Assessment and Tailoring of Technical Processes: A practitioners experience

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Abstract — **This paper is the second part of a four-part series concerning the development and deployment of Systems Engineering. In this paper we tackle the technical processes and the requirements from three key and recognized systems engineering documents respectively, ISO/IEC/IEEE 15288, ISO/IEC/IEEE 29148 and the INCOSE Systems Engineering Handbook. The authors explain, adapt and then exploit a suite of tools and methods including IPOs (Inputs-Processes-Outputs), ConOps, Requirements specification documents, to develop an approach that concludes with a 'Technical Processes Matrix' and tailoring framework. This suite is exercised within the context of product development processes (PDP) of complex systems. The paper concludes with several key findings to explain the challenges faced by organizations when developing and deploying SE with special emphasis on process assessment and SE relevant process tailoring.**

Keywords — *Systems Engineering, ISO/IEC/IEEE 15288, ISO/IEC/IEEE 29148, INCOSE SE handbook, Tailoring, IPO, ConOps, OpsCon, Technical Processes Matrix.*

I. PREAMBLE

Modern organisations often interchange product development model (PDM or PD model) with product development process (PDP). To make things even fuzzier the term life cycle (LC) or product life cycle (PLC) is also included. In the context of this paper we consider the PDM and PDP to be comparable and then discern the LC as a collection of PDP stages or phases that form a model used for engineering design. A further complexity stems from the type of product the organization designs, produces and/or markets and, in the case of Flex, also how the customer considers product development, especially during engineering design of the system. To simplify matters we leverage the INCOSE handbook to compare the FLEX PDP to the INCOSE system life cycle model to that of a high-tech company as follows [1, p. 29]:

FIGURE 1 HIGH-TECH COMMERCIAL SYSTEMS INTEGRATOR LIFECYCE MODEL (INCOSE HANDBOOK V.4, P.29)

Study Period				Operations Period			Implementation Period		
User Reqs. Def. phase	Concept Def. Phase	System Specif. Phase	Acq. Prep. Phase	Source Selection Phase	Development Phase	Verification Phase	Deployment phase	Oper. And Maint. Phase	Deactivation phase

A further consideration is that we deem system, project, product interchangeable and analogous while respecting potential differences.

II. INTRODUCTION

Consolidated product and service-oriented organizations rigorously define and apply their PDP to ensure a standardized and smooth engineering design approach. This often entails investing a huge and concerted effort even though the resulting PDP may not be suitable for every project and phase of execution. Redefining the PDP for each project or leveraging organizational processes differently are both impractical as they tend be more embedded in the organization. The next logical option is to tailor the processes already in place for the PDP as people will remain familiar with the overall development approach while having the opportunity to better match inputs to outputs through their relevant tasks/procedures.

However, this raises two issues: 1. How to build an awareness of tailoring and 2. Finding a way to systematically tailor system life cycle processes while remaining faithful to the overall PDP [2].

A proper organizational process depends on the size of the development organization, the qualification of the personnel, the application domain of the projects they develop, and the complexity of these projects, among others. But the most suitable process for a particular project also depends on other characteristics of the project under development such as the risks involved, the novelty of the expertise used, the budget or a constrained time schedule. So, the same process may not be convenient for all projects the organization needs to develop. Defining and applying a suitable technical process to specific projects requires tailoring from the time of development of project itself. Directly applying the process (either organizational or from the standards) in all projects may result in a suboptimal solution in many cases. Defining an 'optimal' process for each different project is practically unrealistic and it does not necessarily reuse the process knowledge captured in the organizational process. So, tailoring the organizational process for each project seems to be a convenient trade-off, reusing the knowledge and the effort invested in the

organizational process, but adjusting it to the particularities of the project at hand. Unfortunately, there is no standard way to tailor the processes. It is necessary to support the process adaptation at the conceptual level and provide mechanisms to make it portable and executable in different process environments. To do this, the starting point would be to understand first the organization's own product development process (PDP) as this gives insight into how products are developed.

The first part of this four-part series discusses about the origin of systems engineering and related standards and this part focuses on the processes explained in those key standards and the approach of tailoring. From the previous paper [3] it had been observed that ISO/IEC/IEEE 15288 and Iso/IEC/IEEE 29148 along with the INCOSE SE handbook state and list the categories of processes that shall be applied for an organization for the SE approach. Focusing on the technical processes, this paper develops a tool which elaborates the process of tailoring within the company-customer framework. The organizational development process must adapt to the characteristics and nature of projects, standard or novel. So, the project or organization characteristics shall be captured by means of the proposed model [2], [4]. In paper 1 we provided a high-level view of the why, when, how and which processes or elements of process to tailor [3]. Table 1 reports answers to such questions:

TABLE 1 TAILORING QUESTIONS

Tailoring questions	Possible scope/reasons/answers
Why	Improve Efficiency/Effectiveness/Optimisation, Customer satisfaction, Flexibility, exploit Opportunity to learn and improve, anticipate needs and change
When	Refers to the stage of the system or product life cycle stage and/or PDP. It requires that the 'why' and the needs behind it are clear
How	Refers to the tailoring framework
Which	Refers to which processes to tailor starting from the process category i.e. Technical, Organisational, Technical-Managerial and Acquisition and then specific process

Later we provide a tailoring framework such that the rationale behind it and such questions follow a flow chart as shown in figure 2.

FIGURE 2 BASIC TAILORING FLOW CHART
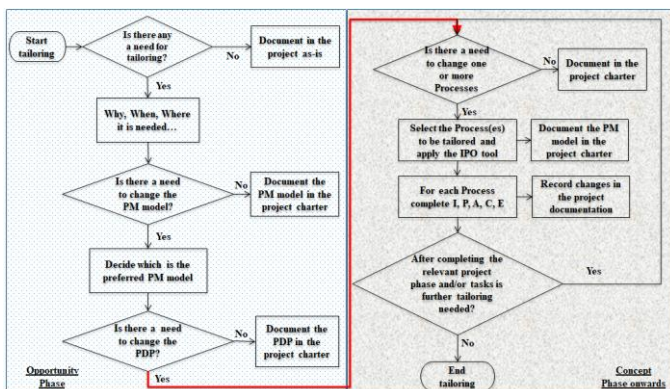
Here the flow chart is split into 2 sections. The first section refers to the phase in which the business opportunity is being assessed and prepared. In this phase only, high-level tailoring is foreseen such as the PD and/or model PDP. The second section is about the real processes which would be assessed for tailoring starting from the concept phase. Typically tailoring will occur at operational level and more likely involve engineering design processes. This implies tailoring technical processes first and exploiting the IPO diagram as the principal tailoring tool.

III. THE TAILORING FRAMEWORK

The discipline of SE and tailoring are applicable to any size and type of system and organisation. However, this does not mean that SE and relevant tailoring should be blindly applied in the same fashion on every system, SE standard and process. Indeed, while the same SE fundamentals apply, different domains need different 'lenses' to be successful, hence medical and military both address systems but have different areas of focus. This is the reason most organizations consider the tailoring of processes as a luxury and opportunity rather than a necessity. So, overall the purpose of tailoring, if needed, is to adapt processes to satisfy particular circumstances or factors [1], [2].

To this end the authors have devised a framework to tackle tailoring starting the product development model and ending with tailored processes linked to applicable standards. This walk-through is depicted in the next figure:

FIGURE 3 TAILORING FRAMEWORK
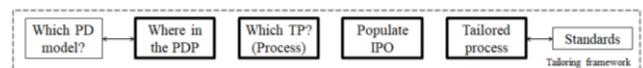
To implement the framework, it must be understood that the tailoring depends on the level of application. At the organization level, tailoring contextualises standards, models, methods and procedures and adapts the relevant processes to suit organizational needs. Typically, at this level we discuss the PD model, PDP and LC of the product.

At a lower-level i.e. the project level, the tailoring process adapts organizational processes to suit the unique needs of the project and drives the buyer-supplier relationship to function better. Typically, at this level we discuss protocols, deliverables, technical standards etc. of the product within the domain of engineering design.

IV. SYNOPSIS OF THE PRODUCT DEVELOPMENT MODELS (PDM) AND PROCESS (PDP)

In general, a PDP process is defined as the procedure of formalized planning from the opening stage of idea generation up to market launch [5].

The PDP process consists of activities carried out by enterprises when developing and launching new products. A new product that is introduced on the market evolves over a sequence of stages, beginning with an initial product concept or idea that is evaluated, developed, tested and launched on the market [6]. This sequence of activities involves a series of

information gathering and evaluation stages that together form a process. The sequence sets up a PD model that can be enterprise and market specific.

As the new product evolves, the enterprise becomes increasingly more knowledgeable (and usually less uncertain) about the product and can assess and reassess its initial decision to undertake development or launch. The start of this process of SE information gathering and evaluation is usually captured in the Business Requirements Specification (BRS), Stakeholder Requirements Specification (StRS) and high-level System Requirements Specification (SRS) documentation. Following a structured PDP approach, as also suggested by INCOSE handbook and the ISO/IEC/IEEE 15288, limits the level of risk and optimises project resources (people, capital etc.) and time.

Both the PDP process and PD model differ from industry to industry and from enterprise to enterprise [7] [1].This is due to the need to adapt product development to match market type, maturity and enterprise needs. Hence there is not 'one size fits all', rather a collection of PD models that portray a basic process of product development that has evolved over the years [8]. So here a PD model is a development framework or product development reference footprint/outline. These models can be summarised and categorized as follows (see figure 4), starting from the oldest:

A. *Technology-push model*

Is typical of enterprises that have an acknowledged technological leadership in the market, or who are considered subject matter experts and trusted advisors by their customers. The start of a project is initially propelled by technology, science and their authors as in technology centred start-ups or R&D focused organisations. It is considered the oldest form of PM and dates back to the '50s.

B. *Market-pull model*

Incorporates a market focus into the innovation process to overcome the technology-push blindness to customers' needs. Like the previous model it is a simple sequential model in which the market is a primary source of ideas for directing R&D: it dates back to the mid.60s. R&D becomes a passive actor and, in some regards even a reactive one in the process. For example, when there is a business opportunity or problem that requires a solution from R&D.

C. *Mixed, Push-Pull or Coupling model*

is a model that combines the previous two models. As such it remains a sequential process but includes feedback loops. It is intrinsically iterative and recursive as the project stakeholders work in tandem [1] and parallel.

D. *Concurrent or Interactive-parallel processing model*

The sequential approach becomes heavier to manage when timelines are compressed and a 'quick and dirty' approach is needed to assess and prime the market with the product. This approach usually ends up by conducting several stages simultaneously and in a parallel. Japanese companies pioneered this concurrent approach to address internationalization, intensified competition, shorter product life cycles, speed-up development to gain market share, improve competitive standing and be first to the market.

E. *e-Integrated model*

This model was the West's answer to the previous model of Japanese origin. It is a model that exploits electronification and IT via integrated resources including **people, processes, and technology** suppliers.

F. *Network model*

The most recent model was developed in the late 1990s when customers increasingly desired customized products to fulfil their unique needs. This meant that more innovation was needed with even faster development and greater efficiency was required. This led to the creation of tighter internal linkages and access to additional resources and capabilities i.e. networking was born.

All 6 PD models can be represented from a historical perspective in figure 4 and the older ones can still be found in many enterprises and relevant industries even today:

FIGURE 4 PD MODELS AND THEIR EVOLUTION
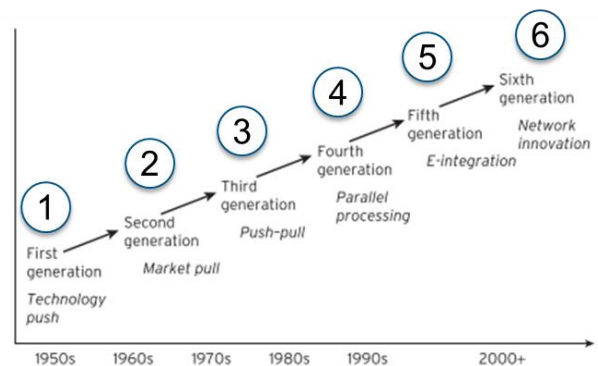
According to SEBoK 'A life cycle for a system generally consists of a series of stages regulated by a set of management decisions which confirm that the system is mature enough to leave one stage and enter another.' This means that a PDP can be compared to a PLC or just simply, LC [9]. This ensures that the system meets its required functionality and performance throughout its life, which usually ends when the system is retired from operation. It is also essential to have the enabling systems available to perform required stage functions [1]. The INCOSE SE handbook explains various SE life cycle models and compares them with the generic model of PLC. This generic model of product lifecycle from ISO/IEC/IEEE 15288 consists of six stages starting from system concept and ending at system disposal. The other life cycle models include that of US department of Defense (DoD), Department of Energy (DoE), NASA, etc. These lifecycles may vary considering the stages and the sub-stages which depend on the DNA of the organizations [1]. The project/product lifecycle for Flex Corporate is split into 2 parts (figure 5). The first part

concerns the PDP in the Flex Design centres like the one in Milan. The second part concerns the Flex factory. The sum of the two parts represents the life cycle of the product for Flex and is known as 'sketch-to-scale' or S2S. Since Flex Milan is a design centre only the factory part is excluded in this discussion although certain TP are nonetheless relevant e.g. implementation. Moreover, the support, maintenance, retirement and recycling of the system is usually handled by the customer as shown in figure 5. This implies that the tailoring of technical processes focus on the first 11 of the 14 TPs considered in our assessment [1].

FIGURE 5 FLEX CORPORATE PDP PROCESS AND LIFE CYCLE
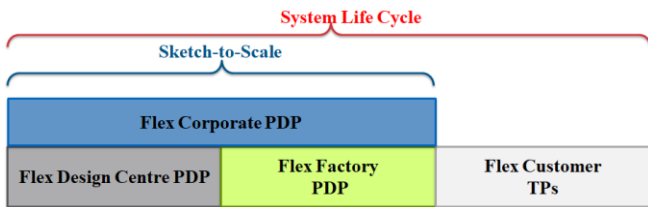
The Flex design centre PDP consists of 3 main stages (see figure 6): 1. opportunity stage, 2. concept stage and 3. development stage. In the first stage called 'business opportunity', Flex prepares a project proposal for the prospective customer and enquires about the overall requirements of the system (product). If the proposal is successful a purchase order is issued, and the concept phase starts. In the concept phase the project is planned, the product conceptualized and the system architecture is proved feasible i.e. the system or product is considered worthy of further development. In the third phase i.e. the development phase, the system is characterized, verified and subsequently validated along with the verification and validation of manufacturing processes tied to that design. The final product design is then transferred to the factory for manufacturing, this gate is therefore called Design Transfer.

FIGURE 6 FLEX DESIGN CENTRE PDP

So, in summary the three phases (see figure 6) are:

1) The opportunity phase:

Consisting of proposal generation which ends up with the business, stakeholder and system requirements, product brief, applicable standards etc.

2) The concept phase:

Is divided into three sub-stages: a. Planning design input analysis, b. Architectural concept generation and, c. Proof of concept feasibility.

3) The development phase:

It is also divided into 3 sub-stages: a. Product and process development and characterization, b. Design verification and c. Process optimization and validation respectively. At the end of each of these stages a decision gate is in place that serves to

approve or disapprove moving the project to the next PDP phase.

Analysing further the S2S concept we may include other crucial system services such as distribution, logistics etc. So, the S2S combines all of Flex's expertise irrespective of the field of application. In brief, S2S means, "bringing the customer's product to life and shipping it worldwide with their solutions along with helping them build scalable products in the global market place from conception and prototyping to engineering and advanced manufacturing to reverse logistics."[10]. S2S therefore includes; concept design, prototype creation, advanced engineering, intellectual property protection, new product introduction, additive manufacturing, global expansion and active supply chain, distribution, and logistics. The customer may choose the preferred combination of such capabilities although Flex's drive is to pull-through from design to manufacturing and therefore complete the PDP. In terms of S2S deliverables each capability can be summarised as follows:

a) Concept design:

Conceptualizing, designing, and testing the ideas through co-innovation, a platform which enables companies to successfully innovate, create, and accelerate time to market as they grow their customer base. Whether fully detailed or just a back-of-the-napkin sketch, they help to engineer and optimise the design of the product and propel it forward. Flex draws on deep multi-industry expertise to cross-pollinate ideas and core technologies. Flex's CIP or Collective Innovation Platform is an 'ecosystem' approach that helps customers monetize their investments, reduce their time-to-market and enhance product functionality by leveraging core technology blocks that have been qualified as part of their technology CoE (Centers of Excellence).

b) Prototype creation:

Creating a practical design form which shortens the distance to a viable, quality product. Sketch-to-Scale solutions help to meet strict milestones and tight deadlines, especially in the early stages of a product's life, where prototyping and engineering samples are critical to success. The innovation Labs focus on operating with selected customers within the early concept stages of product development for new market applications or when product requirements are extremely ambiguous. As a part of the collaborative and exploratory process, the Labs offer the necessary system design and engineering with focus on concept analysis, system viability and iterative prototyping. The put- together created product specifications and proof-of- concept can then be transferred to a global centre to optimize for production.

c) Advanced engineering:

For the advanced engineering, they access core technologies and product and system design engineers with cross-industry expertise to connect intelligent product and services, Source or build new technologies or modify existing ones, develop manufacturing processes for emerging new products, create assembly and technology testing processes to

improve product design, minimize risk and accelerate time to market.

d) Intellectual property protection:

In today's smart, connected and highly competitive market, IP protection is more important than ever. Propelling the innovation from a 2D sketch to a physical sample is almost impossible without best-in-class security. Flex Innovation Centers operate with the highest security solutions in place, so that they can create highly differentiated products and services, without worrying about damaging leaks or security breaches, ensuring that every aspect of the project is fully protected.

e) New product introduction:

Flex provides a comprehensive set of services that enable companies, from start-ups to multinationals, successfully innovate, create, and gain access to new markets. They offer extensive knowledge across industries and the disruptive technology within businesses that can the product and achieve the visibility it needs to be competitive. For this, the key capabilities in New Product Introduction include: Manufacturing process development; Manufacturing test development and Rapid product introduction services for first-generation consumer products at initially, low volumes.

f) Additive manufacturing (AM)

AM makes the optimization possible to quickly and cost-effectively create prototypes. With more than 100 leading-edge facilities around the world equipped with advanced robotics/automation and specializing in quality controls and Six Sigma lean manufacturing principles, Flex has the capabilities to turn the customer's concept/idea into a reality, specializing in: extensive program management; ramp to volume manufacturing and Sustaining engineering through end -of-life (EOL).

g) Global expansion:

When moving from development to piloting a product and bringing it to full-scale manufacturing, supply chain expertise can help identifying the opportunities and foresee challenges. Their knowledge across industries and disruptive technologies within businesses can help pilot the product and achieve the visibility it needs to be competitive.

h) Active supply chain, distribution and logistics:

Flex provides supply chain distribution and logistics for product development and fulfilment across a network of industries, suppliers and distribution partners around the world. They provide sustaining engineering through product end of life and deliver forward and reverse logistics including vendor managed inventory, fulfilment, product configuration and repair. The result is improved visibility with less waste and overhead and a more stable, balanced supply chain, responsive to constantly changing market demands.

V. EXPLAINING THE CONCPETS OF CONOPS AND OPSCON

The journey from ConOps and OpsCon starts with linking the needs of the marketplace to those of the enterprise. The enterprise can be seen from the buyer's or supplier's perspective. Within the context of this paper the buyer is either the customer of Flex or a supplier of Flex.

The need(s) can be considered as a product and/or service or relevant inherent features that are not currently satisfied by the product/service offerings in the marketplace [11]. On this basis the enterprise decides to address this circumstance as either:

- A need that generates one or more ideas and ends usually with a Portfolio of Ideas/Concepts;

- A problem that generates one or more solutions and ends usually with a Portfolio of Solutions;

- A need that is 'dressed' as an opportunity that generates one or more business proposals and ends usually with a Portfolio of Proposals or a Program.

Once the need(s) is (are) clarified the enterprise will endeavour to define their response and characterize a business space which usually ends up in a high-level business case. This process is both iterative and recursive and involves the business leaders of the enterprise as well as potential customers [1]. The end-product of the process should be a business requirements specification (BRS) and is used by the supplier to formulate a product/project offering for the buyer e.g. Flex or its customer incl. end-user. Typical aspects of the BRS include Volumes, Potential Industrial Earnings, (gain in) Market share, ROI, end-user definition, cost-of-goods, prospective markets, competition assessments, overall vision, mission, legislation, strategy, business portfolio etc. The BRS is typically an integral part of the Concept of Operations or ConOps, meaning that it captures the essence of the enterprise, its relevant organization, and its business space and business case at hand [12].

In the Flex PDP the BRS is captured in a project proposal (developed during the business opportunity or B.O. phase) which addresses several other aspects such as:

- Project charter;

- Project governance including organization of steering committees, working groups, RACI etc.;

- Planning;

- Financials and Staffing;

- In-scope and out-of-scope definitions etc.

During early development numerous diverse actors from both sides are involved i.e. stakeholders. Both sides will therefore have their respective project sponsors such as business developers, marketing & sales, manufacturing, R & D, engineering, logistics, planning and so forth. Consequently, their input will generate the next set of requirements that are known as the stakeholder requirements or StRS. Moving from the BR to the StRS means moving into the business operation environment which is where the stakeholders have accountability. Clearly both the BRS and StRS are examples of Systems of Interest (SoI) and are expressed in these two specifications. If Flex is considered as the buyer then the StRS

usually ends in a document that defines the specifications of a part, component, sub-assembly, assembly or sub-system that is then given to the prospective or selected supplier. This buyer-supplier relationship is therefore crucial for system development, is also based on contractual requirements and is illustrated in the following figure [9].

FIGURE 7 BUYER - SUPPLIER RELATIONSHIP
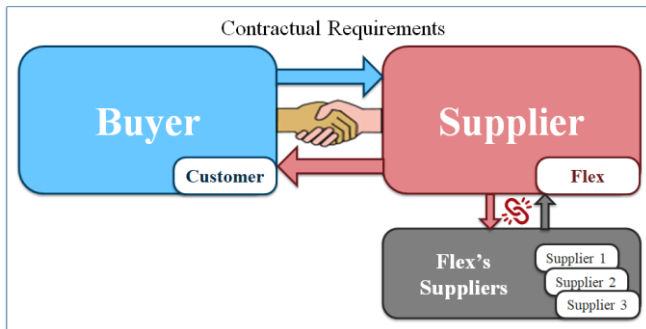
Once the BRS and StRS are defined, the systems engineer (SE), and the other disciplines can then start system design and relevant and delivered based on the project proposal. If one is still in the BD phase this work will usually be captured in one or more high-level system architectures (SAs). If not, then once the purchase order (PO) is received and the project officially starts, the SA will be one of the first deliverables of the SE, and team. Typically, in the early stages of Concept (see figure 6) there is more than one configuration of SA. As one approaches and reaches the feasibility milestone of the concept phase just one SA or variations of one SA (configurations) will be chosen for the development phase.

During the concept and development phases the SE, together with the disciplines, will develop and mature the product/service. This will require entering into the detailing of the system requirements specification which is part of the system operation environment. For this reason, it is called the 'Operations Concept' domain or simply OpsCon [1]. Again, this work is both iterative and recursive under the guidance of the SE and PM. In a similar way also, the sub-system requirements will be developed and refined, all the way down to component and/or part levels. In summary the walk-through from the needs to the BRS, to the StRS and SRS represents the journey from ConOps to OpsCon as illustrated in figure 8:

FIGURE 8 FROM CONOPS TO OPSCON THROUGH THE BRS, STRS & SRS
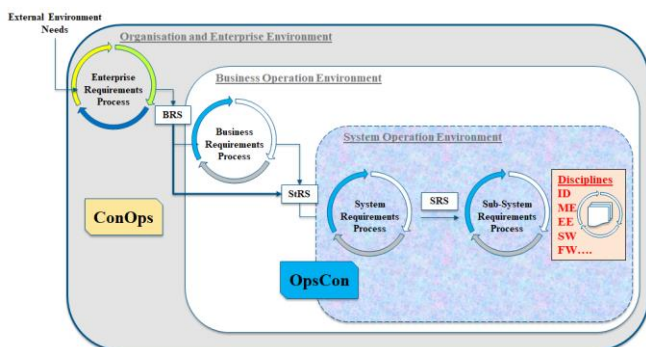
VI. TECHNICAL PROCESSES INCEPTION

The BRS, StRS and SRS are the first three technical processes considered in the INCOSE handbook and are also part of any system life cycle and relevant standards including ISO/IEC/IEEE 15288. The scope of these processes is as follows:

1) BRS: details the business solution for a project including the documentation of customer needs and expectations. It is a specification which once delivered provides value and describes the characteristics of the proposed system from the viewpoint of system end user.

2) StRS: describes the organization's motivation for why the system is being developed or changed, defines processes and policies/rules under which the system is used and documents the top-level requirements from the stakeholder perspective including needs of users/operators/maintainers as derived from the context of use.

3) SRS: defines the high-level system requirements from the domain perspective, along with background information about the overall objectives for the system, its target environment and a statement of the constraints, assumptions and non-functional requirements.

These three processes are key elements to any system development and a comparison between what Flex has in-place already is not so dissimilar to what is declared in the INCOSE handbook and the ISO/IEC/IEEE 15288 standard. What has been seen though is that discrepancies appear in later technical processes such as system integration and the way technical processes are, in general, leveraged to facilitate and accelerate system design. A key reason behind the discrepancies is that Flex Milan is a design centre (DC) and not the factory. Hence not all the PDP is tackled in the Flex DC (see figure 5).

It should also be recognized that there are the 3 other categories of process as per the same handbook, namely:

a) *Agreement processes*

b) *Organizational project-enabling processes*

c) *Technical management processes*

These were not tackled in the tailoring of the technical processes although different correlated parts were included in their alignment e.g. IPOs.

Indeed, since all four categories are linked it makes sense to consider their alignment, starting from the needs of the marketplace and ConOps. As mentioned previously the SoI's represent the viewpoints of all the stakeholders, that may vary across the life cycle of the system i.e. across the life cycle stages. Nevertheless, the rationale behind their management and linkages is dictated by categories 2 and 3 with help of category 4 and of course category 1, namely the technical processes. This is portrayed by and captured in the following figure (figure 9) [13]:
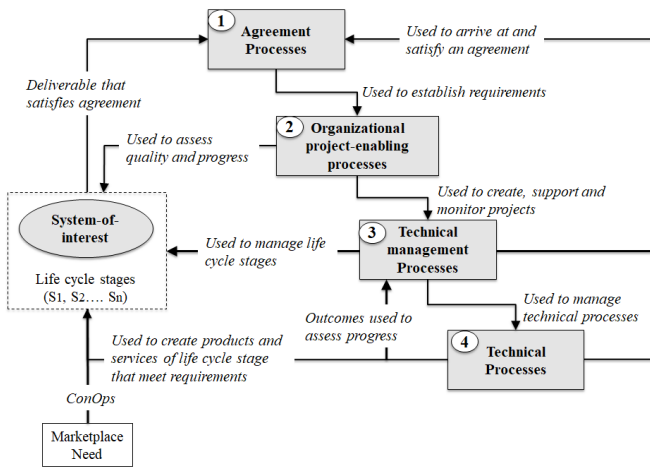
VII. INCOSE IPO DIAGRAM AND ITS IMPORTANCE IN TAILORING

In this paper tailoring is considered to be a process in which either something new is generated to match the needs of an organization to deliver or, tackle a specific context or deliverable(s) or, an existing process is modified to align it with newer needs. It goes without saying that the concept of supply and demand is the driver behind process tailoring i.e. without a need tailoring is not required, is surplus and/or source of inefficiency for the organization. In other words for all processes there is an INPUT, followed by a series of TASKS, ACTIVTIES or even other PROCESSES that end with an OUTPUT. When the INPUT is comprehensive, and the OUTPUT matches the expectations of the end-user(s) of the process the process can be considered successful.

That said the measure of success in terms of efficiency and effectives relies on how the TASKS, ACTIVTIES or PROCESSES are tackled, managed and of course, carried out. Clearly if the INPUT is unclear or worse, incorrect, then the process will deliver a corresponding OUTPUT no matter how good the outcome of tasks, activities or processes in between. Similarly, even if the INPUT is complete and accurate the following tasks, activities or processes may still deliver the wrong, inappropriate or even hazardous OUTPUT. In this paper we take on board the IPO diagram suggested in the INCOSE SE Handbook and therefore add two other key elements in process tailoring, namely, CONTROLS and ENABLERS [14].

In the first case the tasks, activities or processes are controlled in such a way to guarantee and govern the efficiency and effectiveness of expected OUTPUTS. Controls are not limiting elements or obstacles but checks and regulations the organization carries out or applies such as gate keeping, milestones, team meetings. Indeed, controls are a way of certifying the INPUT to OUTPUT journey. In the second case ENABLERS are elements that facilitate the same journey and range from people e.g. experts, tools e.g. CAD, processes e.g. testing, methods e.g. formulating a model and solving an equation or products e.g. machinery, materials etc.

Clearly CONTROLS and ENABLERS are complimentary and for specific things can be interchanged for example a kick-off meeting, test method, reviewer role etc. The duty of the systems engineer is to ensure that both are exploited to ensure that tasks, activities or processes are carried out judiciously and diligently.

In this paper a further aspect of the IPO diagrams is the introduction of feedback and feedforward mechanisms. Based on the case studies to be discussed in paper 4 (but briefly summarized in the conclusions), the authors have found that such mechanisms not only improve and qualify the above mentioned 'journey' but are also fuel for future tailoring, a sort of 'gemba kaizen' for customizing on a perpetual basis. So, why feedback? A key deficit of the IPO diagram is that the journey from inputs to output is rarely straightforward and even with scrupulous planning there will always be the need to review either the output or the input or both. So as a minimum the IPO will be iterated at least once or until the output satisfies the owner(s) of the whole IPO process. Similarly, during the execution of the tasks (central box) there will be inevitably learnings and findings that will either require a change in the inputs, the outputs (deliverables) or both. Interestingly this might lead to either a modification or even replacement of enablers and/or controls.

A picture of the IPO diagram described is shown below:

FIGURE 10 IPO DIAGRAM TEMPLATE
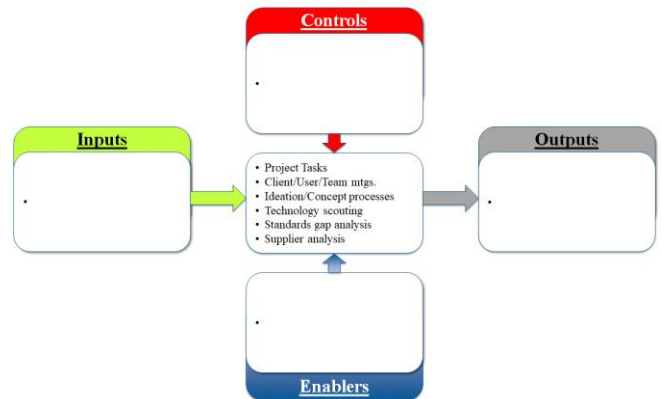
As an example, suppose the required output is Cost-of-Goods (COGs) and the input is volume for a given product. If the volume change and/or the product specification changes then it might mean changing an assembly method from say, semi-automatic to automatic. This might involve investing more capital to provide the benefit of reducing assembly time. From a controls perspective this might generate different quality control requirements and require specific expertise e.g. the involvement of an automation expert to enable this change. Further, since we are speaking of feedback, such a mechanism will require a change in governance. Hence the project proposal/contract will necessarily have to have RACI and project governance clarified from the onset.

The feedforward mechanism is rather less than obvious because it not intended to be in the IPO diagram being tailored rather the one or ones that follows. The reason is that with the reduction of product development time processes are being

anticipated and, in some cases, run parallel. So the input of one IPO will be deliberately fed into other IPOs 'down the line' [15]. So rather than wait for a process to be finished the next one is anticipated (to some degree). Similarly, the feedforward mechanism may take one or more outputs before all the outputs are considered closed. This saves engineering time and resources but introduces more risk of failure.

One way of observing feedforward is to consider the whole of the product development process (PDP) and plot the IPOs it will be found that several processes can start either simultaneously or with an acceptable time lag or lead. Typically, this occurs when a 'quick and dirty' approach is used and should the 'experiment' fail the process can be stopped, rethought and then rebooted. Hence the increased risk due to feedforward is counterbalanced by killing the work should it backfire. Indeed, customers increasingly need to convince their management that a project idea is a winner and providing quicker wins (but lower gains) before deciding to ramp-up. Still, quicker doesn't necessarily mean cheaper as project staffing needs increase and structural changes for the organization may be incurred/necessary.

FIGURE 11 EXAMPLE OF FEEDBACK AND FEEDFORWARD OF IPO
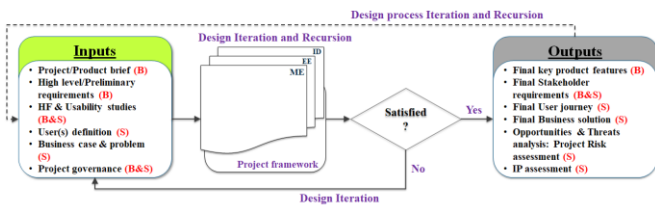
VIII. TAILORING TECHNICAL PROCESSES

Previously we mentioned that a decision needs to be made on which processes to tailor, namely in the concept phase onwards (see right of figure 2). For sake of brevity here we focus on technical processes as described by INCOSE handbook because these processes are typical of engineering

design challenges and are at the core of many man-made systems and their projects [1].

Project tailoring applies specifically to the work executed through programs and projects meaning the tasks, activities, processes and deliverables. Forces that influence tailoring at the project level are many but often include:

• Project budget, schedule, and business requirements;

• End-users, Stakeholders and Customers requirements;

• Risk management and control measures;

• Complexity and system priorities including enabling systems;

• Technical challenges tied to processes, tasks, activities that convert inputs to outputs etc.

Under these forces organizations with intense engineering design rely heavily on technical processes. So, in such organisations including Flex, tailoring of technical processes is a prime 'target' to satisfy such forces.

To simplify and conclude this discussion on assessment and tailoring we provide a technical process matrix that serves as a checklist of tailoring criteria for organizations involved the tailoring of technical processes.

This matrix, which comes in the form of a quick reference table, elaborates the outcomes of the IPO diagrams explained previously starting from business analysis and ending at the disposal process. The matrix therefore provides an idea of what is expected in terms of outcomes that can then be further refined to defining specific deliverables.

As a simple example technical process No.1 (Business or mission analysis process) outcome a) problem or opportunity space could be split into: product configurations, user types, reference markets etc.

TABLE 2 TAILORING OF TECHNICAL PROCESSES - TP MATRIX

Processes	Outputs	Check
1. Business or mission analysis process	a) Problem or opportunity space is defined	
	b) Solution space is characterized	
	c) Preliminary operational concepts and other concepts in the lifecycle stages are defined	
	d) Candidate alternative solution classes are identified and analysed	
	e) The preferred candidate alternative solution class is selected	
	f) Any enabling systems or services needed for business or mission analysis are available	
	g) Traceability of business or mission problems and opportunities and the preferred alternative solution classes is established	
2. Stakeholder needs & requirements definition process	a) Stakeholders are identified	
	b) Required characteristics and context of use of capabilities and concepts in life cycle stages, including operational concepts are defined	
	c) Constraints on a system are identified	
	d) Stakeholder needs are defined	
	e) Stakeholder needs are prioritized	
	f) Critical performance measures are defined	
	g) Stakeholder agreement that their needs and expectations are reflected adequately in requirements is achieved	
	h) Any enabling systems or services needed for stakeholder needs and requirements are available	
	i) Traceability of stakeholder requirements to stakeholders and their needs is established	

3. System requirements definition process	a)	System description including interfaces, functions and boundaries for a system solution is defined
	b)	System requirements and design constraints are defined
	c)	Critical performance measures are defined
	d)	System requirements are analysed
	e)	Any enabling systems or services needed for system requirements definition are available
	f)	System requirements traceability of system requirements to stakeholder requirements is developed
4. Architecture definition process	a)	Identified stakeholder concerns are addressed by the architecture
	b)	Architecture viewpoints are developed
	c)	Context, boundaries and external interfaces of the system are defined
	d)	Architecture views and models of system are developed
	e)	Concepts, properties, characteristics, behaviours, functions that are significant to architecture decisions of the system are allocated to architectural entities
	f)	System elements and their interfaces are identified
	g)	Architecture candidates are assessed
	h)	Architectural basis for processes throughout lifecycle is achieved
	i)	Alignment of architecture with requirements and design characteristics is achieved
	j)	Any enabling systems needed for architecture definition are available
	k)	Traceability of architecture elements to stakeholder and system requirements is developed
5. Design definition process	a)	Design characteristics of each system element are defined
	b)	System requirements are allocated to system elements
	c)	Design enablers necessary for design definition are selected
	d)	Interfaces between system elements composing the system are defined or refined
	e)	Design alternatives for system elements are assessed
	f)	Design artefacts are developed
	g)	Any enabling systems or services needed for design definition are available
	h)	Traceability of the design characteristics to the architectural entities of the system architecture is established
6. System analysis process	a)	System analysis needs are identified
	b)	System analysis assumptions and results are validated
	c)	System analysis results are provided for decisions
	d)	Any enabling systems needed for system analysis are available
	e)	Traceability of the system analysis result is established
7. Implementation process	a)	Implementation constraints are identified
	b)	System element is realized
	c)	System element is packaged or stored
	d)	Any enabling systems or services needed for implementation are available
	e)	Traceability is established
8. Integration process	a)	Integration constraints are identified
	b)	Approach for the correct operations of assembled interfaces are defined
	c)	Any enabling systems or services needed are available
	d)	System composed of implemented system elements is integrated
	e)	Interfaces between implemented systems elements that compose the system are checked
	f)	Interfaces between system and external environment are checked
	g)	Integration results and anomalies are identified
	h)	Traceability of integrated system elements is established
9. Verification process	a)	Constraints of verification that influence requirements, architecture and design are identified
	b)	Enabling systems needed for verification are available
	c)	System or system element is verified
	d)	Data providing information for corrective actions is reported
	e)	Objective evidence that the realized system fulfils the requirements, architecture and design is provided
	f)	Verification results and anomalies are identified
	g)	Traceability of the verified system elements is established
10. Transition process	a)	Transition constraints are identified
	b)	Enabling systems needed for transition are available
	c)	Site is prepared
	d)	System installed in operational location is capable of delivering its specified functions
	e)	Operators, users and other stakeholders are trained
	f)	Transition results and anomalies are identified
	g)	Installed system is activated and ready for operation
	h)	Traceability of transitioned elements is established
11. Validation process	a)	Validation criteria is defined
	b)	Availability of services is confirmed

		c)	Constraints of validation are identified	
		d)	System or system element is validated	
		e)	Any enabling systems needed for validation are available	
		f)	Validation results and anomalies are identified	
		g)	Objective evidence that the realized system or system element satisfies stakeholder needs is provided	
		h)	Traceability of the validated system elements is established	
12.	*Operation process*	a)	Operation constraints are identified	
		b)	Enabling systems needed for operations are available	
		c)	Trained, qualified operators are available	
		d)	System services that meet stakeholder requirements are delivered	
		e)	System performance during operation is monitored	
		f)	Support to customer is provided	
13.	*Maintenance process*	a)	Maintenance constraints are identified	
		b)	Enabling systems are available	
		c)	Replacement, repair or revised system systems are made available	
		d)	Need for changes to address corrective, perfective or adaptive maintenance is reported	
		e)	Failure and lifetime data including associated costs is determined	
14.	*Disposal process*	a)	Disposal constraints are provided as inputs to requirements, architecture, design and implementation	
		b)	Enabling systems are available	
		c)	System elements or waste products are destroyed, stored, reclaimed or recycled	
		d)	Environment is returned to its original or an agreed state	
		e)	Records of disposal actions and analysis are available	

IX. CONCLUSIONS

There is no doubt that connecting a PDP to technical processes and relevant IPOs is challenging, especially as it needs intimate knowledge of the workings of the enterprise. Nonetheless, this paper set-out to approach this challenge by first examining the 4 categories of system life cycle processes as per the ISO/IEC/IEEE 15288 standard and then subsequently focusing on tailoring. We exploited also the INCOSE handbook and especially the IPO tool, which we subsequently developed further by including both feedback and feedforward mechanisms. In refining such mechanisms, it was witnessed that the INPUT and subsequent tasks/processes in each IPO heavily dictate the quality and quantity of the OUTPUT. Moreover, the said mechanisms were put into place to ensure that iteration and 'recursivity' occurred within and across the disciplines [1], [16]. A further eye opener was that the enterprise, in this case Flex, was tailoring its processes to respond to specific project deliverables and dynamics. So, in a way the question of technical process tailoring i.e. Tailored, Tailorable and Non-tailorable was more a forgone conclusion. The issue was more how much tailoring was needed and where? This became evident in the development of the technical processes matrix. This matrix approach provides a checklist of outputs and allows their verification. In other words, the matrix provides a snapshot of what can be tailored, requires tailoring and cannot or should not be tailored.

The matrix can be further extended to include the IPO diagram i.e. each of the 5 boxes. In doing so the IPO tool, becomes not only a navigation tool but also a means of documenting the journey and how the processes are linked. Indeed, the feedforward and feedback mechanisms ideated and introduced by the authors are a perfect example of this approach.

To provide substance to this discussion it was decided to provide a collection of case studies in the fourth and concluding paper. In anticipation of this fourth paper we may conclude that both the framework discussed herein, the relevant tools developed, and outcomes obtained provide further food for thought and steering. Indeed, it is not only the single stages of the journey taken in engineering design that count but also the complete journey including how and who interlaces them. This poses an interesting topic for further discussion in paper 4 and further: systems engineering is a mix of Project, Process and People. Something the authors refer to the 3P law of systems engineering. Needless to say but tailoring of all processes need to take in account this law: more of this will appear in our concluding paper.

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