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# Boosting COSYSMO to derive a comprehensive Acquisition benchmarking tool

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**Abstract.** The combination of the Constructive Systems Engineering Cost Model (COSYSMO) version 2.0 with the Capability Maturity Model Integration (CMMI) creates a groundbreaking approach to optimizing public sector acquisition. This methodology enhances cost estimation accuracy, supplier evaluation, and risk management by also incorporating the comprehensive SE frameworks from ANSI/EIA 632, Total Cost of Ownership (TCO), and Technology Readiness Levels (TRL). The proposed model addresses the complexities inherent in public acquisition by aligning technical and organizational assessments with evidence-based metrics.

To adapt COSYSMO 2.0 for public sector use, the model uses metrics derived from INCOSE's Guide to Writing Requirements (GtWR), enabling the segmentation of requirements into 'easy,' 'nominal,' and 'hard' categories. The classification, based on an analysis of bidder submitted Request for Information (RFI) and Request for Quote (RFQ) documentation, creates a comparable and baselined Total Cost of Ownership (TCO) cost estimations. The inclusion of requirement quality analysis using the correctness, completeness, and consistency metrics per INCOSE's standards supports a robust quality assessment of requirements early in the process, helping the contracting agencies to make a robust and fair decision answering:

***Who is the best supplier from a technical, economical and project perspective and what risks are associated with the different potential contractors?***

**Keywords:** COSYSMO, GtWR, Public Acquisition, Risk, CMMI, TRL, LCC, TCO

## Introduction

The COSYSMO 2.0 cost model calibration process is a cornerstone of this integration, ensuring the model reflects the unique context of public acquisitions (Valerdi, 2006). Calibration involves collecting historical project data from prior projects and aligning key cost drivers such as requirements complexity, team size, and schedule constraints from real-world scenarios. This iterative adjustment enhances the accuracy of cost predictions by tailoring COSYSMO's baseline parameters to the acquisition environment, particularly when estimating the costs associated with different technical maturity levels of the proposed solutions.

The challenge for organizations performing public acquisition is the lack of valid historical data for this calibration since; no acquisition is equal in size and complexity, the time elapsed and the arm's length distance between the acquirer and supplier makes the calibration a virtually impossible challenge. But measures and activities can be taken to use the model as a cornerstone and base for a comparable assessment of different bids from multiple possible suppliers before signing a contract. The actual data received is collected through a controlled and comparable process. A more correct TCO estimate can be obtained after the contract is signed. This based on the initial data and then eventually updated when the system design and contractual relationship has matured.

Another key feature of the integration of this acquisition bench marking technique is the incorporation of TRL-based technical maturity assessments. Bidders are required to provide evidence-backed TRL evaluations of their proposed solutions, allowing contracting agencies to assess both technical readiness and associated developmental risks. TRL evaluations directly influence TCO estimations by identifying gaps between current technology maturity and project goals. These gaps are quantified as technical debt, which increases the projected cost of further development, testing, and finally production. By integrating TRL into the cost model, contracting agencies can gain a clear understanding on how the maturity of a proposed solution impacts both acquisition and lifecycle costs, including potential delays and cost overruns during development, production and final delivery.

The ANSI/EIA 632 standard further enhances this framework by defining work breakdown structures (WBS) that clarify the allocation of responsibilities between contracting agencies and suppliers, ensuring accountability across the project lifecycle (Valerdi & Wheaton, 2005). This alignment simplifies the integration of COSYSMO outputs with project management practices and facilitates communication between stakeholders. The different engineering tasks have been divided in size between the purchaser and the supplier based on an best practice and historical estimate.

CMMI capability areas are leveraged to evaluate organizational maturity in performing development and delivery of the contract. By integrating CMMI domains such as Process Management, Risk Management, and Product Integration, the framework provides an evidence-based self-assessment methodology that ensures the supplier's alignment with contractual and technical objectives. The resulting data informs decision-making during bidder evaluation and negotiation, mitigating risks associated with immature organizational processes and will enhance the correctness in the COSYSMO data model.

Cost analysis is embedded within this bench marking methodology to enable comprehensive cost estimation over the system's lifecycle, including acquisition, operation, and maintenance costs. Leveraging best practice principles, the model supports a Total Cost of Ownership (TCO) perspective, capturing costs related to spares, training, maintenance, and system unavailability (Ellram, 1995). The integration of TRL risk assessments into financial analysis enables a nuanced analysis of how technology maturity (and technical depth) affects not just upfront acquisition costs but also long-term operational expenditures.

## ***The Public Acquisition Dilemma***

In public procurement, achieving the optimal balance between cost and quality presents a significant challenge. Contracting agencies must ensure that public funds are utilized efficiently while delivering goods and services that meet required standards. This dilemma involves several key issues:

1. **Defining 'Best Value':** Determining what constitutes the best value is complex, as it requires evaluating both quantitative factors (like cost) and qualitative aspects (such as quality and performance). The subjective nature of quality assessments can lead to inconsistencies and disputes.
2. **Risk of Overemphasis on Cost (price):** Focusing primarily on the lowest bid can result in selecting suppliers who may not meet quality standards, leading to unacceptable outcomes and potential long-term costs due to rework or failures.
3. **Measurement Challenges:** Quantifying quality in a standardized manner is difficult, making it hard to compare bids objectively. This challenge is compounded when dealing with complex or innovative products and services.
4. **Regulatory Constraints:** Public procurement is often governed by strict regulations aimed at ensuring fairness and transparency. These rules can limit flexibility in decision-making, making it harder to consider qualitative factors adequately.
5. **Supplier Diversity:** Balancing cost and quality must also account for promoting competition and supporting small and medium-sized enterprises (SMEs). Overemphasis on cost can disadvantage smaller suppliers who may offer higher quality but at a higher price point.

According to literature (Fröling, 2022), these challenges necessitate a comprehensive approach to procurement that includes:

- **Developing Clear Evaluation Criteria:** Establishing transparent and measurable criteria for both cost and quality to guide decision-making.
- **Implementing Total Cost of Ownership (TCO) Analysis:** Considering all costs associated with a product or service over its lifecycle, not just the initial purchase price.
- **Engaging Stakeholders:** Involving end-users and other stakeholders in defining quality requirements to ensure that procurement decisions align with actual needs.
- **Training of Procurement Officials:** Providing education on best practices for evaluating quality and cost to enhance decision-making capabilities.

We need a robust model to help the Contracting agencies to manage a fundamental trinity and “balancing act”:

**Technology:** Not too much detailed requirements, putting restraints on the market or purchasing old solutions, but also not too little details to increase the risk of not meeting stakeholder needs during system validation at the end of the delivery project.

**Project:** The supplier delivery project must be defined without forcing the supplier to work with unknown processes or adding unnecessary bureaucracy and cost. We also need to understand and accept that systems quality is the sum of its functions, enforced constraints and fulfilled quality requirements and this easily becomes a “hen and the egg” problem, since the contracting agency cannot fully define the quality of the system or service before the detailed solution is contracted and design and delivery work has started.

**Business:** The contracting body need to adhere to both internal procurement practices, national laws and other economic judgements made early in an acquisition project. While the procurement official wants less detailed requirements to fulfil business laws and regulations the technical department inevitable wants more requirements to control risk and uncertainty and to ultimately “know what’s to be delivered”.

It’s often a source of frustration and internal struggle to get these three views aligned and we need a common ground and solid model to guide the acquisition in the right direction towards a contract with the best supplier fulfilling all three points of views in an optimal way (Figure 1).

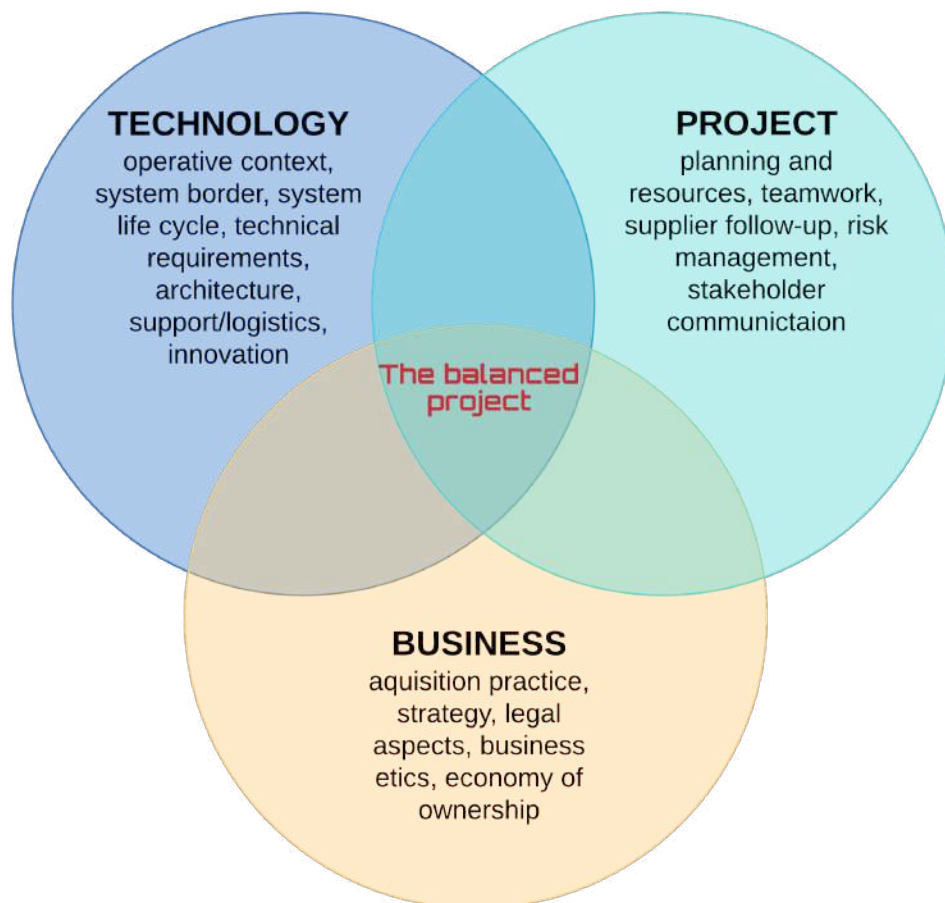


Figure 1 The procurement balancing act: Technology, Project control and business law

An efficient project is a balanced project where the contracting agency has been able to properly define the requirement for the SOI as a combination of technical system requirements within a defined and clearly described context, a clear project scope not enforcing any unnecessary process constraints on the supplier and all of this within the business and legal aspects of a public procurement down select, negotiation and contract.

## Using COSYSMO 2.0 for Public Acquisition

COSYSMO 2.0 (Constructive Systems Engineering Cost Model) is an advanced cost-estimating data model specifically designed for Systems Engineering (SE) tasks (Figure 2). It helps organizations predict the effort required for SE activities based on system characteristics and project parameters. COSYSMO 2.0 builds on the original COSYSMO framework with enhancements for modern SE practices, reflecting advancements in technology, project complexity, and iterative development methodologies.

Core concepts of COSYSMO 2.0 is the effort estimation where the effort is estimated in the person-months required to perform SE tasks throughout the system's lifecycle.

CO SYS MO  
CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

2.0

8-Jul-10

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ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

Reuse?

|                            | Easy | Nominal | Difficult |                   |
|----------------------------|------|---------|-----------|-------------------|
| # of System Requirements   |      |         |           | } equivalent size |
| # of System Interfaces     |      |         |           |                   |
| # of Algorithms            |      |         |           |                   |
| # of Operational Scenarios |      |         |           |                   |

0.0  
0.0  
0.0  
0.0

0.0

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

|  |      |                             |
|--|------|-----------------------------|
| Requirements Understanding                 | N    | 1.00                        |
| 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 learn cohesion                 | N    | 1.00                        |
| Personnel/team capability                  | N    | 1.00                        |
| Personnel experience/continuity            | N    | 1.00                        |
| Process capability                         | N    | 1.00                        |
| Multisite coordination                     | N    | 1.00                        |
| Tool support                               | N    | 1.00                        |
|  | 1.00 | composite effort multiplier |

SYSTEMS ENGINEERING PERSON MONTHS 0.0

Figure 2 The basic COSYSMO 2.0 data model

This is the list of COSYSMO 2.0 effort multipliers used in the calculation:

1. **Requirements Understanding** – Clarity and stability of requirements.
2. **Architecture Complexity** – Difficulty in designing the system architecture.
3. **Technical Risk and Maturity** – Readiness and uncertainty of technologies.
4. **Team Capability** – Skill and experience of the SE team.
5. **Process Capability** – Maturity and efficiency of SE processes.
6. **Tool Support** – Quality and extent of tools aiding SE tasks.
7. **Multisite Coordination** – Effort to manage distributed teams.
8. **Integration Complexity** – Difficulty of integrating system components.
9. **Schedule Pressure** – Impact of tight deadlines.
10. **System Scope** – Size and breadth of the system's functionality.

This list of multipliers has one problem in our chosen context; These multipliers are designed without public procurement in mind and focuses on SE tasks, soft factors and the system life cycle from the SOI perspective. For a setting where the system is shaped, designed, produced and integrated in symbiosis between an acquirer and a supplier, this means new challenges and uncertainties:

How to divide the SE tasks and how to assess and determine the different judgements being made to feed the COSYSMO data model with correct and evidence-based data? For this we need a solid approach with a valid and explainable outcome where we can divide the workload and estimate uncertainty.

### Aligning the Systems Engineering Effort

The System and software engineering standard, ISO/IEC/IEEE 15288:2023, includes a broad spectrum of technical, process and project processes and we need a valid breakdown of the planned SE tasks planned according to the planned and contracted SE scope. The standard ANSI/EIA 632 was used to create an estimated “work share” between the contracting agency and the supplier.

ANSI/EIA-632, **Processes for Engineering a System**, is a standard providing a structured model for performing systems engineering (SE) tasks. It defines an integrated set of processes to guide the development of complex systems across their lifecycle (Figure 3). The framework emphasizes integrating technical and management activities to ensure system success. It’s divided into a set of useful **13 essential processes** grouped into five categories:

| Fundamental Processes  | Process Categories              | Activities   |
|------------------------|---------------------------------|--|
| Acquisition and Supply | Supply Process                  | (1) Product Supply   |
|                        | Acquisition Process             | (2) Product Acquisition, (3) Supplier Performance  |
| Technical Management   | Planning Process                | (4) Process Implementation Strategy, (5) Technical Effort Definition, (6) Schedule and Organization, (7) Technical Plans, (8) Work Directives                                      |
|                        | Assessment Process              | (9) Progress Against Plans and Schedules, (10) Progress Against Requirements, (11) Technical Reviews   |
|                        | Control Process                 | (12) Outcomes Management, (13) Information Dissemination   |
| System Design          | Requirements Definition Process | (14) Acquirer Requirements, (15) Other Stakeholder Requirements, (16) System Technical Requirements  |
|                        | Solution Definition Process     | (17) Logical Solution Representations, (18) Physical Solution Representations, (19) Specified Requirements   |
| Product Realization    | Implementation Process          | (20) Implementation  |
|                        | Transition to Use Process       | (21) Transition to use   |
| Technical Evaluation   | Systems Analysis Process        | (22) Effectiveness Analysis, (23) Tradeoff Analysis, (24) Risk Analysis  |
|                        | Requirements Validation Process | (25) Requirement Statements Validation, (26) Acquirer Requirements, (27) Other Stakeholder Requirements, (28) System Technical Requirements, (29) Logical Solution Representations |
|                        | System Verification Process     | (30) Design Solution Verification, (31) End Product Verification, (32) Enabling Product Readiness  |
|                        | End Products Validation Process | (33) End products validation   |

Figure 3 ANSI/EIA 632 basic activities

Both ISO/IEC/IEEE 15288:2023 and ANSI/EIA 632 take the systems lifecycle perspective, and this introduces a faulty bias into our estimate. The contracting agency are performing some parts of the initial SE tasks and defines the SOI, contextual boundaries, OPSCON/CONOPS, etc, while the supplier(s) perform the majority of the SE tasks with the contracting agency as the system authority and approver.

The contracting agency therefor needs to divide these tasks into a proper workshare between the contracting organisation and Supplier. The estimates were made together with the contracting organisation and their own experts. The work share was divided into a set of early defined life cycle steps (Figure 4). An estimate of the workshare based on a basic assessment of the work to be performed by the supplier and the work already done by the contracting agency as part of a contracting work and later participation in the development, test, verification/validation and final transition into use can be seen below:

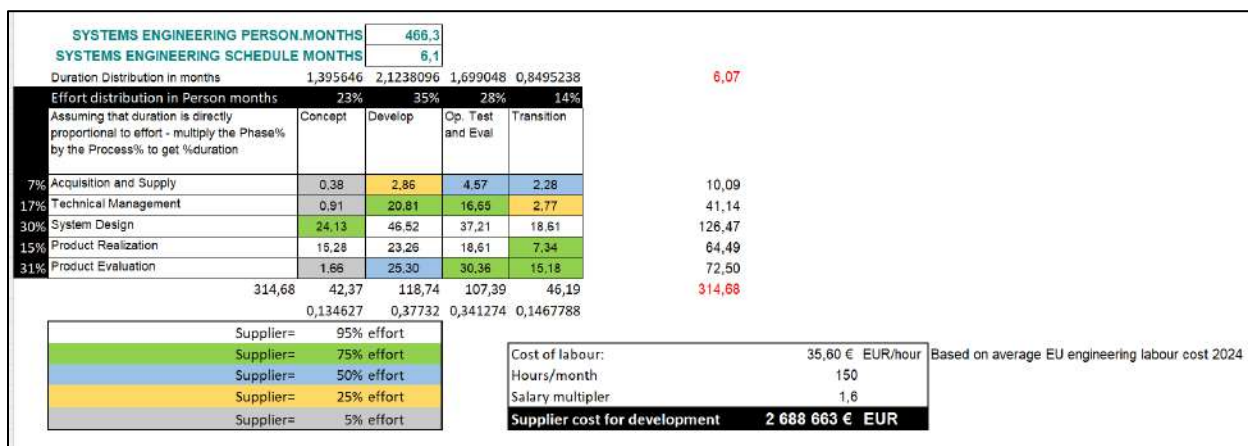


Figure 4 Workshare of engineering tasks

This enables us to define a transparent workshare to analyze the actual SE related engineering cost obtained by the COSYSMO model where the estimated SE cost for each supplier can be estimated.

## Using the INCOSE GtWR to assess Requirements Quality

The SE workshare is important to get an accurate total estimation with less biased result, but there are other parameters as well in the COSYSMO data model to consider, i.e. the different size parameters; # of System requirements, # of System architecture, # of algorithms and # of operational scenarios.

By creating a good view of the system of interest being purchased, including a solid stakeholder and contextual definition, it's not too difficult to estimate these parameters. There is one exception from this statement. The # of System requirements should be assessed according to the defined number of EASY/NOMINAL/DIFFICULT of requirements. The question arises on how to judge these characteristics towards a set of defined requirements?

There are numerous works and papers done to describe different characteristics of a good requirement (Wiegiers, 2006), efficient requirement analysis (Halligan, 2017) or applying knowledge-based approach to requirements definition (Góngora, Llorens & Gallego, 2017). They all describe good versus bad requirements and it all boil down to the fact that there is a need to define specific quality metrics to analyse the quality on one requirement to be able to place this requirement in the correct category according to COSYSMO.

The decision was made when this approach was developed to utilise INCOSE GfWR (INCOSE, 2023). Basic requirements quality rules for requirements correctness, consistency and completeness were analysed according to their applicability and suitability (Figure 7) and 28 metrics out of 42 was selected:

| Quality Focus          | Rule | Subject                          | Characteristics for Individual needs and requirements |    |    |    |    |    |    |    |    |     | Characteristics for Sets of needs requirements |     |     |     |     |
|------------------------|------|----------------------------------|---|----|----|----|----|----|----|----|----|-----|--|-----|-----|-----|-----|
|                        |      |                                  | C1  | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11  | C12 | C13 | C14 | C15 |
| Accuracy               | R1   | Structured Statements            |   | X  | X  |    |    |    | X  | X  | X  |     |  |     |     |     |     |
|                        | R2   | Active Voice                     |   | X  | X  | X  |    |    | X  |    |    |     |  |     |     |     |     |
| Non-ambiguity          | R3   | Appropriate Subject-Verb         |   | X  | X  |    |    |    | X  |    |    | X   |  |     |     |     | X   |
|                        | R4   | Defined Terms                    |   |    | X  |    |    |    | X  |    |    | X   |  | X   | X   | X   | X   |
| Concision              | R5   | Definite Articles                |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
|                        | R6   | Common Units of Measure          |   |    | X  | X  |    |    | X  | X  |    |     |  |     |     |     |     |
| Singularity            | R7   | Vague Terms                      |   |    | X  | X  |    |    | X  |    |    |     |  |     |     |     |     |
|                        | R8   | Escape Clauses                   |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
| Completeness           | R9   | Open-ended Clauses               |   |    | X  | X  | X  |    | X  |    |    |     |  |     |     |     |     |
|                        | R10  | Superfluous infinitives          |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
| Uniqueness             | R11  | Separate Clauses                 |   |    | X  | X  |    |    | X  | X  |    |     |  |     |     |     |     |
|                        | R12  | Correct Grammar                  |   |    | X  |    |    |    | X  | X  | X  |     |  |     |     |     |     |
| Modularity             | R13  | Correct Spelling                 |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
|                        | R14  | Correct Condition                |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
| Uniformity of Language | R15  | Logical Expressions              |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
|                        | R16  | Use of "Not"                     |   |    | X  |    |    |    | X  | X  |    |     |  |     |     |     |     |
| Consistency            | R17  | Use of Oblique Symbol            |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
|                        | R18  | Single-thought Sentence          |   |    | X  |    | X  |    | X  |    | X  |     |  | X   |     |     |     |
| Completeness           | R19  | Combinators                      |   |    | X  |    | X  |    |    |    |    |     |  |     |     |     |     |
|                        | R20  | Purpose Phrases                  | X   |    |    |    | X  |    |    |    |    |     |  |     |     |     |     |
| Uniqueness             | R21  | Parentheses                      |   |    |    |    | X  |    |    |    |    |     |  |     |     |     |     |
|                        | R22  | Enumeration                      |   |    | X  | X  |    |    |    |    |    |     |  |     |     |     |     |
| Completeness           | R23  | Supporting Diagram, Model or ICD |   |    | X  | X  | X  |    |    |    |    |     |  |     |     |     |     |
|                        | R24  | Pronouns                         |   |    | X  | X  |    |    | X  |    |    |     |  |     |     |     |     |
| Realism                | R25  | Headings                         |   |    | X  |    |    |    |    |    |    |     |  |     |     |     |     |
|                        | R26  | Absolutes                        |   |    |    |    |    | X  | X  | X  |    |     | X  |     |     |     |     |
| Conditions             | R27  | Explicit Conditions              |   |    |    | X  |    |    | X  | X  |    |     |  |     |     |     |     |
|                        | R28  | Multiple Conditions              |   |    | X  |    |    |    | X  |    |    |     |  |     |     |     |     |
| Uniqueness             | R29  | Classification                   |   |    |    |    |    |    |    |    | X  | X   |  |     |     |     |     |
|                        | R30  | Unique Expression                | X   |    |    |    |    |    |    | X  |    | X   |  |     |     |     |     |
| Abstraction            | R31  | Solution Free                    |   | X  |    |    |    |    |    |    |    |     |  |     |     |     |     |
|                        | R32  | Universal Qualification          |   |    | X  |    |    |    | X  | X  |    |     |  |     |     |     |     |
| Tolerance              | R33  | Range of Values                  |   |    | X  | X  |    | X  | X  | X  |    |     | X  |     |     |     |     |
|                        | R34  | Measurable Performance           |   |    | X  | X  |    |    | X  |    |    |     | X  |     |     |     |     |
| Quantification         | R35  | Temporal Dependencies            |   |    | X  | X  |    |    | X  |    |    |     |  |     |     |     |     |
|                        | R36  | Consistent Terms and Units       |   |    | X  |    |    |    | X  | X  |    | X   |  | X   | X   | X   | X   |
| Uniformity of Language | R37  | Acronyms                         |   |    | X  |    |    |    |    | X  |    | X   |  | X   | X   | X   | X   |
|                        | R38  | Abbreviations                    |   |    | X  |    |    |    |    | X  |    | X   |  | X   | X   | X   | X   |
| Modularity             | R39  | Style Guide                      |   |    | X  | X  |    |    |    | X  |    | X   |  | X   | X   | X   | X   |
|                        | R40  | Decimal Format                   |   |    | X  | X  |    |    |    | X  |    | X   |  |     |     |     |     |
| Modularity             | R41  | Related Needs and Requirements   |   |    | X  |    |    |    |    | X  | X  | X   |  | X   |     | X   | X   |
|                        | R42  | Structured Sets                  |   |    |    |    |    |    |    | X  | X  |     | X  | X   | X   | X   | X   |

Figure 5 Quality characteristics cross reference matrix

The quality analysis was made on the system requirements developed by the contracting agency and the overall quality was transferred to the COSYSMO data model after the quality analysis (Figure 6) using a requirement quality analyzing tool to reduce effort and increase the overall data quality.

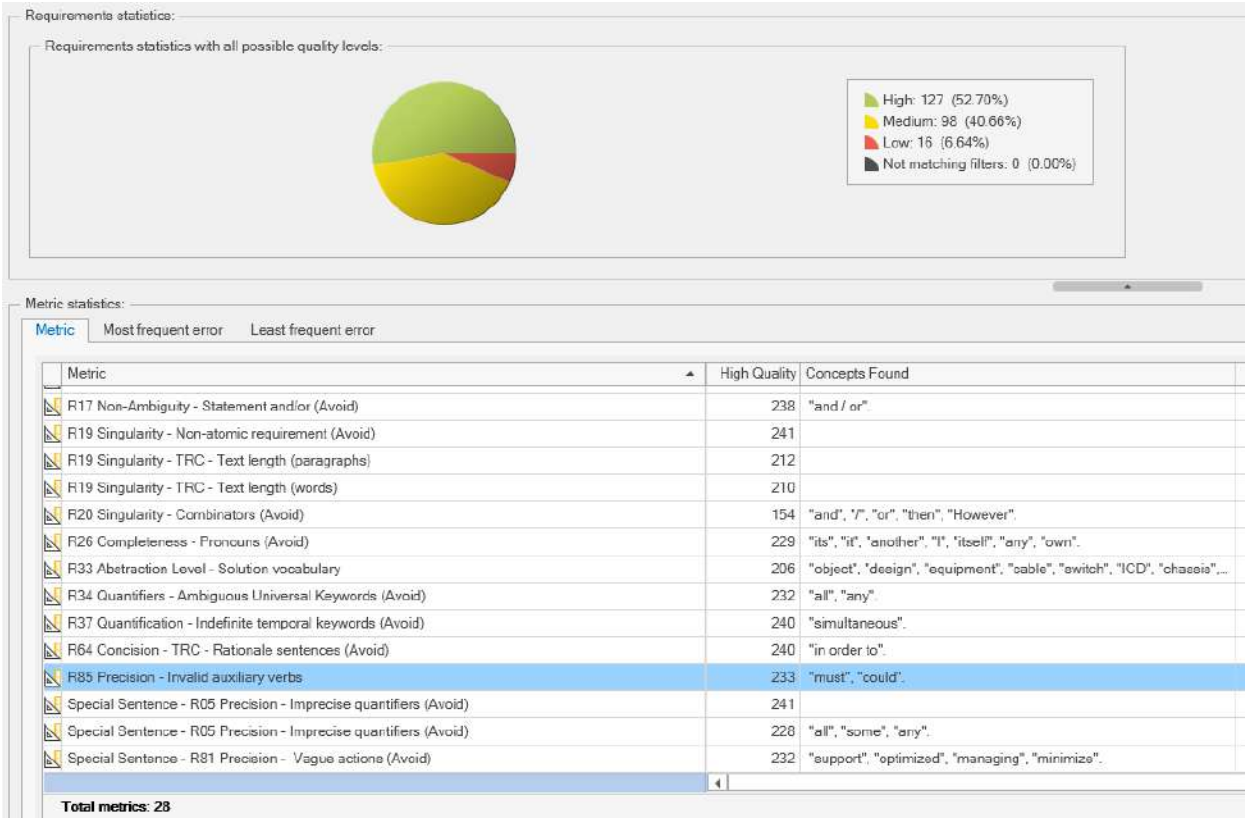


Figure 6 The result of the requirements quality analysis

The chosen set of quality characteristics were divided and assigned to the three different COSYSMO categories where different quality functions were used to provide a summary result on the individual requirements quality (Figure 7) and the resulting number were put into the COSYSMO data model.

| EASY                          | Nominal                                    | Difficult                             |
|-------------------------------|--|---------------------------------------|
| - Simple to implement         | - Familiar                                 | - Complex to implement or engineer    |
| - Traceable to source         | - Can be traced to source with some effort | - Hard to trace to source             |
| - Little requirements overlap | - Some overlap                             | - High degree of requirements overlap |
| Quality score: HIGH           | Quality score: MEDIUM                      | Quality score: LOW                    |

Figure 7 The COSYSMO model system requirements categories aligned to requirements quality score

## Assessing Acquisition Risk Technology Readiness Level (TRL)

Before signing a development contract, bidders can be asked to provide a self-assessment of their technology readiness level (TRL) and an evidence-based cost estimate to advance the technology to the mature system level (TRL 9) and therefore lower the technical risk. This approach ensures that the contracting agency has a clear understanding of the maturity and financial implications of the proposed solutions before making a firm contractual commitment. This will be used to evaluate and compare different bidder who has proposed different solutions all fulfilling the stated requirements, but with different levels of technical immaturity and hence technical risk.

To begin, the contracting agency must clearly define the different levels in the TRL framework to be used, specifying the criteria for each level from TRL 1 (basic principles observed) to TRL 9 (actual system proven in operational environment). This framework should be included in the instructions to the bidders, along with a requirement for bidders to perform a self-assessment of their current TRL. Bidders should be instructed to provide detailed evidence supporting their claimed TRL. This evidence might include test data, reports from prior demonstrations, results from simulations, or any other verifiable documentation that substantiates the claimed level of technological maturity.

In addition to assessing their current TRL, bidders should be required to outline the steps, milestones, and activities needed to advance the technology to TRL 9. This “roadmap” should include specific technical and operational tasks, risk mitigation strategies, and resource requirements. Alongside this roadmap, bidders must provide a cost estimate for achieving TRL 9. This can be used to analyse the risk budget to reach a mature SOI with each specific bidder.

To ensure consistency and enable a fair comparison among bidders, the contracting agency should provide a standardized template or format for reporting TRL assessments and cost estimates. This done with a series of guided MS excel datasheets for bidders to state compliance, answer questions, state TRL, CMMI self-assessment and cost. Example on corresponding summary file can be seen below (Figure 8). This structure ensures that all submissions are comparable and align with the organization's expectations and ensure a transparent and fair procurement process. The evaluation criteria for assessing the TRL and cost submissions should also be made transparent, with emphasis on the validity of evidence provided, the feasibility of the proposed steps to TRL 9, and the reasonableness of the cost estimate.

| Order | Object | Project Item   | TRL<br>Required | Expected<br>Verification<br>Method | Expected<br>Verification<br>Evaluation       | Expected Acceptance<br>Criteria   | Compliant | Compliance Comments | Technology Readiness<br>Level | Verification<br>Method | Verification Method<br>Justification   |
|-------|--------|--|-----------------|------------------------------------|--|---|-----------|---------------------|-------------------------------|------------------------|--|
|       |        |  |                 |                                    |  | Maintain temperature between 25 and 25 °Celsius. Temperature difference between head and feet are less than 5 °Celsius.   |           |                     |                               |                        |  |
|       |        | The bidder is requested to state operational time for increasing the temperature in the Driver compartment from -40 °C to 15 °C. | No              |                                    |  |   |           |                     |                               |                        |  |
|       |        | The bidder is requested to state operational time for reducing the temperature in the Driver compartment from 35 °C to 25 °C.    | No              |                                    |  |   |           |                     |                               |                        |  |
|       |        | The Medical compartment, SHOULD be equipped with a heating system conforming to EN 1789:2007+A2:2014.                            | Yes             | Test                               | Climatic chamber EN 1789:2007+A2:2014, 5.11. | From -10 °C, conforming to EN 1789:2007+A2:2014, 4.5.5.1.<br><br>In upper and lower temperature range of the climatic zones A3-C2, maintain temperature between 15 and 25 °Celsius. | Compliant |                     | Prototype 6-7                 |                        |  |
|       |        | The bidder is requested to state operational time for increasing the temperature in the Medical compartment from -40 °C to 5 °C. | No              |                                    |  |   |           |                     |                               |                        | Technology Readiness<br>Indicates needed development to fulfil the requirement, based on the US-DoD TRL scale, grouped levels. See sheet "Technology Readiness Level" for details. (1789:2007+A2:2014, 5.11) |

Figure 8 Bidder response sheet with TRL assessment on selected requirements

This process not only provides the contracting body with valuable insights into the maturity and development needs of the proposed solutions but also holds bidders accountable for realistic planning and self-assessment. It minimizes the risk of selecting a solution not technologically feasible or financially sustainable within the project constraints and will be used as another parameter in the COSYSMO data model for acquisition.

### **Capability Maturity Model Integration (CMMI)**

After obtaining insight through the TRL analysis obtaining data on the technical maturity (technical debt) of each bidders proposed solution, there is a need to also define more soft risk factors by evaluation the bidders proposed project organisation's ability to deliver the contract.

A great number of COSYSMO costing parameters are focused on organisational (soft) aspects and we can apply the same self-assessment technique as for TRL but for organisational aspects using CMMI.

In a public acquisition, bidders can be required to provide evidence-based self-assessments of their **Capability Maturity Model Integration (CMMI)** levels to inform the development of accurate costing parameters for COSYSMO 2.0. This approach ensures that the bidders' organizational capabilities are objectively evaluated and used to tailor systems engineering (SE) cost estimations based on their process maturity.

The contracting agency can integrate a requirement into the solicitation by asking each bidder to perform a self-assessment of their CMMI maturity level in areas relevant to the project scope, such as systems engineering, development, or acquisition processes. Bidders should be asked to identify their maturity level, ranging from Level 1 (immature) to Level 5 (mature) and provide substantiating evidence, such as certification reports from official CMMI appraisals, internal process audits, or records of continuous process improvement activities. If formal CMMI certification is not available, bidders can be required to submit documentation demonstrating compliance with equivalent process maturity standards, validated by third-party audits or industry-recognized benchmark (Figure 9).

| Object Identifier | Section | Object Heading         | Object Text  | Class | Process # | Capability Level | Capability Statement  | RFQ reply input validation        |
|-------------------|---------|------------------------|--|-------|-----------|------------------|---|-----------------------------------|
| CMMI_MA_6         |         |                        | The bidder is requested to do a self-assessment of the process areas included in the response section of this appendix. The bidder is also requested to provide supporting evidence of the maturity level stated. This could include process guidelines, process web pages, methods, plans and descriptions. The amount of data supplied by the bidder depends upon the capability maturity level selected for each process. | Info  | Frozen    |                  |   | Completed                         |
| CMMI_MA_7         | 2       | Bidder self-assessment |  | Head  |           |                  |   | Completed                         |
| CMMI_MA_8         |         |                        | CMMI-DEV consists of a set of processes organized into 22 different process areas across four categories. NDMA has chosen a subset to evaluate and these processes are required for the MA acquisition project success. The processes are listed below and shall be assessed by the bidder and the response will be evaluated by NDMA during its bidder evaluation before contract award.                                    | Info  | Frozen    |                  |   | Completed                         |
| CMMI_MA_9         |         |                        | Requirements Management (RM)   | PA    | Frozen    | Level 2          | Please see provided RM process, ref XYZ   | Completed                         |
| CMMI_MA_10        |         |                        | Project Planning (PP)  | PA    | Frozen    | Level 3          |   | Please state Capability Statement |
| CMMI_MA_11        |         |                        | Project Monitoring and Control (PMC)   | PA    | Frozen    |                  |   | state Capability Level            |
| CMMI_MA_12        |         |                        | Supplier Agreement Management (SAM)  | PA    | Frozen    |                  | Capability Statement<br>Please provide sufficient proof of evidence supporting the process capability judgement made by the bidder. | state Capability Level            |
| CMMI_MA_13        |         |                        | Process and Product Quality Assurance (PPQA)   | PA    | Frozen    |                  |   | state Capability Level            |
| CMMI_MA_14        |         |                        | Configuration Management (CM)  | PA    | Frozen    |                  |   | state Capability Level            |
| CMMI_MA_15        |         |                        | Product Integration (PI)   | PA    | Frozen    |                  |   | state Capability Level            |
| CMMI_MA_16        |         |                        | Verification (VER)   | PA    | Frozen    |                  |   | state Capability Level            |
| CMMI_MA_17        |         |                        | All process areas are explained in detail in CMMI-DEV, CMMI for Development, version 1.3.  | Info  | Frozen    |                  |   | Completed                         |
| CMMI_MA_18        |         |                        | Please note that the bidder capability statement should clearly describe the bidder's reason behind the selected maturity level. It MUST be complimented by sufficient proof of evidence supporting the process capability judgement made by the bidder.   | Info  | Frozen    |                  |   | Completed                         |

Figure 9 Bidder CMMI self-assessment data sheet

In addition to declaring their maturity level, bidders should provide a narrative explaining how their organizational capabilities, as reflected by their CMMI level, align with the project requirements. This explanation should include details of process discipline, quality assurance practices, risk management frameworks, and previous projects where these processes were successfully applied. This evidence-based assessment enables the contracting organization to correlate the maturity level with anticipated SE effort multipliers used in COSYSMO 2.0 data model.

The contracting organization can then use the declared and evidenced CMMI levels to adjust COSYSMO 2.0 cost drivers, such as **process capability** and **team capability**, to reflect the bidders' process maturity. Higher CMMI levels (e.g., Levels 4 or 5) would generally indicate greater process standardization, predictability, and efficiency, potentially lowering the SE effort multipliers. Conversely, lower maturity levels may indicate less disciplined processes, increasing the estimated effort and associated costs.

Evaluation criteria for these self-assessments should be made transparent in the solicitation, emphasizing the credibility of evidence, alignment with project requirements, and the ability of the declared maturity level to inform accurate cost modelling. This structured approach enhances the reliability of COSYSMO parameters and supports informed decision-making in the public acquisition process.

The complete evaluation matrix becomes an integrated capability and risk breakdown supplying the contracting agency with compliance information from each bidder together with information on TRL and CMMI data to feed into the COSYSMO data model. The bid evaluation model is often a complex tree model to obtain evidence on who the winner is as it supposes to weigh price/cost against a definition of quality. Below is an example with two bidders and their resulting score to different topics (Figure 10).

| Object Identifier | Section | Object Heading                               | Object Text | Normed Weight | B03_Grade step 1 | B03_Grade step 1 Adjusted | B13_Grade step 1 | B13_Grade step 1 Adjusted |
|-------------------|---------|--|-------------|---------------|------------------|---------------------------|------------------|---------------------------|
| Eval_1            | 1       | System Evaluation                            |             |               | 6,435            | 8,964                     | 6,480            | 9,399                     |
| Eval_2            | 1.1     | Capability                                   |             | 0,500         | 4,949            | 8,473                     | 5,841            | 10,000                    |
| Eval_6            | 1.2     | Cost   |             | 0,300         | 9,555            | 10,000                    | 7,641            | 7,997                     |
| Eval_9            | 1.3     | Risk   |             | 0,200         | 5,470            | 8,636                     | 6,334            | 10,000                    |
| Eval_63           | 1.3.1   | Capability Maturity Model Integration (CMMI) |             | 0,200         | 5,200            |                           | 5,900            |                           |
| Eval_64           | 1.3.2   | Technical Readiness Level (TRL)              |             | 0,600         | 4,702            |                           | 6,566            |                           |
| Eval_202          | 1.3.2.1 | Should                                       |             | 0,500         | 5,016            |                           | 6,389            |                           |
| Eval_203          | 1.3.2.2 | Shall  |             | 0,500         | 4,387            |                           | 6,742            |                           |
| Eval_78           | 1.3.3   | CLS Service Network                          |             | 0,200         | 8                |                           | 6                |                           |

Figure 10 Example of a bidder evaluation tree model with weighed score

## Obtaining an evidence based Total Cost of Ownership (TCO)

When risk and compliance data has been obtained and analyzed for each bidder, its time to shift focus on the most valuable and often the most important factor and that's the cost of the specified SOI. Cost for each unit is quite easy to obtain, and we can ask for a work breakdown of the proposed and scheduled project-related costs, but what about the cost for the system over its life cycle?

The **Total Cost of Ownership (TCO)** refers to the comprehensive assessment of all costs associated with acquiring, operating, maintaining, and eventually disposing of a product, system, or asset over its entire lifecycle (Ellram, 1995). It provides a holistic view of the financial implications of an investment beyond the initial purchase price. TCO includes direct costs, such as procurement, installation, and implementation expenses, as well as indirect costs like training, ongoing maintenance, energy consumption, repairs, and potential downtime. It also considers end-of-life costs, which might involve decommissioning, recycling, or disposal of the asset.

The concept of TCO is especially critical in decision-making processes, as it helps organizations evaluate the long-term value and economic impact of different options. By accounting for all lifecycle costs, TCO enables stakeholders to compare alternatives more effectively, identify hidden expenses, and make informed choices that optimize both financial and operational outcomes. It is a tool for understanding not just the immediate costs, but also the broader implications of ownership, ensuring that decisions align with long-term strategic goals.

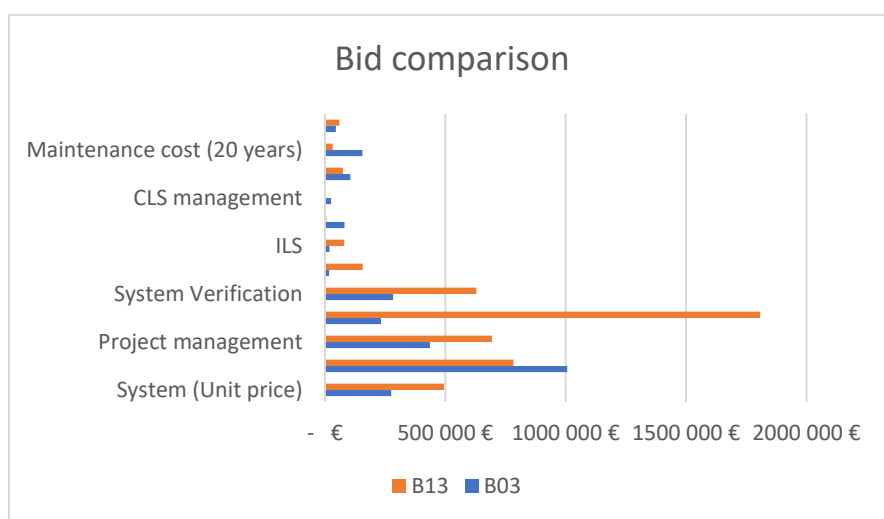


Figure 11 Example of TCO components

The traditional TCO based cost parameters must be identified by asking the bidders to break the typical operating, maintenance and end-of-life costs down into comparable parts using typical maintenance scenarios described in the RFQ material (Figure 11) using a well-defined cost breakdown structure.

With this cost data collected the total acquisition cost will come as a combined result from the COSYSMO data model where the engineering cost is summed together with the cost of the SOI itself. This is an alternative to ask the bidders to provide prices connected to a WBS price-based cost sheet, or the COSYSMO result can be used to stress test the bidders own provided cost estimate against the engineering cost provided by the COSYSMO data model. Has the bidder in question hidden some cost in the price estimate or has he misjudged the engineering or technical complexity of the contract?

## Conclusion

The integration of the outlined methodologies establishes a comprehensive tool for enhancing public acquisition processes. By leveraging COSYSMO 2.0 as the foundation and incorporating frameworks like TRL and CMMI, the model ensures a balanced approach to cost estimation, risk management, and supplier evaluation. This integration strengthens transparency and supports evidence-driven decision-making by aligning technical, organizational, and financial considerations.

Through these enhancements, the model not only delivers accurate acquisition cost benchmarks but also allows for robust assessments of supplier capabilities and risks. By addressing the key challenges in public procurement, such as balancing cost and quality, aligning stakeholder expectations, and adhering to regulatory frameworks, the model provides a structured pathway for optimizing acquisition outcomes.

Future work should focus on refining evidence-based calibrations for metrics such as GtWR classifications and SE workshare distributions, ensuring adaptability across diverse acquisition contexts. Additionally, extending the Total Cost of Ownership (TCO) framework to encompass detailed lifecycle costs will provide stakeholders with a more nuanced understanding of the long-term financial implications of procurement decisions. These refinements will further align the model with the practical realities and strategic objectives of public acquisition, ensuring its effectiveness as a decision-support tool.

## Recommendations

To further enhance the acquisition model outlined in the document, a structured focus on evidence-based refinements is necessary to improve its accuracy, reliability, and applicability. This involves several key aspects.

**First**, evidence-based calibration of metrics derived from the INCOSE Guide to Writing Requirements (GtWR) is essential. The classification of requirements into categories like easy, nominal, and difficult depends on the clarity, consistency, and correctness of requirements. To achieve reliable calibration, historical data from various projects should be collected and analyzed. This data would help establish baseline values for these categories, ensuring that the classification rules can be consistently applied. Furthermore, edge cases or ambiguities in rule applications need detailed analysis to refine the categorization process, providing a stronger foundation for accurate cost estimation within the COSYSMO data model.

**Second**, the calibration of systems engineering (SE) workshare is critical for a balanced distribution of tasks between contracting bodies and suppliers. The model would benefit from adopting a systematic approach to dividing responsibilities, using standards like ANSI/EIA-632 to define and allocate SE tasks across the project lifecycle. This requires gathering detailed input from both contracting agencies and suppliers on the nature of their contributions in past projects. Such data can then inform adjustments to the model, allowing it to reflect realistic divisions of labor that enhance accountability and efficiency. Additionally, the calibration process must consider the variability in workshare across different procurement contexts, ensuring that the model is adaptable to various scenarios.

Another area that needs attention is the integration of organizational and technical risk assessments, such as those based on CMMI and TRL. For the CMMI framework, bidders' maturity levels must be calibrated not just through self-assessments but by correlating these levels with actual project outcomes. This involves validating self-reported maturity levels against performance metrics like schedule adherence, quality of deliverables, and cost control in completed projects. Similarly, for TRL assessments, the model would benefit from a structured methodology that quantifies the financial and technical implications of advancing technologies to TRL 9. This requires collecting data on costs, risks, and timeframes associated with technology maturation across diverse procurement efforts.

**Finally**, the Total Cost of Ownership (TCO) perspective needs to be strengthened. This involves extending the model's ability to capture lifecycle costs beyond acquisition, such as operational, maintenance, and end-of-life costs. To enhance TCO accuracy, a systematic framework for gathering and analyzing data on these aspects from previous projects must be implemented. By doing so, the model can provide a more holistic view of financial implications, allowing stakeholders to make informed decisions.

Overall, enhancing the model requires a concerted effort to integrate and calibrate metrics, workshare distributions, and risk assessments based on robust empirical evidence. This process not only strengthens the accuracy and reliability of cost estimations but also aligns the model more closely with the practical realities of public acquisition projects.

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## Biography



**Christer Fröling.** Is currently acting as CEO for Reuse Company Scandinavia. He has over two decades of experience in the successful implementation of Systems Engineering (SE) and its sub-disciplines in a variety of roles and technical domains.

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