example

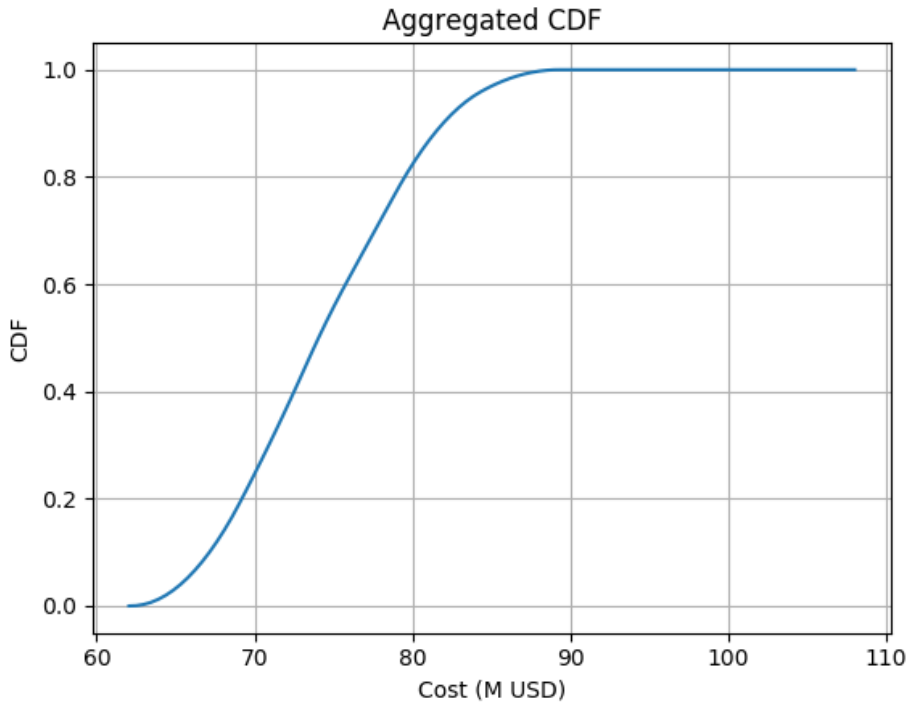


Aggregated PDF with non-optimal weights



Aggregated PDF with Optimal weights

Example



Cumulative Aggregated Cost Distribution Function

$$P(Cost \leq 78.56\ M\ USD) = 0.75$$

$$P(Cost \leq 79.52\ M\ USD) = 0.8$$

Cost (M USD)	Aggregated CDF
75,0	0,557
76,0	0,612
77,0	0,666
78,0	0,720
79,0	0,773
80,0	0,823
81,0	0,866
82,0	0,902
83,0	0,931
84,0	0,953
85,0	0,969
86,0	0,982
87,0	0,991
88,0	0,997
89,0	1,000
90,0	1,000
91,0	1,000
92,0	1,000
93,0	1,000
94,0	1,000
95,0	1,000

Agenda

1. Introduction to naval ship cost estimating
2. Motivation for a decision-making approach on preliminary naval ship cost estimating
3. The proposed approach
4. Example of usage
5. **Concluding remarks**

Concluding remarks

A **rational methodology for the aggregation of probability distributions** has been applied for the development of the cost estimate of a naval ship, during early stages of design.

The presented methodology can be used to assist during decision **making processes around the cost estimate of naval vessels** in the early design phases, where more than one estimation method can be used.

Thanks for your attention!

Kevin E. Patrón kpatron@cotecmar.com

Luis D. Leal lleal@cotecmar.com

Omar D. Vásquez ovasquez@cotecmar.com

COTECMAR
Zona Industrial Mamonal Km 9, Cartagena, Colombia
(+57 5) 653 5035 Ext. 5508

Colombia mar 2019