Co-Engineering: A Key-Lever of Efficiency for Complex and Adaptive Systems, Throughout Their Life Cycle

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Abstract Thales Group designs, develops, produces, supports, operates innovative solutions in large and various domains (Aerospace, Space, Defence, Aerospace, Ground Transportation, Security, etc.) where the operational performances are more and more critical. In this context, to ensure competitiveness and remain leader on the market, Thales has investigated in an extension of the recommended Integrated Product and Process Development approach (see [DoD IPPD], [INCOSE SE HB], [CMMI]), applied for Co-Development towards a "Co-Engineering approach" addressing all stages and concerns of the operational system as a key lever of efficiency and SE benefits achievement. This paper presents the implementation in Thales of this Co-Engineering approach identifying major principles to be mutually agreed and applied (on Technical and Organisational aspects) per System Life Cycle stage, necessary changes to be led, and finally, an illustration by typical scenarios as Returns of Experience.

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1 Introduction

“Why Co-Engineering”? The genesis of this approach is linked to the main features of Thales Group and to the new challenges that the group has to face to.

Co-Engineering addresses both Collaborative and Concurrent Engineering. It impacts both organisation but also team mind-set sharing objective and system vision, and so achieving Systems Engineering benefits.

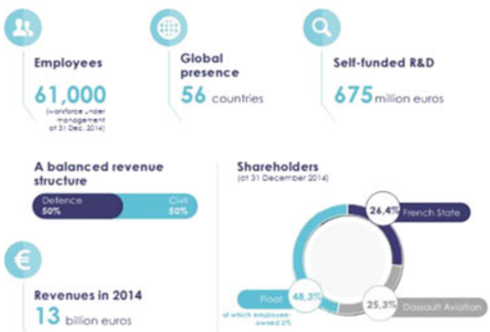
Co-Engineering approach contributes to satisfy one main Customer expectation: optimize the system Life Cycle Cost, a main concern for complex and adaptive systems notably when life time extends over several decades.

Note: Any engineering artefact (product, service, piece of software or hardware) is discussed in this document with a systemic approach and is called a “system”.

1.1 The Main Features of Thales Group

Thales Group is a “key player” in various domains (Aerospace, Space, Ground transportation, Defence and Security) aiming to promulgate “**A collective intelligence for a safer word**” (Fig. 1).

This collective intelligence is based on a word wide implementation of employees, supported by recurrent investments.



Thales is precisely involved in following domains (Fig. 2).

Thales commits itself in various engineering activities all along the **System Life cycle stages** with an increasing effort in after-development stages. The scope must address all stakeholders so encompass both the **System of Interest** and the necessary **Enabling Systems** that interoperate (Figs. 3 and 4).

Fig. 1 The Thales Group positioning on markets

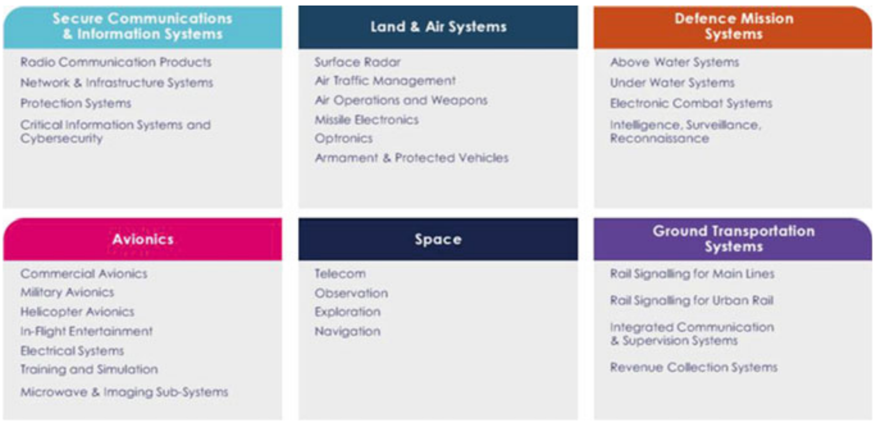


Fig. 2 The diversity of domains addressed by Thales Group

1.2 The Genesis of Co-Engineering Within Thales

To remain competitive whilst maintaining Customer satisfaction, focus has been made on a necessary Engineering “Collective value”, aiming to carry an “efficiency” mind-set within stakeholders beyond the Integrated Product and Process Development initiative (see [DoD IPPD], [INCOSE SE HB], [CMMI]) which is efficient for small teams with one scope of responsibility.

The objective is to reach the real challenge for both Systems providers, Acquirers and Users: “**Optimise the Life Cycle Cost”** (as illustrated in Fig. 5, from [INCOSE SE HB]) for an observable and compliant “**operational performance**”

The “**Co-Engineering**” approach is an answer to this challenge.

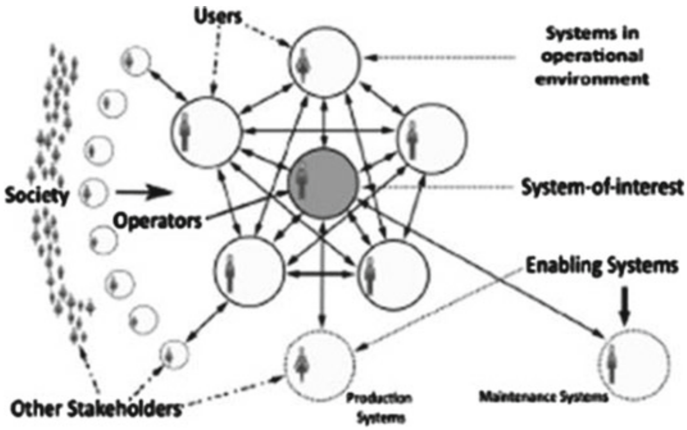


Fig. 3 The system of Interest and its typical stakeholders

Life cycle stages	Purpose
Exploratory Research	Identify stakeholder's needs Explore ideas and Technologies
Concept	Refine stakeholder's needs Explore feasible concepts Propose viable solutions
Development	Refine system requirements Create solution description Build system Verify and validate system
Production	Product system Inspect and verify
Utilization	Operate system to satisfy user's needs
Support	Provide sustained system capability
Retirement	Store, archive or dispose of the system

Fig. 4 Example of system life cycle stages ([INCOSE SE HB])

As foreseeable, "Systems engineering" being basically an **inter-disciplinary** approach that has to consider the **complete problem** (i.e. operations, cost and schedule, performance, training and support, test, manufacturing and disposal) has been delegated to define, implement and experiment this approach then secure its large deployment, especially for "Concept" to "Support (including Services)" stages.

But the drawback of this inter-disciplinary approach is that Systems Engineering could be seen as an upper layer over disciplines and specialties working in silos to deliver systems parts. In that case, each team concentrates his effort on his objectives and may miss the global ones.

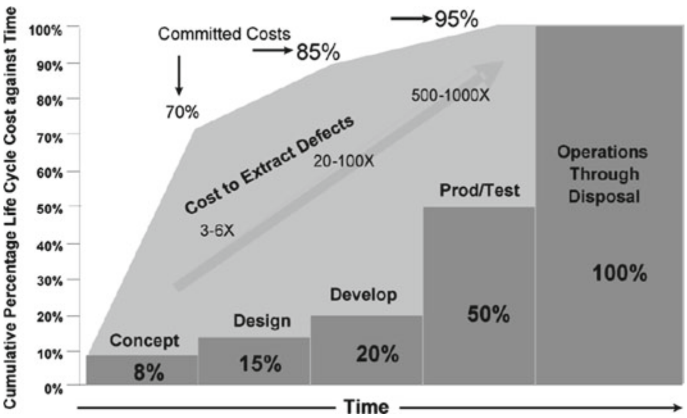


Fig. 5 Early commitments against through life cycle stages costs

2 Co-Engineering Definition and Principles

2.1 The Stakes

To face more and more tightened time constraints, engineering teams involved in a project **work in parallel, rather than in a sequential way** (concurrent Engineering). This is not sufficient to satisfy the requirements in terms of efficiency and competitiveness: the Co-Engineering intends to **improve and increase the collaboration** between these teams.

Today, Systems Engineering of complex systems follows various Engineering development cycles: vee model, spiral model, incremental and iterative model, etc. [see Das V-Modell, August 1992, Spiral model (Boehm 2000)]. As illustrated by following Fig. 6, these models could generate a lack of “global vision” due to “too focused” concerns (deliverables, cost, etc.) and so a lack of coherency between disciplines.

Co-Engineering is based on a **shared vision** of the problem and project outcomes, with common objectives clearly defined in order to get this coherency.

This shared vision should cover **all the stages of the system life cycle**, from Concept up to the Retirement of the system, and involves **all the stakeholders of the system** (e.g. customer, partners and suppliers, Bid and Project management, purchases, product policy, engineering including production and service).

The global objective is to optimize the **way of working** between engineering disciplines, specialties, manufacturing and services and avoid cascading of analysis and loops with rework too often induced by “**silos**” effect.

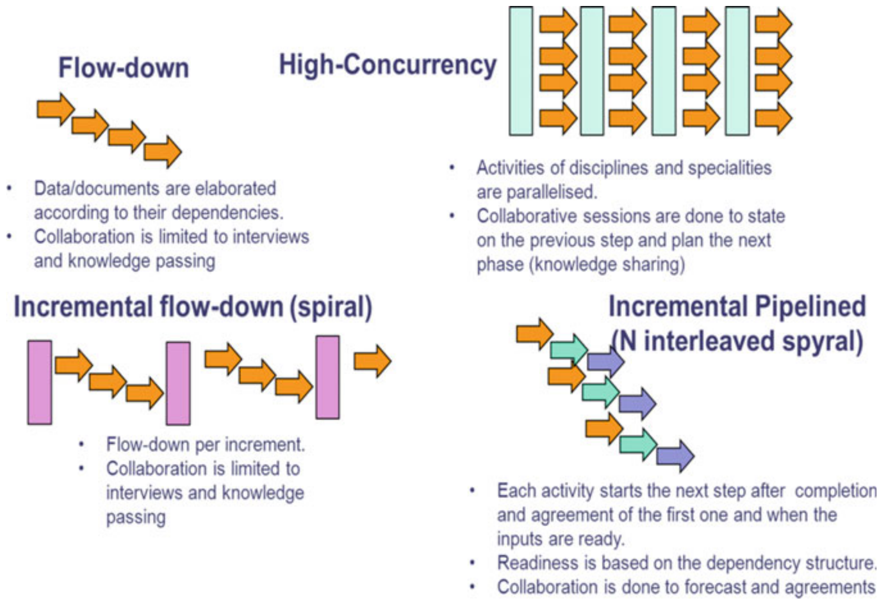


Fig. 6 Typical engineering products development life cycles

2.2 Basic Definitions

Co-Engineering corresponds to "***Concurrent*** *engineering activities performed in a* ***collaborative*** *and* ***cooperative*** *way. Based on a* ***shared vision*** *of the scope of the solution, the actors jointly make analyses, decide and master risks for* ***collective value*** *enhancement*".

Where followings terms must be understood as:

– **Concurrent engineering**:
The application of multiple engineering disciplines to perform allocated activities in several different but related areas at the same time so the activities are coordinated and mutually supportive.
– **Collaboration**:
Collaboration means working together with shared dynamic goals to achieve collective results that benefit to all parties involved. It implies a higher degree of commitment, mutual trust, and sense of belonging and common interest than cooperation.

A critical feature of collaboration is vision sharing by all the stakeholders involved in producing targeted results in complex contexts.

– **Cooperation**:
  Mutual agreement to work on consolidated artefacts conformed to a set of individual objectives

2.3 Main Principles

Multi-points of view approach
Following Fig. 7 aims at representing the typical System life cycle activities so as to facilitate the identification of the essential points of view which must be captured, understood, and confronted to ensure the efficiency of the Co-Engineering approach.

Shared vision concept
The purpose of creating a shared vision is to achieve a unity of purpose regarding the Systems Life activities with respect to the contract limitations and the scope of responsibility.

The value of a shared vision is that people understand and can adopt its principles to guide their actions and decisions. Shared visions tend to focus on an end state while leaving room for personal and team innovation, creativity, and enthusiasm.

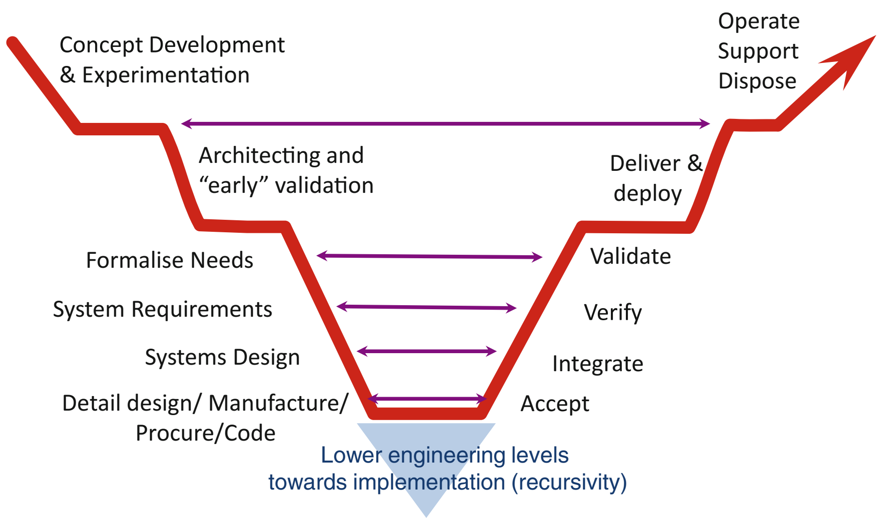


Fig. 7 System life cycle activities concerned by Co-Engineering

The activities of the individuals, teams, and project are aligned with the shared vision (i.e. the activities contribute to the achievement of the objectives expressed in the shared vision).

Initiated by the **Bid team** (or equivalent to launch a "system" development) and consolidated all along project activities as relevant, the shared vision shall propose a global answer to the following questions:

- What is the target in terms of context, contents, and constraints?
- Who is involved for which activity in terms of stakeholder representatives?
- When do activities require Co-Engineering approach to be optimally performed?
- Where does Co-Engineering take place?
- What is the level of collaboration necessary for what activity? What are the adequate means required for the activity?

It is important to ensure that the shared vision is **understood by all stakeholders** involved in the "System" life cycle in a comprehensive and homogeneous way (typically, avoid the well-known divergence of points of view on "swing" concept, illustrated humorously by the following Fig. 8).

Creating a shared vision requires that all involved people in the project have an opportunity to speak and be heard about what really matters to them. The project's shared vision captures the project's guiding principles, including mission, objectives, expected behaviour, and values. Technics of **team building** may be used to raise confidence.

The levels of Co-Engineering

4 imbricated levels have been defined to characterize the Co-Engineering in a bid or a project, as illustrated by the following Fig. 9.

Earliest in Project, preferentially from and for Bid phase, the level of Co-Engineering practices is defined for each concerned Life cycle activity, as an element of an Integrated Development Strategy and plan.

"**Integrated Development strategy**" must be understood as a global strategy ensuring the coherency of "System" development/production/Support/and Retirement strategies.

According to this level, involved responsibilities, roles, engineering tasks are defined (within a "**team charter**"), while identifying enabling means, facilities and infrastructure.

Level 1 as "Organized Co-Engineering team work"

Its main goal is to define the shared vision and concerned stakeholders involvement.

This data, initialized during an "Orientation" step preferably from bid (aiming to frame and justify the Engineering key drivers on technical as well on organizational

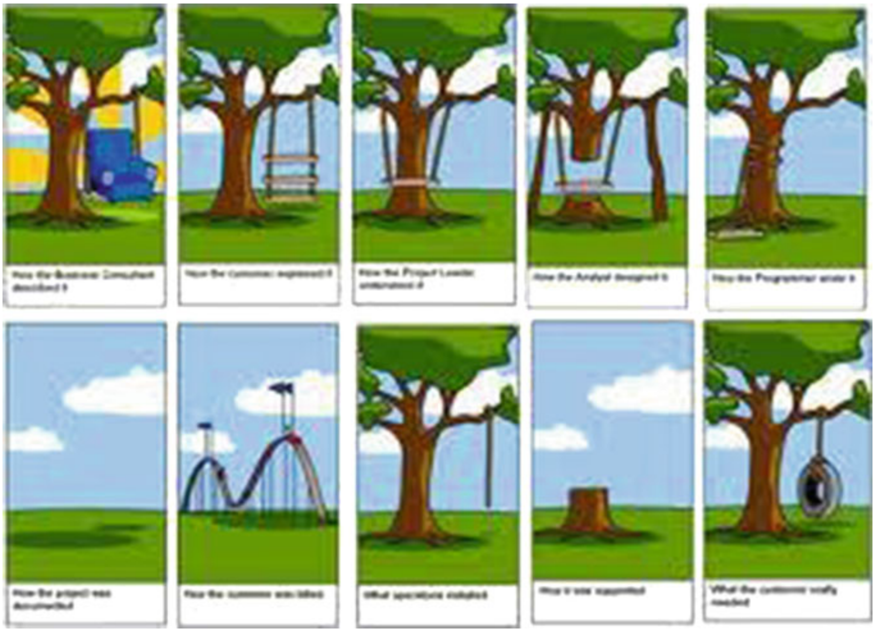


Fig. 8 Typical misunderstanding of stakeholders on “swing” vision

aspects), will be updated only if changes occur in the context of the project. It should be a basis for the elaboration of the “Integrated Development Strategy”.

The stakeholder involvement is detailed in the SEMP (System Engineering Management Plan) and downward in other concerned engineering subordinate plans then updated as necessary during the phases of the development cycle. The period of Co-Engineering meetings is defined depending on the main activities to perform. Extra meetings may be planned on demand.

It is important to introduce the workload due to these meetings in estimates for each stakeholder and take care to avoid overloading due to meetings.

<u>**Level 2**</u> as “Application of the Co-Engineering method” (including level 1)
The Co-Engineering method is based on **field proven** facilities to support the expected efficiency of team work collaboration and cooperation.

During the Co-Engineering adoption phase, it is strongly recommended to take advantage of using standard collaborative facilities (Visio conference, Live meeting, etc.)

Then, all along effective Co-Engineering practice, this method shall be progressively based on identified best practices of entities (from **capitalization** process).

A particular section of the System Engineering plan may describe the planed usage of these facilities. It is fundamental to communicate as appropriate to ensure their availability at the right time.

Fig. 9 The four levels of Co-Engineering defined in Thales

Practice a Co-Engineering method implies, before application in Bid and Project:

- A **Preparation** phase, before starting of concerned engineering activities, ideally earliest in bid:
  - To scope Co-Engineering practices (phase, step, engineering level(s)…)
  - To identify the stakeholders
  - To define, according the level of shared vision, information to be shared between the stake-holders
  - To define the Co-Engineering meeting types and techniques, related infrastructure to be used along the bid and project phase
  - To define the team organisation for the different working meetings
  - If facilitation is required, to identify a facilitator among the organisation
  - To adapt the organisational process as appropriate to consider the defined Co-Engineering practices
  - To put in place the management of shared Engineering data: a Model Based System Engineering (MBSE) approach being recommended.

- Then, a **Kick-Off** phase

Level 3 as "Usage of dedicated facilities" (including levels 1 and 2)
Some facilities can support and enhance the meeting efficiency. Meeting room configuration, display, space can have a significant impact on the meeting dynamics and in the participant involvement. Different types of facilities are recommended depending of the project phase and meeting objectives.

- A **creativity centre** ("creativity corner"), room or space: will help early phases, concepts and trade identification, but also problem solving. Creativity centre has to provide:
  - Room for a stand-up meeting
  - White board wall, to provide a large surface to exchange information, draft concept.
  - Large free space for people to exchange, walk around the elements.
  - Material to draft concepts (blocks, hard paper …)
- A **concurrent design centre** will provide extended engineering capabilities enabling to perform work during the session. The meeting will be around a table, the participant having to perform work on computers, to exchange data and update models. The meeting room shall facilitate the sharing of information between participants in a responsive way by ensuring to display different PCs displays on different screens. All work stations or participant lap top should be connected (multiplexer) to the different screens. This design enabling should also provide white boards to facilitate rapid graphic communication among participants or to display information, guidelines.
- An **OBEYA room** that is effective, to perform project coordination and manage actions status, solves in a short term problems. The principle is to display the key project information on the wall, to provide a global system vision, such as: baseline, risks, planning, but in particular to display the short and mid-term actions, check their progress and update or take new actions. OBEYA is based on a stand-up meeting to keep people focus on the project and to avoid distractions. OBEYA can be also implemented in a virtual way e-OBEYA using electronic boards, when the team is spread other different premises (Fig. 10).

Fig. 10 Co-Engineering dedicated facilities (creative/design center, Obeya room)

Level 4 as "Usage of advanced tooling for integrated system model" (including levels 1, 2 and 3)

As example, **Capella** provides means to ensure an engineering-wide collaboration with all stakeholders sharing the same **reference architecture**, including architects and engineers for system and subsystems, development teams, specialty engineers (e.g. interfaces design, performance, security, RAMS—Reliability Availability Maintainability and Safety—costs, mass, product line, etc.), integration and validation, customer, etc.

Capella is the provided tool that implements Thales ARCADIA (MBSE) method (related to CLARITY project): one of the main noticeable features of Arcadia is to support enterprise-wide collaboration and Co-Engineering.

Collaboration with engineering specialities is supported by **modelled engineering viewpoints** to formalise constraints and to evaluate architecture adequacy with each of them.

Collaboration with customer and subsystems engineering relies on **co-engineered models** (e.g. physical architecture), automatic initialisation of need model for sub-systems, and impact analysis means between requirements and models of different engineering levels (as illustrated by Fig. 11).

A dedicated Engineering environment, integrating as wider as possible a set of tooled-up services addressing all concerned stakeholders, is recommended for optimally enables the Co-Engineering practice at level 4, as illustrated (partially) by the following Fig. 12.

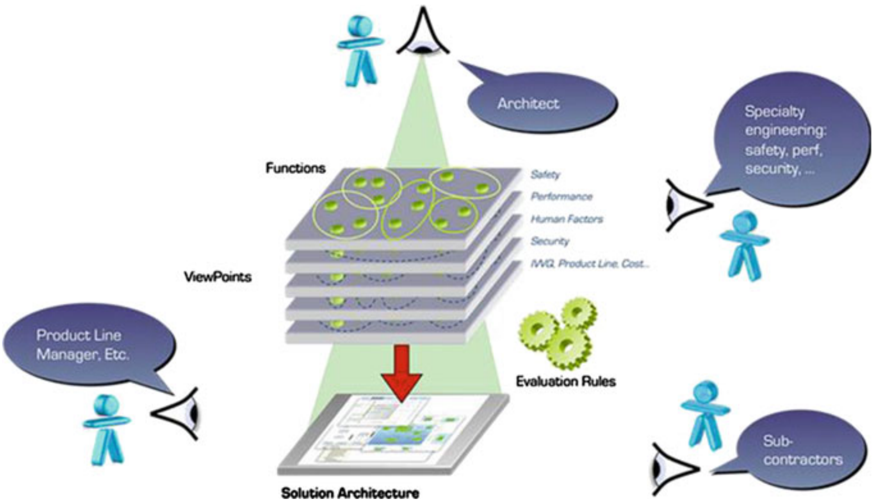


Fig. 11 Capella, the Thales "multi-points of view" System modeler

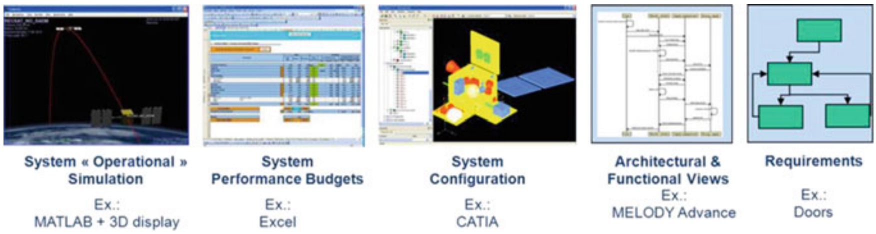


Fig. 12 Example of integrated engineering environment to support Co-Engineering

3 When and How to Practice Co-Engineering?

This chapter intends to illustrate through typical scenarios, how to assess the opportunity to implement the practice based on predefined "Co-engineering implementation criteria".

Note: *Concerning facilitation, the involvement of a facilitator is mainly relevant for first experimentations of a given scenario (especially to enable exchange, mutual understanding and collaboration for an effective decision-making).*

3.1 The Co-Engineering Implementation Criteria

These criteria intend to justify ("fitted to relevant") any Co-Engineering practice before its implementation; they must be reviewed and agreed by concerned managers whilst the strategy for system engineering (all activities included) is defined:

- **Stake**: "what is the objective?"; "what are the Business constraints to face to?", "what's the shared vision?"
- **Scope**: "What are the concerned Trough Life Cycle engineering activities"
- **Stakeholders** (the Co-Engineering team)—"Who must be involved" for acting and decision-making
- **Added-value:** "what is the observed value of the Co-Engineering practice?"
- **Level(s): "**what are the appropriate levels" so the resources (means, facilities,) to be available (and so invested beforehand)

3.2 Typical Scenarios for Co-Engineering Implementation

Figure 13 illustrates four fruitful approaches applied within Thales

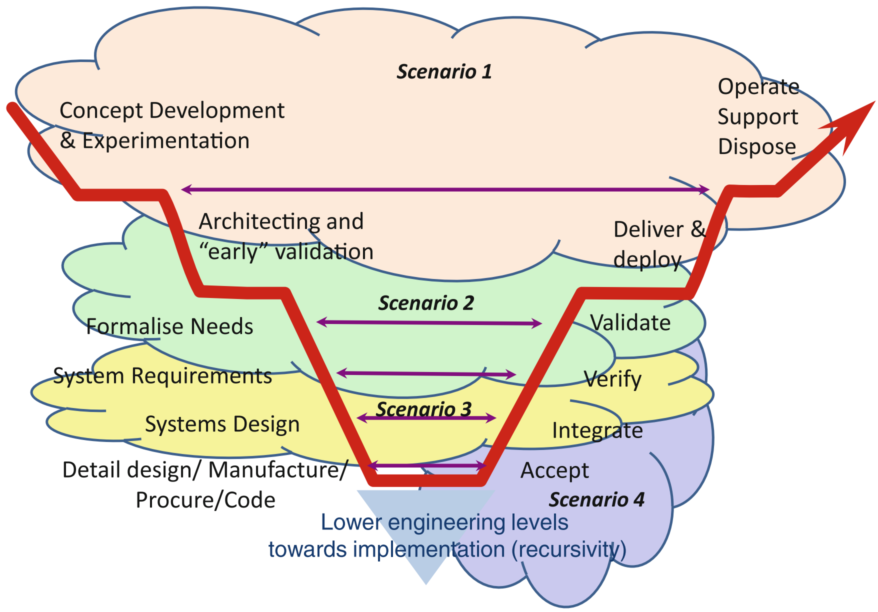


Fig. 13 Four fruitful Co-Engineering scenarios for system engineering

Scenario 1  "Consolidate the Operational fit for purpose"

- <u>Stake</u>: Reinforce the competitiveness, in Bid phase, by mastering the Operational fit for purpose. The contract includes Development, Deploy, Install, Support the "system". The offer must address the feasibility of a future transition to capability to "Operate" while ensuring that disposal will be in compliance with current regulations.
- <u>Co-Engineering scope</u>: "Architecting & Early validation" activities in coherence with "Deliver, Deploy, Operate, Support, Dispose" activities. The shared goal is to comply with Operational needs, usages and expected performances in an adaptive way (required capabilities can question the current Technical Offer, operational organisation being in full transformation).
- <u>Co-Engineering team</u>: Acquirer, Design authority, Operational expert/user, System/Support/IVVQ Engineering managers.
- <u>Co-Engineering added value</u>: Facilitated the capture (and mutual agreement on) of operational concepts (CONOPS, CONEMP, CONUSE) allowing to master the required capabilities and performances towards the expected global performance. Identified Architecture key drivers and highly critical non-functional constraints. Developed mind set of "Design for Operation, for Deployment, for Installation, for maintenance, for Disposal".

- Relevant levels: Level 4 recommended due to necessary operational simulations to be performed, based on dedicated tools.

Scenario 2  **"Early validate the certification"**

- Stake: Optimise the Certification activity while minimizing "time to delivery". Certification is a main constraint to transition into Service (Operate). Related Test campaigns are costly; optimisation is required.
- Co-Engineering scope: "Architecting & Early validation" activities, as source of references for "Formalize Needs" activity, in coherence with "Validate" activity. The shared goal is to comply with Certification constraints and reduce as far as possible Integration, Verification, Validation, Qualification and Certification [IVVQC] activities whilst providing with necessary evidences of conformity.
- Co-Engineering team (minimum): Acquirer, Design authority, Architect, Operational expert, Certification authority, IVVQ manager.
- Co-Engineering added value: Facilitated the capture (and the mutual agreement on) operational scenarios addressing the Certification and includes them in the contract. These inputs contributed to de-risking via "early validation" (based on simulation capabilities) the Certification process. Significant reduction of IVVQC activities has been observed. Acquirer's confidence increased.
- Relevant levels: Level 3 minimum; Level 4 may be useful to take benefit of powerful Engineering tools (domain simulations notably), as appropriate.

Scenario 3  **"Secure Integration and Verification"**

- Stake: Enforce the integrability and the verifiability of the system and implicitly secure Development delays and costs.
- Co-Engineering scope: "Systems Requirements" and "System Design" activities in coherence with "Integrate" and "Verify" activities. The shared goal is to establish while defining the system, a de-risked Integration and Verification strategy.
- Co-Engineering team: System Architect, IVVQ manager, Systems Engineering manager, necessary specialists (for non-functional criticalities).
- Co-Engineering added value: Secured the execution of "Integration & Verification" activities from the "System requirements" phase (notably when their validation) then during the "Systems Design" by considering integrability and verifiability as "Key Design" drivers ("Design for Testability" approach).
- Relevant levels: Level 2 is sufficient; (as appropriate) level 3 optimizes decision-making and level 4 enforces the decision via powerful Engineering tools.

Scenario 4  **"Optimize cross-disciplines IVV strategy"**

- Stake: Optimize whole IVV strategy so as to secure it at minimum cost; break the potential "silo" between engineering levels and increases synergy.
- Co-Engineering scope: "IVV" activities (multi-levels): a global vision for Systems IVV, Software and Hardware IV strategy (IVV Test campaigns, necessary resources, multi-levels synchronization).
- Co-Engineering team: System IVV manager, Software IV manager, Hardware IV manager, necessary specialists for critical specialties and certification constraints.
- Co-Engineering added value: Reinforced confidence and efficiency (avoiding recursive tasks on same scope) within the integrated IVV team. It facilitated the elaboration of a collaborative strategy notably the allocation of System tests campaigns to the relevant level (e.g. System [HMI]—"Agile development" to Software IV team, being responsible of).
- Relevant levels: Level 2 is sufficient; level 3, as appropriate, notably in case of decision-making in an initially conflicting context.
  Note: This scenario is particularly efficient in case of "Product Policy" context. By integrating the (Domain) Product IVV manager in the Co-Engineering team, it optimizes IVV tasks—for the generic and reusable features and a given variability—within teams concerned by:
- Engineering of "Product **for** Projects" (Domain investment, marketing and competiveness value).
- Engineering of "Product **of** Projects" (Business and Project consequent value).

4 Conclusion

The benefit of Co-Engineering practice within Thales is indisputable, as illustrated by previous scenarios. In a few words, it contributed to:

- Increase the **efficiency** and the **maturity** of engineering teams, securing lead time and costs
- Improve the **satisfaction** and the **confidence** of the customer:
  - by enforcing the **Quality** of engineering deliverables,
  - by optimizing the product **Life cycle Cost**, that is a key discriminating factor for both "**Win Bid**" and "**keep one's Customer**"
- Stimulate the "**value pulled**" approach

- And implicitly:
  - reinforce **competitiveness**
  - attract and keep "**talents**"

Nevertheless, the adoption and the massive deployment of this practice have to face to **basics breaks**: as example, investment costs (when an effective ROI?), real conviction (global value vs. own value?), human behaviour (Is this "shared" vision really mine?).

To mitigate these breaks, Thales implemented a **dedicated support** aiming to facilitate and reinforce the Co-Engineering deployment.

At Thales Group level, thanks to:

- **Sponsoring** (Head of Engineering communication to Engineering stakeholders by valorisation of Co-Engineering as main lever for breaking the « silo » effect)
- **Synergy with Lean Engineering** deployment (notably on human behaviour and facilities aspects)
- **Dedicated Training** within "Thales Université": The training course has been designed for improving skills in Co-Engineering for organisation & animation, addressing:
  - Collaborative Engineering across project phases (Bid and Project)
  - Methods, Types of meetings
  - Facilities and Infrastructure enhancing Co-Engineering approach
  - (e.g.: CDF Room, Creativity centre, OBEYA Room)
    ***25** sessions of this course have been delivered in **2014** to train about **300** engineers, and the same volume is planned in 2015*
- **Dedicated events** (called "Co-Engineering" days)
- **Capitalisation** ("Good practices" and "pitfalls to avoid" based on RETEX, community of Interest)

At "Entity" level:
Equivalent approach has been applied at "local" level [sponsoring, capitalisation, events, mutualisation in necessary means and facilities, participation to Thales Université training (as trainee and/or as co-designer, testimony provider)].

As example of testimony capture, **the "TSA Co-Engineering day" (from Edmond Tonnellier, organizer)**

> Thales Systems Aéroportés (TSA) has organized an Engineering Day concerning the Co-Engineering to exchange experiences and points of view on Co-engineering with representatives stemming from various jobs (businesses, engineering system, software, material, specialties, production, support) with attendees coming from various sites of DMS (Division Missions Systems, Thales Avionics, the Corporate, Global Thales Services and Thales Université).
>
> Indeed, to meet constraints of deadline, teams involved in a project lead their works in parallel, rather than in a sequential way.

Co-engineering has for ambition to improve the degree of collaboration between teams. It encourages in particular a shared vision of the project, with common objectives clearly definite. This shared vision covers the entirety of the life cycle of the system, the design in the deployment, up to the operational support, and involves all the stakeholders of the system, the customer to the suppliers, the purchases in the production and the service.

The human dimension was advanced, as one of the first success factors in the implementation of an approach of Co-engineering.

Today, Co-engineering is a necessity for all the new large-scale projects of Thales. There is an imperative of deployment, in particular on the international projects, requiring the implication of teams of engineering geographically taken away. Co-engineering increases in importance.

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