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From Bespoke to Industrialized Space Systems: A Hybrid COSYSMO 4.0 Calibration for ISO 15288-Compliant Lifecycle Costing using MBSE and Machine Learning

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Today's Agenda

- The Spatial Market Transition
- Hybrid MBSE & COSYSMO 4.0 Framework
- INCOSE's Framework: Affordability Analysis
- Parametric Cost Estimation & Lifecycle Alignment
- COSYSMO 2.0 (Valerdi 2005)
- From COSYSMO 2.0 to Lifecycle-Integrated: COSYSMO 4.0
- Case Study
- Final Conclusions



The Spatial Market Transition

1. Institutional Era (Baseline)	2. Commercial Emergence (Current State)	3. Strategic Imperative (The Challenge)
Bespoke Paradigm	New Space Ecosystem	Service-Centric Paradigm
<ul style="list-style-type: none">• Anchor Demand: Institutional monopsony (e.g., ESA, NASA).• Procurement: Cost-plus contracts and custom architectures.• Dynamics: High fixed costs and extended lead times.	<ul style="list-style-type: none">• Drivers: Supply-push dynamics and private equity financing.• Scale: Series manufacturing and launch commoditization.• Outcome: Sharply declining marginal cost curves.	<ul style="list-style-type: none">• Shift: From CapEx procurement to standardized Firm-Fixed-Price (FFP) services.• Requirement: Transition from reactive accounting to Predictive Target Costing.



Hybrid MBSE & COSYSMO 4.0 Framework

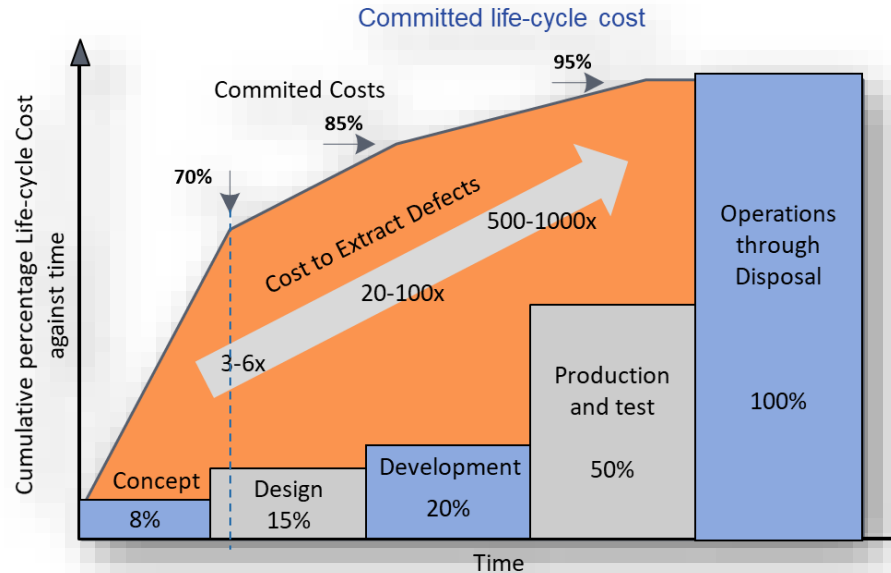
Dimension	1. Methodological Pillar (Methodology)	2. Private Domain (Governance)	3. Digital Thread (Interoperability)
Technical Core	MBSE + COSYSMO 4.0 Translation of requirements into technical complexity parameters.	Local OLS / M5P Models Processing within the contractor's private domain (Edge).	ECOS 6 / API Integration Exporting parametric vectors to the digital thread.
Operations & Control	V-Model (ISO/IEC 15288) Shift from reactive accounting to Target Costing from TRL 4+.	Data & IP Protection Availability & confidentiality of (internal) cost accounting data.	Real-Time Synchronization Linking changes in MBSE authoring tools/ERP with ECOS 6.

INCOSE's Framework: Affordability Analysis

Commitment Paradox: 70% of total LCC is committed during the *Concept & Design Stages*, yet actual expenditure remains below 10%.

Estimation Gap: Traditional heuristics fail to account for non-linear complexity in integrated Hardware/Software systems.

Affordability Risk: Inaccurate early-stage sizing leads to technical debt and late-stage defect leakage.

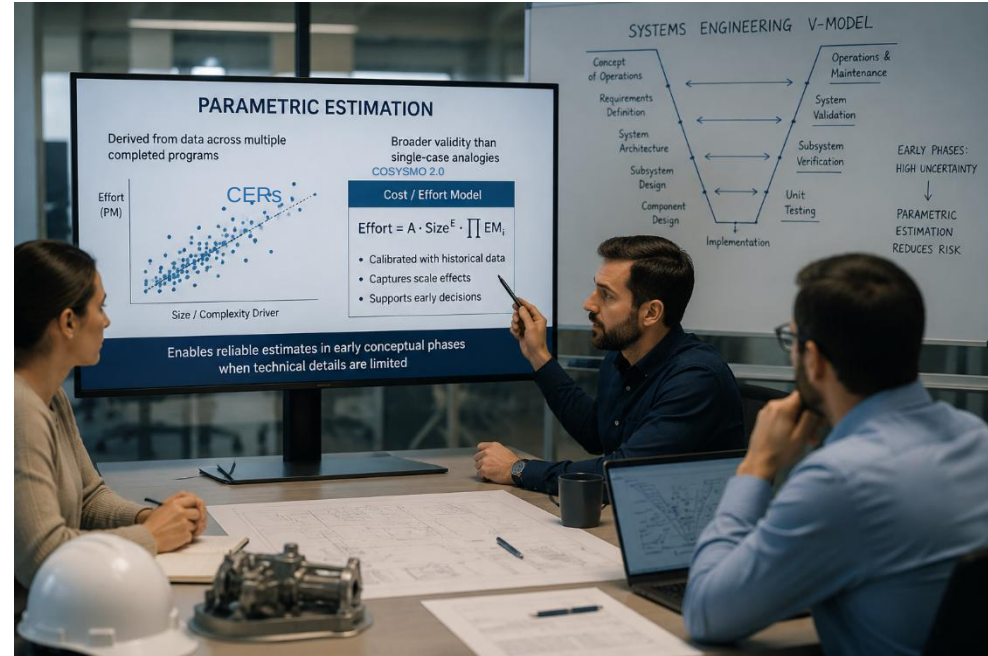


INCOSE Systems Engineering Handbook

The target selling price drives architectural, effort, and performance decisions, balancing Cost-Effectiveness Analysis (CEA) and Cost-Benefit Analysis (CBA).

Parametric Cost Estimation & Lifecycle Alignment

- **Parametric Predictive Modeling:** Utilizes historical data to derive statistically grounded Cost Estimating Relationships (CERs) for Affordability Analysis.
- **MBSE-Enabled Digital Thread:** Integrates mathematical cost drivers directly with the system's architectural model (SysML/PBS).
- **ISO/IEC/IEEE 15288 & 24748-4 Governance across the V-model.**
- **Continuous Calibration Loop:** Feeds empirical closed-loop data into the parametric engine, refining the model's predictive fidelity.





COSYSMO 2.0 (Valerdi 2005)

$$\text{Effort} = A \cdot \text{Size}^E \cdot \prod_{i=1}^n \text{EM}_i$$

It was designed to estimate the effort required for SE projects, expressed in person-months. The translation from effort to cost was left to the practitioner, typically by applying an appropriate cost rate per person-month.

Element	Description	SE Interpretation
A	Calibration coefficient	Absolute effort per unit of system size; varies with complexity and domain.
Size	System size	Based on requirements (REQ), interfaces (IF), algorithms (ALG), and scenarios (SCN), weighted by difficulty and reuse level
E	Productivity exponent	<1 → economies of scale; =1 → linear scaling; >1 → diseconomies of scale
EMi	Effort multipliers	Adjust effort for system and team factors (experience, technology risk, complexity, etc.)

$$\text{Effort} = 38.55 \cdot \text{Size}^{1.06} \cdot \prod_{i=1}^n \text{EM}_i$$

Note: 'A' calibrated for large-scale, highly complex and heavily regulated engineering projects (e.g., aerospace): 38.55

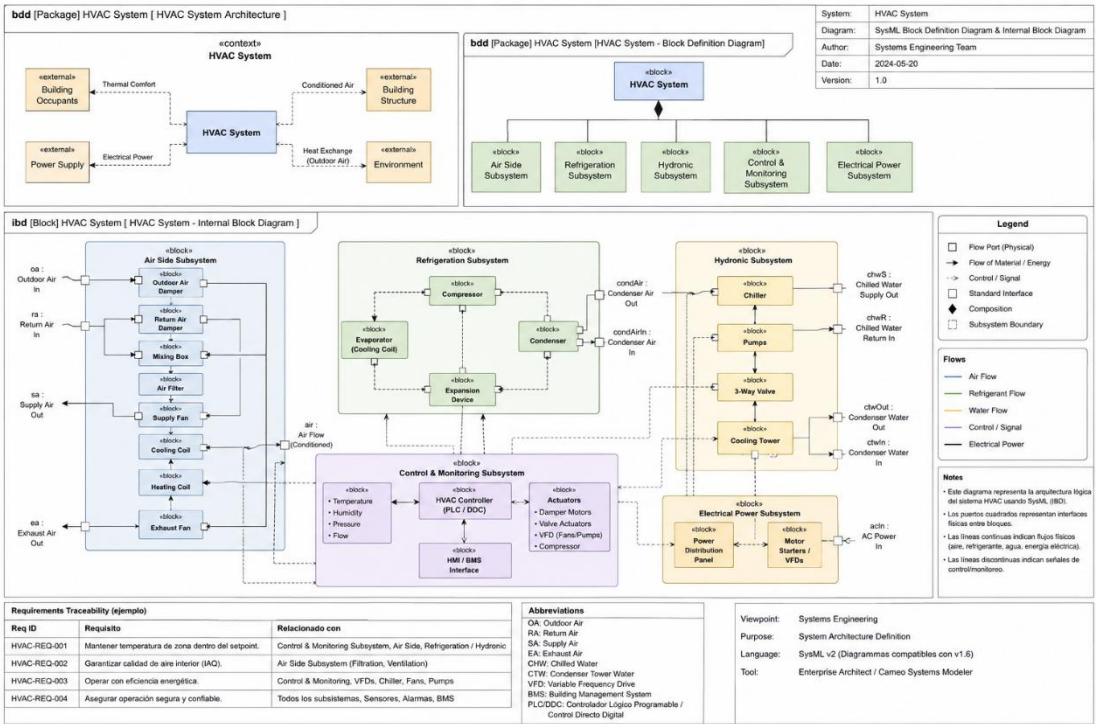


Case Study: HVAC system

An **HVAC system** designed to operate in Manual, Operational, and Autonomous modes, maintaining ambient temperature within defined ranges under automatic control.

The system complies with safety restrictions, energy efficiency standards and project governance requirements with periodic regulatory validation.

Additionally, the project objectives include conducting a formal Cost-Benefit Analysis (CBA) derived from the project's Product Breakdown Structure (PBS) and Cost Breakdown Structure (CBS)



Affordability Analysis: the financial viability of manufacturing 513 units under a total budget allocation of 50,000 \$, optimizing the balance between component costs—such as core control units, sensors, and heating/cooling subsystems—and the projected operational efficiency benefits of the system.

Case Study

Requirement ID	A Requirement Summary	Category	Difficulty
SysR-002	Modify the physical environment temperature	New	Nominal
SysR-025	System operates autonomously	New	Nominal
SysR-036	Provide bidirectional web services	Modified	Nominal
SysR-057	Include electrical protection equipment	Managed	Easy
SysR-073	Use Netduino 2 Plus motherboard	Adopted	Easy
SysR-084	Project manager meets regulator 3 times	Managed	Easy

Requirement Origin	B System Interfaces	Easy	Nominal	Difficult
New	SV ± 0.4V current (SysR-079)	n.a.	Ethernet cable RJ45-IP4 (SysR-083)	Temperature Actuation System (SysR-012)
Design for Reuse	Peltier Plate connection (SysR-162)	n.a.	Netduino 2 Plus motherboard (SysR-073)	n.a.
Modified System	10. Time Measurement Component (SysR-077)	n.a.	n.a.	n.a.
Deleted	n.a.	n.a.	n.a.	n.a.
Adopted	n.a.	n.a.	n.a.	n.a.
Managed	Peltier Plate connection (SysR-162)	n.a.	n.a.	n.a.

	C Algorithms		
Requirement Origin	Easy	Nominal	Difficult
New	n.a.	1. Temperature Regulation Algorithm (SysR-044)	7. Autonomous Control Algorithm (SysR-025, SysR-105)
Design for Reuse	2. Time Control Algorithm (SysR-140)	n.a.	n.a.
Modified System Req.	6. Ranking & Scoring Algorithm for Competition (SysR-097)	n.a.	n.a.
Deleted	n.a.	n.a.	n.a.
Adopted	5. Mode Transition Logic (SysR-126 to SysR-134)	n.a.	n.a.
Managed	n.a.	9. Safety & shutdown logic on overheat/underheat (SysR-020, SysR-021)	n.a.

CO SYS MO		2.0	
CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL		© 2009 Jared Fortune	
ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST			
# of System Requirements	Easy	Nominal	Difficult
# of System Interfaces	3	3	0
# of Algorithms	4	3	1
# of Operational Scenarios	3	2	1
	5	2	1
	4.5	19.1	26.3
	89.8		
	139.7		
equivalent size			
SELECT COST PARAMETERS FOR SYSTEM OF INTEREST			
Requirements Understanding	H	0.77	
Architecture Understanding	N	1.00	
Level of Service Requirements	N	1.00	
Migration Complexity	N	1.00	
Technology Risk	N	1.00	
Documentation	N	1.00	
# and diversity of installations/platforms	N	1.00	
# of recursive levels in the design	N	1.00	
Stakeholder team cohesion	N	1.00	
Personnel/team capability	N	1.00	
Personnel experience/continuity	N	1.00	
Process capability	H	0.85	
Multisite coordination	N	1.00	
Tool support	L	1.15	
		0.78	
composite effort multiplier			

SYSTEMS ENGINEERING PERSON MONTHS 0.35

SYSTEMS ENGINEERING PERSON HOURS 53.3

	D Operating Scenarios			
Requirement Origin	Easy	Nominal	Difficult	
New	10. Environmental Adaptation Scenario (SysR-184)	6. Operation Mode (SysR-019, SysR-002 to SysR-050, SysR-081, SysR-082, SysR-044, etc.)	8. Emergency Mode (SysR-091 to SysR-110, SysR-096, SysR-105, etc.)	
Design for Reuse	6. Operation Mode (SysR-019, SysR-002 to SysR-050, SysR-081, SysR-082, SysR-044, etc.)	9. Shutdown/Failure Modes (SysR-020, SysR-021, SysR-093, SysR-121)	n.a.	
Modified System Req.	7. Post-Operation Mode (SysR-130, SysR-131, SysR-133)	n.a.	n.a.	
Deleted	n.a.	n.a.	n.a.	
Adopted	1. Initialization Mode	n.a.	n.a.	
Managed	2. Authentication Mode (SysR-015, SysR-123, SysR-134)	n.a.	n.a.	

ESA/CNES Space Cost Engineering Conference 2026

Note: 'A' calibrated for small-scale and moderately complex engineering projects (e.g., HVAC System): 0.364

$$\text{Effort} = 0.364 \cdot 139.7^{1.06} \cdot 0.78 =$$

$$= 0.35 \text{ Person Months (PM)}$$

$$0.35 \text{ PM} \times 152 \text{ hours/PM} = 53.3 \text{ hours}$$

$$53.3 \text{ hours} \times 30 \text{ (M.U.)}/\text{hour} = 1,600 \text{ M.U.}$$

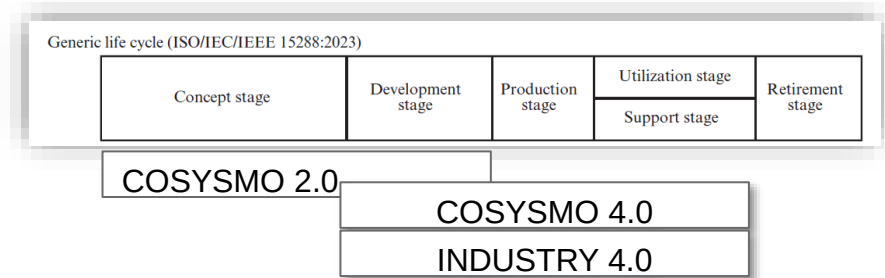
PBS & CBS Categories	Components & cost categories	Description	CBS: Estimated Unit Cost (M.U.)	Total (513 units) (M.U.)	%
Sensors					
1.1 Temperature Sensor	DHT22 / LM35	Measures return air temperature	2,50		
1.2 Humidity Sensor (optional)	DHT11 or AM2302	Optional environmental feedback	1,50		
Control Unit					
2.1 Microcontroller	ESP32 (preferred) / Arduino Nano	Data processing & Wi-Fi	4,80		
2.2 Power Management	Relay / MOSFET board	220 V AC switching for resistances or valves	2,20		
2.3 PCB & Small Components	Resistors, capacitors, ADC, connectors	Signal filtering & assembly	1,10		
Heating Subsystem					
3.1 Heating Element	Nichrome 300 W, 220 V	Auxiliary heating (fan coil / split)	5,80		
3.2 Heat Sink / Mount	Aluminum bracket / mica plate	Heat dissipation & mounting	1,00		
3.3 Fan for Air Distribution	DC axial fan	Ensures uniform air temperature	2,50		
Cooling Subsystem					
4.1 Cooling Element	Peltier or small DC fan	Local cooling (optional)	2,80		
4.2 Heat Sink	Aluminum finned	Thermal management	1,00		
Power Supply & Distribution					
5.1 Power Source	12 V DC / 35 W adapter	Powers control electronics	6,00		
5.2 Relay / MOSFET Interface	Power electronics	Switching 220 V heating/cooling loads	1,50		
User Interface					
6.1 Display	OLED 0.96" / LCD 16x2	System status display	3,00		
6.2 Buttons / Rotary Encoder	User input for setpoint		1,00		
6.3 Status LEDs	Operation indicators		0,40		
Enclosure & Insulation					
7.1 Casing	ABS plastic or aluminum	Outer frame	5,00		
7.2 Insulation	Foam / thermoplastic	Thermal isolation	1,00		
Assembly & Testing	Labor	Wiring, soldering, calibration	4,50		
Miscellaneous	Shipping, tools, contingencies	Consumables, packaging	0,80		
0. Personnel	Management / supervision	53.33 h / week × 30 M.U./h (1 week)	—	1,600.00	4,3%
1. General & Administrative (G&A)	x % of direct costs (subtotal)	Overheads, admin, QA	—		
TOTAL BUDGET (M.U.)					

From COSYSMO 2.0 to Lifecycle-Integrated: COSYSMO 4.0

Originally focused on early conceptual estimation, COSYSMO can evolve toward a lifecycle-wide estimation framework by leveraging continuous operational and engineering data generated across the V-model.

Digital Enablers of Industry 4.0

- Information Technologies for Data Processing and Communication : Big Data & Analytics, Cloud Computing, and Cybersecurity.
- Automation and Data Collection Technologies: Data Acquisition Systems, SCADA & Embedded Systems, Advanced Robotics, Cyber-Physical Systems, Internet of Things (IoT).



COSYSMO 4.0



$$eProdTime_i = A \cdot SIZE_i^E \cdot EM_i^Z$$

COSYSMO 4.0 Cost Estimation: An advanced systems engineering cost model utilized to develop Cost Estimation Relationships (CERs) by calibrating empirical variables from manufacturing orders, serving as a key metric provider for Model-Based Systems Engineering (MBSE) environments.

Element	Manufacturing Interpretation
A	Overall efficiency constant → lower A = lower investment -> higher productivity
SIZE _i	Technical parameters of each MO (m odels, r equirements, operations, manufacturing routes, etc.)
E	Productivity exponent → captures economies of scale in MOs
EM _i	Cost multipliers → production-specific factors: <ul style="list-style-type: none"> • Understanding → team knowledge of MO • Complexity → technical difficulty and risk • Operations → planning and execution • People → personnel skills and performance • Environment → production context and variability
Z	Captures organizational intangibles (knowledge management, innovation, creativity); lower Z = higher efficiency

Case Study: Electrical Heating Elements

Digital thread: Requirements & Parameters, Data Acquisition System, and Enterprise Resource Planning

Context:

- Real-world case from a **make-to-order SME** specialized in electrical elements.
- Workshop: **17 sections, 244 centers, 374 operations.**

Time span:

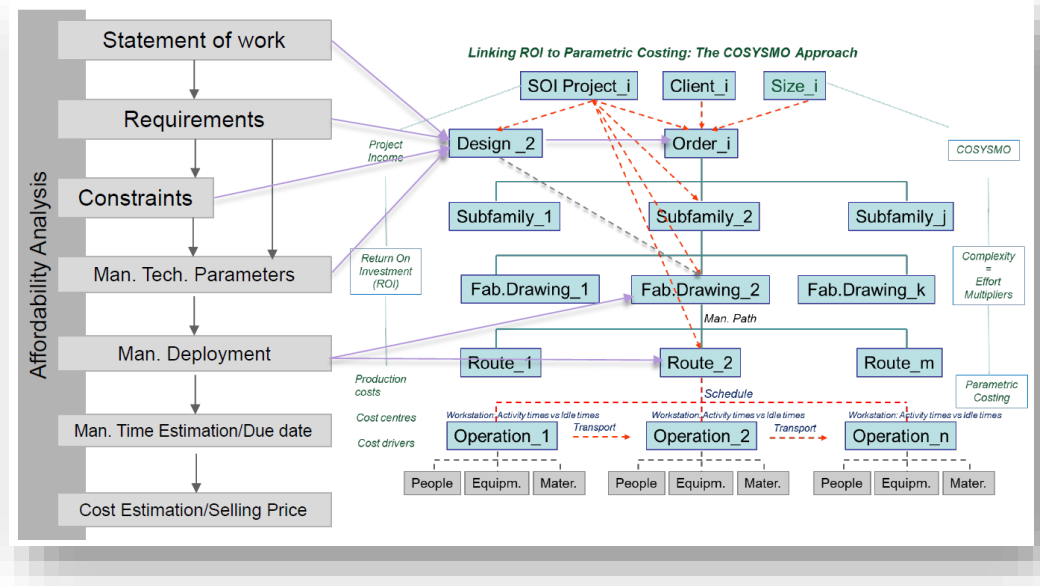
- **Feb 2005 – Dec 2008** (3 years, 11 months).
- **5,700 Manufacturing Orders (MOs)** generated, covering **660K task duration records.**

Final dataset:

- After outlier detection → **NULLs and Anomalous values.**
- Data structure: 67 fields (technical specifications, manufacturing data, and temporal information).

Data acquisition:

- Initially manual logging on MO sheets → later automated with **barcode readers & terminals.**
- Records structured hierarchically.



Case Study

Parametric MBSE Integration: Translates physical, operational, and environmental design variables into validated parametric cost drivers, allowing engineering teams to evaluate the financial impact of system architecture changes directly within the MBSE model.

Variable	Coeff.	p-Value
S_Watt	-0.001	0
S_OhmIni	-0.020	0
S_Operations	1.033	0
S_TotalSizeMeters	0.021	0
E_E_BadQ	0.054	0
E_O_OrderScheduledQty	0.045	0
E_X_Feature_02	4.204	0
E_X_Feature_03	8.494	0
E_X_Family_07	8.761	0.032
E_X_Family_11	19.233	0.015
E_X_Family_12	10.134	0.047
E_X_Family_17	2.829	0

$$eProdTime_i = 1.571 \cdot SIZE_i^{0.656} \cdot EM_i^{0.398}$$

VARIABLE	Coeff.	Batch 513	Values
S_Watt	-0,001	330	-0,33
S_Onlni	-0,02	174	-3,48
S_Operations	1,033	23	23,76
S_TotalSizeMeters	0,021	188	3,94
TOTAL SIZE			23,89
E_E_BadQ	0,054	1	0,05
E_OrderScheduledQty	0,045	513	22,83
E_X_Feature_02	4,201	1	4,20
E_X_Feature_03	8,494	0	0,00
E_X_Family_07	8,701	0	0,00
E_X_Family_11	19,233	0	0,00
E_X_Family_12	10,134	0	0,00
E_X_Family_17	2,829	0	0,00
TOTAL EM			27,08

$$eProdTime_i = 1.571 \times 23.89^{0.656} \times 27.08^{0.398}$$

$$eProdTime_i = 46.84 \text{ person hours (NS)}$$

Case Study

- **Parameter A** is a measure of the base complexity within each domain
 - Valerdi's **=38.55** reflects the substantial effort required for a **large-scale, highly complex and heavily regulated engineering projects (e.g., aerospace)**.
 - Adapted model for bespoke electrical heating elements manufacturing **1.57** indicates that a unit of SIZE in fabrication entails considerably **less complexity and effort**.
- The **elasticity parameter $E=0.656 < 1$** : implies economies of scale, as SIZE increases, the incremental effort per unit grows less than proportionally, reflecting the **efficiency of repetitive manufacturing processes**.
- Finally, the **effort parameter $Z = 0.398$** indicates that the influence of individual manufacturing steps—accounting for variations in machine, operator, batch size, and setup times—is relatively smaller than the effect of SIZE, as expected in **mature and well-standardized production processes**.

Case Study

Parametric MBSE Integration: Translates physical, operational, and environmental design variables into validated parametric cost drivers, allowing engineering teams to evaluate the financial impact of system architecture changes directly within the MBSE model.

Selling price estimation		Regular batch		%	
Size		513			
Indirect costing		37,26			M. U./Hour
Actual Man.Time (Effort)		46,84			Hour
Indirect cost - CAPEX		1745,11			M. U.
Indirect cost per unit		3,40	58,7%		M. U./unit
Direct cost per unit - OPEX		1,23	21,3%		M. U./unit
Manufacturing cost per unit		4,64	80,0%		M. U./unit
Net Margin (25% Man.Cost.)		1,16	20,0%		M. U./unit
Price per unit (no VAT)		5,80	100,0%		M. U./unit
Batch price		2.973,19			M. U./unit

PBS & CBS Categories	Components & cost categories	Description	CBS: Estimated Unit Cost (M.U.)	Total (513 units) (M.U.)	%
1. Sensors					
1.1 Temperature Sensor	DHT22 / LM35	Measures return air temperature	2,50		
1.2 Humidity Sensor (optional)	DHT11 or AM2302	Optional environmental feedback	1,50		
2. Control Unit					
2.1 Microcontroller	ESP32 (preferred) / Arduino Nano	Data processing & Wi-Fi	4,80		
2.2 Power Management	Relay / MOSFET board	220 V AC switching for resistances or valves	2,20		
2.3 PCB & Small Components	Resistors, capacitors, ADC, connectors	Signal filtering & assembly	1,10		
3. Heating Subsystem					
3.1 Heating Element	Nichrome 300 W, 220 V (split)	Auxiliary heating (fan coil / split)	5,80	2.973,20	8,0%
3.2 Heat Sink / Mount	Aluminum bracket / mica plate	Heat dissipation & mounting	1,00		
3.3 Fan for Air Distribution	DC axial fan	Ensures uniform air temperature	2,50		
4. Cooling Subsystem					
4.1 Cooling Element	Peltier or small DC fan	Local cooling (optional)	2,80		
4.2 Heat Sink	Aluminum finned	Thermal management	1,00		
5. Power Supply & Distribution					
5.1 Power Source	12 V DC / 35 W adapter	Powers control electronics	6,00		
5.2 Relay / MOSFET Interface	Power electronics	Switching 220 V heating/cooling loads	1,50		
6. User Interface					
6.1 Display	OLED 0.96" / LCD 16x2	System status display	3,00		
6.2 Buttons / Rotary Encoder	User input for setpoint		1,00		
6.3 Status LEDs	Operation indicators		0,40		
7. Enclosure & Insulation					
7.1 Casing	ABS plastic or aluminum	Outer frame	5,00		
7.2 Insulation	Foam / thermoplastic	Thermal isolation	1,00		
8. Assembly & Testing					
	Labor	Wiring, soldering, calibration	4,50		
9. Miscellaneous					
	Shipping, tools, contingencies	Consumables, packaging	0,80		
10. Personnel					
	Management / supervision	53.33 h / week x 30 M.U./h (1 week)	—	1.600,00	4,3%
11. General & Administrative (G&A)					
	x % of direct costs (subtotal)	Overheads, admin, QA	—		
TOTAL BUDGET (M.U.)					

Case Study

Parametric MBSE Integration: Translates physical, operational, and environmental design variables into validated parametric cost drivers, allowing engineering teams to evaluate the financial impact of system architecture changes directly within the MBSE model.

Selling price estimation	Regular batch		%	
Size	513			
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PBS & CBS Categories	Components & cost categories	Description	CBS: Estimated Unit Cost (M.U.)	Total (513 units) (M.U.)	%
1. Sensors					
1.1 Temperature Sensor	DHT22 / LM35	Measures return air temperature	2,50	1.282,50	3,5%
1.2 Humidity Sensor (optional)	DHT11 or AM2302	Optional environmental feedback	1,50	769,50	2,1%
2. Control Unit					
2.1 Microcontroller	ESP32 (preferred) / Arduino Nano	Data processing & Wi-Fi	4,80	2.462,40	6,6%
2.2 Power Management	Relay / MOSFET board	220 V AC switching for resistances or valves	2,20	1.128,60	3,0%
2.3 PCB & Small Components	Resistors, capacitors, ADC, connectors	Signal filtering & assembly	1,10	564,30	1,5%
3. Heating Subsystem					
3.1 Heating Element	Nichrome 300 W, 220 V	Auxiliary heating (fan coil / split)	5,80	2.973,20	8,0%
3.2 Heat Sink / Mount	Aluminum bracket / mica plate	Heat dissipation & mounting	1,00	513,00	1,4%
3.3 Fan for Air Distribution	DC axial fan	Ensures uniform air temperature	2,50	1.282,50	3,5%
4. Cooling Subsystem					
4.1 Cooling Element	Peltier or small DC fan	Local cooling (optional)	2,80	1.436,40	3,9%
4.2 Heat Sink	Aluminum finned	Thermal management	1,00	513,00	1,4%
5. Power Supply & Distribution					
5.1 Power Source	12 V DC / 35 W adapter	Powers control electronics	6,00	3.078,00	8,3%
5.2 Relay / MOSFET Interface	Power electronics	Switching 220 V heating/cooling loads	1,50	769,50	2,1%
6. User Interface					
6.1 Display	OLED 0.96" / LCD 16x2	System status display	3,00	1.539,00	4,1%
6.2 Buttons / Rotary Encoder	User input for setpoint		1,00	513,00	1,4%
6.3 Status LEDs	Operation indicators		0,40	205,20	0,6%
7. Enclosure & Insulation					
7.1 Casing	ABS plastic or aluminum	Outer frame	5,00	2.565,00	6,9%
7.2 Insulation	Foam / thermoplastic	Thermal isolation	1,00	513,00	1,4%
8. Assembly & Testing					
	Labor	Wiring, soldering, calibration	4,50	2.308,50	6,2%
9. Miscellaneous					
	Shipping, tools, contingencies	Consumables, packaging	0,80	410,40	1,1%
10. Personnel					
	Management / supervision	53.33 h / week x 30 M.U./h (1 week)	—	1.600,00	4,3%
11. General & Administrative (G&A)					
	x % of direct costs (subtotal)	Overheads, admin, QA	—	10.670,00	28,8%
TOTAL BUDGET (M.U.)				37.097,00	100,0%

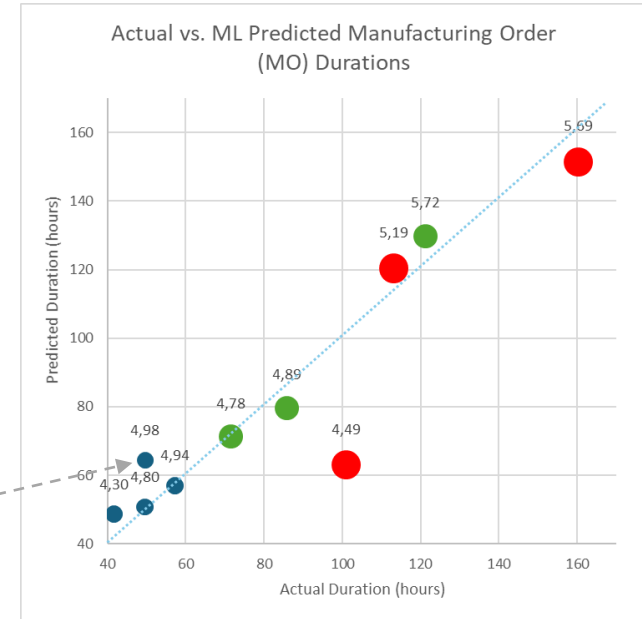
Case Study

The predictive engine utilizes the WEKA M5P decision tree algorithm to construct piecewise linear regression models from historical manufacturing data. The framework segments complex production spaces into linear sub-regions, offering high predictive accuracy for Manufacturing Order (MO) durations while generating fully explainable, rule-based output required for institutional cost auditing.

Comparison of cost and nominal schedule effort across estimation models

Cost and Effort by Model	Person Hours (Nominal Schedule)	Cost (M.U.)
COSYSMO 4.0	46.84	2,973.20
Historical Data (Actual)	49.67	3,036.16
M5P (Prediction)	64.39	3,363.90
Average	53.63	3,124.42

M5P Configuration in WEKA (`weka.classifiers.trees.M5P`) set to generate unpruned, unsmoothed decision trees (`-U -M 10.0 -L`). The minimum number of instances per leaf node was set to 10 to prevent overfitting on local manufacturing noise. Model evaluation was executed via 10-fold cross-validation, exporting full prediction outputs and evaluation metrics directly to structured CSV threads.



At first sight, it looks like M5P overreacts to local variations in the data for this specific MO. However, when the numerical labels that represent the worker inexperience (higher values reflect an increased number of operators and/or shorter tenure). The circle markers are scaled according to the total order length (Blue: 510-530 u.; Green: 1020-1030 u.; Red: 1510-1540 u.).

Case Study

=== Classifier model (full training set) ===

M5 pruned model tree:

```
OperariosSumaIDs <= 4.668133964 :
|   SumOfQFabricar <= 4.600145018 :
|   |   OperariosSumaIDs <= 4.034201479 : LM1 (1325/39.3%)
|   |   OperariosSumaIDs > 4.034201479 :
|   |   |   CantidadTotal <= 3.384246606 : LM2 (686/38.7%)
|   |   |   CantidadTotal > 3.384246606 :
|   |   |   |   QxLonA_mts <= 4.720459309 : LM3 (1033/26.7%)
|   |   |   |   QxLonA_mts > 4.720459309 : LM4 (402/33.1%)
|   SumOfQFabricar > 4.600145018 :
|   |   OperariosSumaIDs <= 4.135134556 : LM5 (541/40.6%)
|   |   OperariosSumaIDs > 4.135134556 :
|   |   |   SumOfQFabricar <= 5.602112013 :
|   |   |   |   RESTBCL2=7,?,11,4,8,5 <= 0.5 :
|   |   |   |   |   RESTBDIF <= 2.128411524 :
|   |   |   |   |   |   SumOfQFabricar <= 4.955727861 :
|   |   |   |   |   |   |   RESWATIO <= 6.704822685 : LM6 (111/17.3%)
|   |   |   |   |   |   |   RESWATIO > 6.704822685 :
|   |   |   |   |   |   |   |   HistoriaVeces <= 2.967447098 : LM7 (129/30.8%)
|   |   |   |   |   |   |   |   HistoriaVeces > 2.967447098 :
|   |   |   |   |   |   |   |   |   QxLonA_mts <= 4.776900194 : LM8 (15/51.4%)
|   |   |   |   |   |   |   |   |   QxLonA_mts > 4.776900194 : LM9 (57/19.3%)
|   |   SumOfQFabricar > 4.955727861 :
|   |   |   RESLONCT <= 2.441400961 :
|   |   |   |   Yearmonth <= 17.5 : LM10 (101/16.0%)
|   |   |   |   Yearmonth > 17.5 :
|   |   |   |   |   Yearmonth <= 39.5 : LM11 (95/19.0%)
```

Note: In the notation LM num (N / percentage), LM is the Local Model (leaf-node linear regression equation); N is the sample size (number of manufacturing orders assigned to the leaf node); and percentage is the LRV, i.e., the Local Residual Variance ($sd(S_i) / sd(S)$ derived from the M5P SDR partitioning criterion).

Technological Regime Identification via M5P Partitioning

The M5P tree automatically stratifies the manufacturing dataset into 56 distinct local linear models (LM1 to LM56), classifying operational spaces based on Local Residual Variance (LRV). For example:

- Exploitation Regimes (LM6, LM9, LM10, LM11): High-stability production (LRV < 20 %), providing predictable cost baselines for mature subsystems.
- Exploration & Prototyping Regimes (LM1–LM5, LM7): Moderate variance (30% - 40%) capturing standard engineering changes and low-rate initial production.
- Operational Anomalies (LM8): Successfully isolates non-standard manufacturing events (LRV > 51%, N=15), preventing systemic noise from distorting institutional cost estimates.

Final Conclusions

1. System Lifecycle Affordability Integration

Synthesizes ISO 15288 and ISO 24748-4 with MBSE into an architectural digital thread—enforcing strict WBS-PBS-CBS structural alignment to transition financial governance toward engineering-driven Target Costing.

2. COSYSMO 4.0 in MBSE Environment

Adapts Valerdi's original COSYSMO model to Industry 4.0 smart manufacturing, bridging system architecture (MBSE) directly with shop-floor execution parameters to convert requirements into actionable cost drivers.

3. Hybrid Parametric & Machine Learning Analytics

Integrates M5P model trees with COSYSMO 4.0 to secure high overall accuracy while partitioning Manufacturing Orders (MOs) into stable Exploitation states vs. volatile Exploration or anomalous events.

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A full-page background image showing a view of Earth from space. The sun is rising directly behind the horizon, creating a bright, glowing effect with lens flare. The Earth's surface is visible, showing continents and oceans. The sky is dark with many stars.

Thank you