

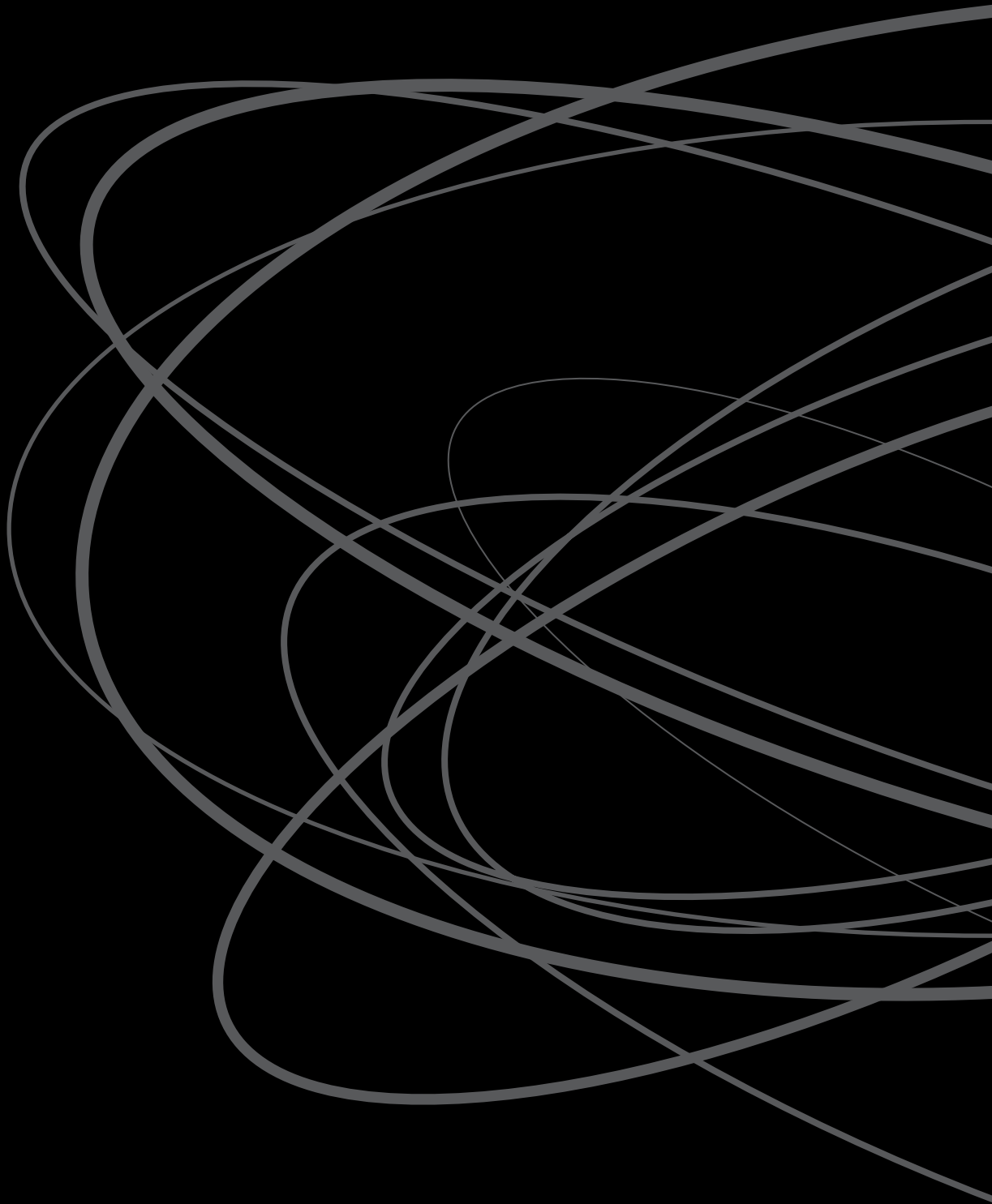


# A Process Research Framework

The International  
Process Research  
Consortium

Eileen Forrester, editor





# **A Process Research Framework**

The International Process  
Research Consortium

**Eileen Forrester, editor**

*December 2006*

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## Executive Summary

The discipline of software process management has grown remarkably since the Software Engineering Institute (SEI) introduced the concept in 1985. Since then, our work in software development process has spurred the growth of a worldwide market, connecting researchers, tool developers, consultants, educators, and software professionals. Today, de facto and de jure standards continue to emerge, signaling a maturing of the field. Yet, new opportunities and new challenges are already before us, extending the discipline of process management into exciting new areas. From software-intensive systems to the software-dependent enterprise, from health care to agriculture, and from technology acquirers to service providers, the SEI has seen growing demand to bring the benefits of process management to a diversity of software-critical domains.

To prepare for the road ahead, the SEI undertook a collaborative effort with other leaders in the process community to explore process needs for today, the foreseeable future, and the unforeseeable future. In August of 2004, the SEI launched the International Process Research Consortium (IPRC) as the primary forum for accomplishing this task. Through a series of six workshops of intensive discussion, debate, imagination, and expertise, the 28 members of the IPRC, along with the support of several notable and objective reviewers, developed this Process Research Framework. It is a thematic guide to critical process research. It is wide-ranging and far-reaching. And while the primary audience is the membership of the IPRC and the organizations and constituents they represent, it is our sincere hope that it will also prove valuable to those with the drive, the influence, and the vision to turn research into solutions.

This framework encompasses our thinking on emerging technology and four research themes:

- Process and Product Quality Relationships
- Process Engineering
- Managing Project Processes
- Process Deployment

The themes comprise 20 research nodes that address more than 230 research questions. Underpinning the themes, nodes, and questions is a set of nine driving forces, derived from an original set of more than one hundred.

Also put forth in the framework are scenarios of possible process needs created by combining the driving forces in plausible, but not necessarily expected, ways. Scenarios provide unique narratives of what the world could look like as various driving forces come into play and how those forces could influence the tightly coupled connections between people, processes, projects, products, services, and organizations. Overall, the framework is meant to be a comprehensive look at the process field both in its current state and in possible future states. We hope that both the detail-oriented and big-picture thinkers among our readers will find something to catch their imagination and attention.

One of the particularly interesting attributes of collaborative work, of which this framework is an example, is access to different voices and experiences by which to express ideas. With the process community being so diverse—involving professionals from systems, software, services, acquisition, development, operations, and maintenance across numerous industry and government domains—the perspectives of the various members are intentionally left visible to reflect the diversity and breadth of the community.

In summary, this framework offers an extensive examination of process management research. We hope that strategic planners, process researchers, and project and product managers will find it to be a helpful guide. Yet, even this extensive body of work is only the first step in a long-term initiative. The SEI plans to make this framework available in an online community forum, enabling the growing base of practitioners, researchers, and other stakeholders to participate in its evolution. The authors and editors of this Process Research Framework hope that you will find the rest of this document adds value to your thinking and that you will join us in this endeavor as we prepare to meet the challenges and opportunities ahead of us.

- Dr. Caroline Graettinger, chair of the IPRC

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## Forces Driving Process Research Framework

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1. **Value Add:** the pushback from users and customers who are demanding more value-added solutions

---

2. **Business Diversification:** businesses changing—getting larger or smaller, adopting different structures and ways of working, or entering new markets

---

3. **Technology Change:** the impact of new technologies both on businesses and, particularly, on systems development operations

---

4. **System Complexity:** new and evolving system architectures

---

5. **Product Quality:** the need to enhance product quality levels

---

6. **Product Turnaround:** the speed and nature of delivery of software-intensive technological solutions

---

7. **Regulation:** new and emerging standards that business is or will be bound to follow; this could include standards for the business community at large or, more specifically, standards imposed on the development and evolution of software-intensive technological solutions

---

8. **Security and Safety:** aspects of security for the development and deployment of systems as well as both the security and safety associated with the operation of software-intensive systems

---

9. **Globalization:** global markets, global work forces, and cultural diversification

---

## About the IPRC

In 2004, the SEI formed the International Process Research Consortium (IPRC) to explore strategic research directions in software and systems processes. The three fundamental components of the IPRC are depicted in Figure 1: (1) the strategic goal, which is essentially permanent; (2) a process research framework, embodied in this document and future editions; and (3) high-priority process research initiatives.

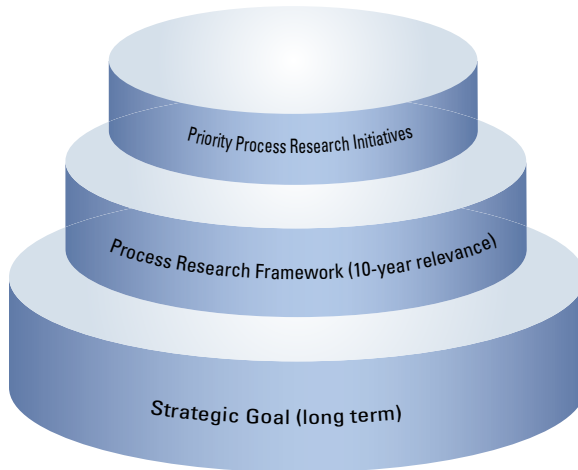


Figure 1: Organizational Components of the IPRC

## Strategic Goal

The strategic goal of the IPRC is to foster an international community of researchers and practitioners who collaborate to formulate a long-term process research agenda that catalyzes investment. Strategic criteria set the tone for all the work of the IPRC and are the basis on which all future work will be selected or defined. The strategic criteria are these:

- developing an agenda that invites collaboration and stimulates innovation
- focusing on long-term issues
- a resulting agenda of importance to the international community

## Process Research Framework

This document, the process research framework, is the first deliverable of the IPRC. The purpose of the framework is to (1) offer an organization of the process research needs for the next 10 years, based on the expertise and imagination of the IPRC members, and (2) act as a catalyst for community-wide discussions that further enhance and expand the framework for future editions. Current plans include the conversion of this document into an online, interactive site where the larger process community will be able to contribute to the framework. The framework will become a living document, offering the process community a unique opportunity to influence the strategic direction of our field.

The scope of this first edition of the framework centers on the following focal question:

*How should the community represented by the IPRC membership invest in process research over the next 10 years?*

We use this phrasing deliberately; that is, we are interested not only in what research should be prosecuted, but also how that research may be organized and who might participate.

To answer our focal question requires consideration of another question:

*What will be the nature of software, systems, and the enterprise over the next 10 years?*

To address this question, one must consider what drives change in the first place:

*What are the drivers that will change the nature of software, systems, and the enterprise over the next 10 years?*

These three questions are central to the ideas and recommendations contained in this document.

## Priority Research Initiatives

Using the framework as a guide and current events and trends as leading indicators for the future, every 12–18 months the IPRC will identify high-priority topics for directed research initiatives. The research teams will be composed of experts from multiple disciplines, with a focus on stimulating innovative thinking and new solutions.

These research initiatives will have to satisfy the following technical criteria as well as attracting funding and sponsorship:

- The research is significant and satisfies the strategic goals of the IPRC.
- The research is within the scope of the framework.
- Current events and trends suggest that the research addresses a plausible future state.

Note that the criteria include a focus on *plausible* future states. This concept is discussed more in Sections 2 and 9 and is an important feature of the work of the IPRC.

## Sponsoring Organizations

The sponsoring organizations of the IPRC provided funding and the visionary force behind this work. These organizations are leaders in their field and stewards of the road ahead, and each deserves recognition for the vital contribution they made to the success of the IPRC.

We thank, in alphabetical order, our sponsors:

- BAE Systems
- Robert Bosch, GmbH
- Lockheed Martin Company
- Software Engineering Institute
- Tata Consultancy Service, USA
- University of Pittsburgh Medical Center

Their commitment and advocacy were crucial to the achievement of this work.



## Members

Twenty-seven leaders in industry and academia from 11 countries were invited to join in this endeavor. The membership reflects an intriguing mix of experience in the practical and speculative, quantitative and qualitative, and investigative and applied domains. The members brought a methodical, questioning, and reasoned approach to creating the framework, along with a valuable mix of intuition and imagination.

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- Vic Basili, University of Maryland
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Ms. Eileen Forrester, co chair and editor  
Dr. Caroline Graettinger, chair

## To the Reader

*This document is meant to provide information that is useful to several different audiences.*

Of general use to all readers is the structured view of process research developed by the group of leaders who make up the consortium. In addition, readers may choose to try the techniques and structures we have used to organize their own content.

For example, a reader from industry may choose to apply particular driving forces that are important in their domain to any and all of the research nodes to develop a set of research questions that are finely tuned to their specific needs.

Strategic planners may examine our drivers and scenarios and use these to validate or examine their own assumptions about the future.

Funding agencies may use our themes, trends, categories, and research questions in evaluating research proposals they receive.

# 1 Introduction to the Framework



*The process research framework includes four research themes and a formulation of research content driven by emerging trends.*

## 1 Introduction to the Framework

This introductory section explains what the process research framework contains, how it was developed, and how it can be used to identify pertinent research for any organization. (Additional details on that last subject are found in Section 2).

The process research framework that follows has two main parts. First is a set of four research themes. Second is a formulation of research content driven by emerging trends; these may stand alone or be relevant in any or all of the four prior themes.

The process research topics represent an intersection of the strategic goals of the International Process Research Consortium (IPRC) and the priorities of the IPRC members. The framework provides an answer to the IPRC's focal question: How should the community represented by the IPRC membership invest in process research over the next 10 years?

Though the framework is an answer to that focal question, it is chock full of other questions. This is what the framework provides: questions, not answers. It is intended to provide guidance to industry, researchers, and funding agencies in determining the fruitful questions to address. Programs of research or investigation can then be formulated to answer these questions. Such programs of research are, themselves, beyond the scope of this document.

In August 2004, the IPRC began the development of what we called then a process research *roadmap*. To signal an important difference between our product and typical roadmaps, we now call our document a *framework*.

By its very nature, research is highly iterative. Further, the consortium members aspired to develop a roadmap that was applicable in a wide variety of contexts. One of the challenges for the IPRC roadmap architecture has therefore been to formulate a structure that does not presuppose a particular order in which research topics must be addressed, but at the same time provides value by indicating linkages between areas.

In this way, we are at odds with the conventional thinking on technology or product roadmaps. A prominent feature of these is to recommend or predict a particular order or sequence of development. As we began our work, we examined several exemplar roadmaps and documents about roadmapping. Many of these were product-oriented or service-oriented roadmaps [Wells 2004, Phaal 2004] developed by organizations as part of their planning exercises. The idea was that when particular events occurred, the product would evolve in a specific direction. While there may often be an element of uncertainty in the timing, such roadmaps generally include some notion of a timeline, or at least an ordered sequence of events.

As the work of the IPRC developed, it became clear that the same notion of a sequence might not be so easily accommodated. The principal distinction between a product-oriented roadmap and what the IPRC is interested in—that is a research roadmap—is that while some ordering of activities might be desirable, often research progresses simultaneously across a range of areas, some of which could be considered more “advanced” than others. This is a manifestation of having some, but incomplete, knowledge of several subject areas. The little bit of knowledge or progress in one area may enable research to begin in another area—no need to wait until the first area is fully resolved. In addition, some topics are more relevant in one context than in another, and we wished to produce something useful for the many domains of practice that depend upon software and systems.

The work of the IPRC started with a partly structured elicitation of ideas and background knowledge from this large group of individuals. The overall group then split into two. One group set about refining and enlarging scenarios for the future from an appreciation of nine emerging technical and business trends and driving forces (presented in Section 2). This group was termed the “requirements pull” group. They were trying to pull research ideas in directions where we have a less well-established need for research because of inattention to a plausible scenario for the future or uncertainty about which forces might prevail.

The other group started refining, categorizing, and documenting known process-related research activity. This group was termed the “research push” group. They were considering directions in which current research is pushing the process community.

The combined work of these two groups has resulted in a core framework that identifies areas of current need for process research. It can also be used in combination with future trends to identify new areas of research need, perhaps for particular development environments or a particular organization.

The principal constituents of the core research framework are

- research themes
- research nodes
- research questions

# 1

## **Step 1: Identify problems and drivers of change**

### **Step 2: Characterize future states**

- 2a. Using known trends
- 2b. Creating plausible scenarios

### **Step 3: Characterize current capabilities**

- 3a. State of the practice
- 3b. State of the art

### **Step 4: Identify the gaps between future states and current capabilities**

### **Step 5: Formulate research questions that, when answered, will help close the gaps**

### **Step 6: Identify common research themes**

Four broad process research themes emerged by abstracting characteristics from the 12 scenarios created by the requirements-pull group. By developing themes through a process of combining forces into complex scenarios rather than identifying critical process needs in response to narrow technical or business trends, it is hoped that the resultant framework will be more widely applicable and resilient to a number of possible futures. Much of the research-push group's output was also brought to bear in the resulting elaborations of each of these research themes, through the research nodes and associated research questions.

Each research theme embodies a common or recurring topic that appears or is implicit through several of the IPRC-developed scenarios. A theme provides a way of categorizing a set of issues that have, at their core, one main focus. Each research theme is oriented to developing process capabilities from the state of today, to a new state for tomorrow, whereby the process needs for the likely business and technical environment of tomorrow can be more completely met.

Each research theme is decomposed into a set of research nodes. A research node is a collection of research questions. Each research node has an objective that is intended to address one aspect associated with that theme's focus.

Finally, research questions are the base constituents of the framework. The research questions associated with a research node are intended to form a cohesive grouping. Depending upon the environment of the framework user, the answers to some of these questions may be relatively straightforward. For other questions, the answers may require significant programs of research.

In all, the core research framework consists of four research themes, a consideration of emerging trends, 20 research nodes, and more than 230 research questions. The broad aspects covered across the themes also involve four fundamental ingredients people, process, project, and product issues. The themes in the IPRC core research framework are these:



---

**1. The Relationships Between Processes and Product Qualities**

This theme emphasizes the **product** perspective. It is concerned with understanding if and how particular process characteristics can affect desired product (and service) qualities such as security, usability, and maintainability.

---

**2. Process Engineering**

This theme emphasizes the **process** perspective. It is concerned with how to define and build processes and understand their performance.

---

**3. Managing Project Processes**

This theme emphasizes the **project** organizational perspective. It is concerned with stakeholder values that drive the organizational structures used to undertake project work.

These values may be political, economic, or social. They may be driven by particular business domain concerns, market conditions, or the nature of competitive environments.

---

**4. Process Deployment and Use**

This theme emphasizes the **people** perspective. It is concerned with getting the right processes effectively deployed into suitable organizational structures so that people are enabled most efficiently to meet the needs of the business.

---

While the framework represents an intersection of the set of possible research topics and the priorities of the IPRC members, the members believe that others will find the framework to be a useful guide in defining their process research strategies. For example, users of this core research framework may select, from the set of research questions, those that are pertinent to their environment. Alternatively, they may choose to apply particular driving forces that are important in their domain to any and all of the research nodes and then develop a set of research questions that are finely tuned to their specific needs, thereby creating their own instantiation of the research framework. In this way, the IPRC core research framework acts as a tool, supporting structured thinking in the process domain. It does not answer questions. It is intended to help determine the questions for which answers are needed.



# 2

## Architecture of the Research Themes

**This section was developed by Dr. George Wilkie, framework architect, and introduces the structure of the four research themes defined over the course of the IPRC workshops.**



*Each research theme enables an examination of how process capabilities can be developed from the state of the practice today to a new state to succeed in tomorrow's environment.*

## 2.1 The Core Process Research Areas

The four broad process *research themes* are presented in Figure 2. In the main, these themes were inspired by abstracting characteristics from the 12 scenarios we created in the requirements-pull group (See Section 9 for brief summaries of the scenarios). Much of the research-push group's output can be found in the resulting elaboration of each research theme, through the *research nodes* and associated *research questions*. Thus, the themes represent concerns from plausible future settings and current conditions.

By allowing us to categorize a set of issues that share a single main focus, the research theme lends cohesiveness to the presentation of a common or recurring topic that appears in or is implicit through several of the IPRC-developed scenarios. Each of our four research themes is structured to permit an examination of how process capabilities can be developed from the state of the practice today to a new state to succeed in tomorrow's likely business and technical environment. By developing themes through a process of abstraction rather than identifying critical process needs in response to specific technical or business trends, we intend this framework to be widely applicable.

In all, the four research themes include 17 research nodes that together total more than 175 research questions. Additional nodes and questions are included in the section on process effects of emerging technologies, bringing the total questions to more than 230. The research nodes and questions are meant to lead us to process capabilities that would move us from the current state to the desired state, which we describe for each theme. However, the exact path to progress from one state to the other is not prescribed; many paths are possible.

As shown in Figure 2, the four research themes and their associated nodes are

The Relationships Between Processes and Product Qualities  
(Section 3)

- Q.1 Eliciting and Specifying Product Quality Requirements
- Q.2 Establishing Product–Process Relationships
- Q.3 Modeling Product Quality–Process Relationships
- Q.4 Verification and Validation of Product Qualities
- Q.5 Sustaining Product Qualities

Process Engineering (Section 4)

- E.1 Specifying Processes Using Evidence
- E.2 Organizing Processes for Reuse
- E.3 Providing Process Engineering Infrastructure

## Managing Project Processes (Section 5)

- P.1 Operating Under Autonomous Control
- P.2 Managing Through Centralized Cooperation
- P.3 Agreeing Under Federated Collaboration

## Process Deployment (Section 6)

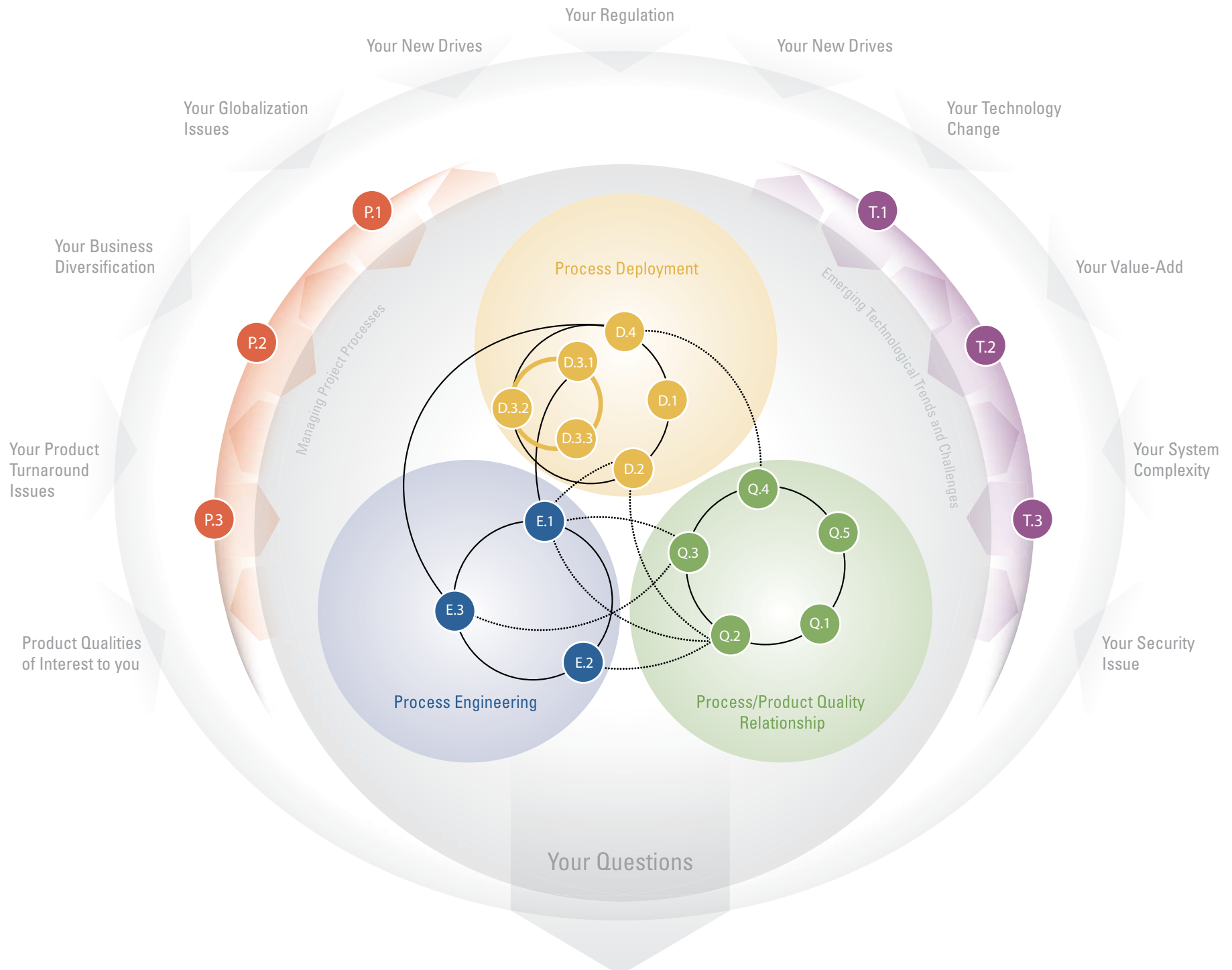
- D.1 Establishing the Infrastructure for Deployment
- D.2 Motivating Process Use
- D.3 Effective Adoption and Deployment
  - D.3.1 Formulating Process and Deployment Requirements
  - D.3.2 Supporting Effective Adoption
  - D.3.3 Assessing Effectiveness
- D.4 Managing Ongoing Process Deployment

As Figure 2 shows, the research nodes in some themes (such as The Relationships Between Processes and Product Qualities) show a progression in terms of evolving knowledge (a dashed line connector) while within and between other themes, the nodes show operational progress (solid line connector).

The figure presents further elaboration on the cross-theme research node interconnections. The bold arrows to and from the Managing Project Processes theme denote that it can provide contextual overlay detail to be used when building an instantiation. For example, you may be interested in understanding how to manage process adoption (research Node D.3.2) for an organization managed through centralized cooperation (research Node P.2). Likewise, any of the research nodes in each of the theme Managing Project Processes can provide a contextual overlay for any and all of the research nodes within all of the other themes.

PAGE	NODE	LABEL
<b>Process and Product Quality Relationship</b>		
25	Q.1	Eliciting and Specifying Product Quality Requirements
26	Q.2	Establishing Product–Process Relationships
26	Q.3	Modeling Product Quality–Process Relationships
27	Q.4	Verification and Validation of Product Qualities
28	Q.5	Sustaining Product Qualities
<b>Process Engineering</b>		
32	E.1	Specifying Processes Using Evidence
34	E.2	Organizing Processes for Reuse
36	E.3	Providing Process Engineering Infrastructure
<b>Managing Project Processes</b>		
45	P.1	Operating Under Autonomous Control
49	P.2	Managing Through Centralized Cooperation
51	P.3	Agreeing Under Federated Collaboration
<b>Processes Deployment</b>		
58	D.1	Establishing the Infrastructure for Deployment
59	D.2	Motivating Process Use
60	D.3	Effective Adoption and Deployment
61	D.3.1	Formulating Process and Deployment Requirements
62	D.3.2	Supporting Effective Adoption
63	D.3.3	Assessing Effectiveness
64	D.4	Managing Ongoing Process Deployment
<b>Emerging Technology Trends and Challenges</b>		
74	T.1	Continuous Requirements Evolution
77	T.2	Incomplete Knowledge
80	T.3	Heterogeneous Component-Based System Integration

► Figure 2: The Architecture of the Framework



## 2.2 Instantiating the Core Process Research Themes

The four core process research themes can act in concert as a tool supporting structured thinking in the process domain. These research themes do not answer questions; rather, they are intended to help determine what questions need to be answered in your environment.

The core process research themes and nodes are necessarily generic and intended to be used as a starting point in creating specific “mappings” (derivations or instantiations of the core areas) based upon the context of your environment and the driving forces affecting it. These instantiations are essentially lists of specific questions motivated by or inspired from the research questions within the research nodes presented in Sections 3–6. (See example instantiation in the Appendix.)

The context for your environment includes issues arising from or pertaining to these fundamental areas: people, process, project, and product.

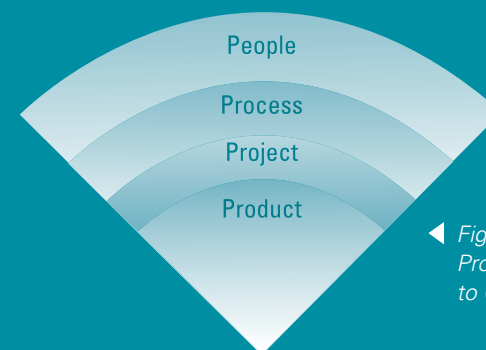
While there is a complex interplay among all four of these “Ps,” it may help to think of each in the following terms:

- **Products**<sup>1</sup> harness technology and have both external and internal qualities.
- **Projects** involve organizational structures and have scope.
- **People** have motivations, abilities, and culture.
- **Processes** provide the “glue” to hold it all together.

While product, project, and process issues are the primary focus of specific research themes in the core process research area architecture, the people factors such as education, culture, team building, leadership, communication, competencies, roles, and motivation are very important and are covered, where appropriate, throughout all the themes.

*People factors such as education, culture, and team building are pervasive and are covered, where appropriate, throughout the themes.*

PAGE	NODE	LABEL
<b>Process and Product Quality Relationship</b>		
25	Q.1	Eliciting and Specifying Product Quality Requirements
26	Q.2	Establishing Product–Process Relationships
26	Q.3	Modeling Product Quality–Process Relationships
27	Q.4	Verification and Validation of Product Qualities
28	Q.5	Sustaining Product Qualities
<b>Process Engineering</b>		
32	E.1	Specifying Processes Using Evidence
34	E.2	Organizing Processes for Reuse
36	E.3	Providing Process Engineering Infrastructure
<b>Process Deployment</b>		
58	D.1	Establishing the Infrastructure for Deployment
59	D.2	Motivating Process Use
60	D.3	Effective Adoption and Deployment
61	D.3.1	Formulating Process and Deployment Requirements
62	D.3.2	Supporting Effective Adoption
63	D.3.3	Assessing Effectiveness
64	D.4	Managing Ongoing Process Deployment

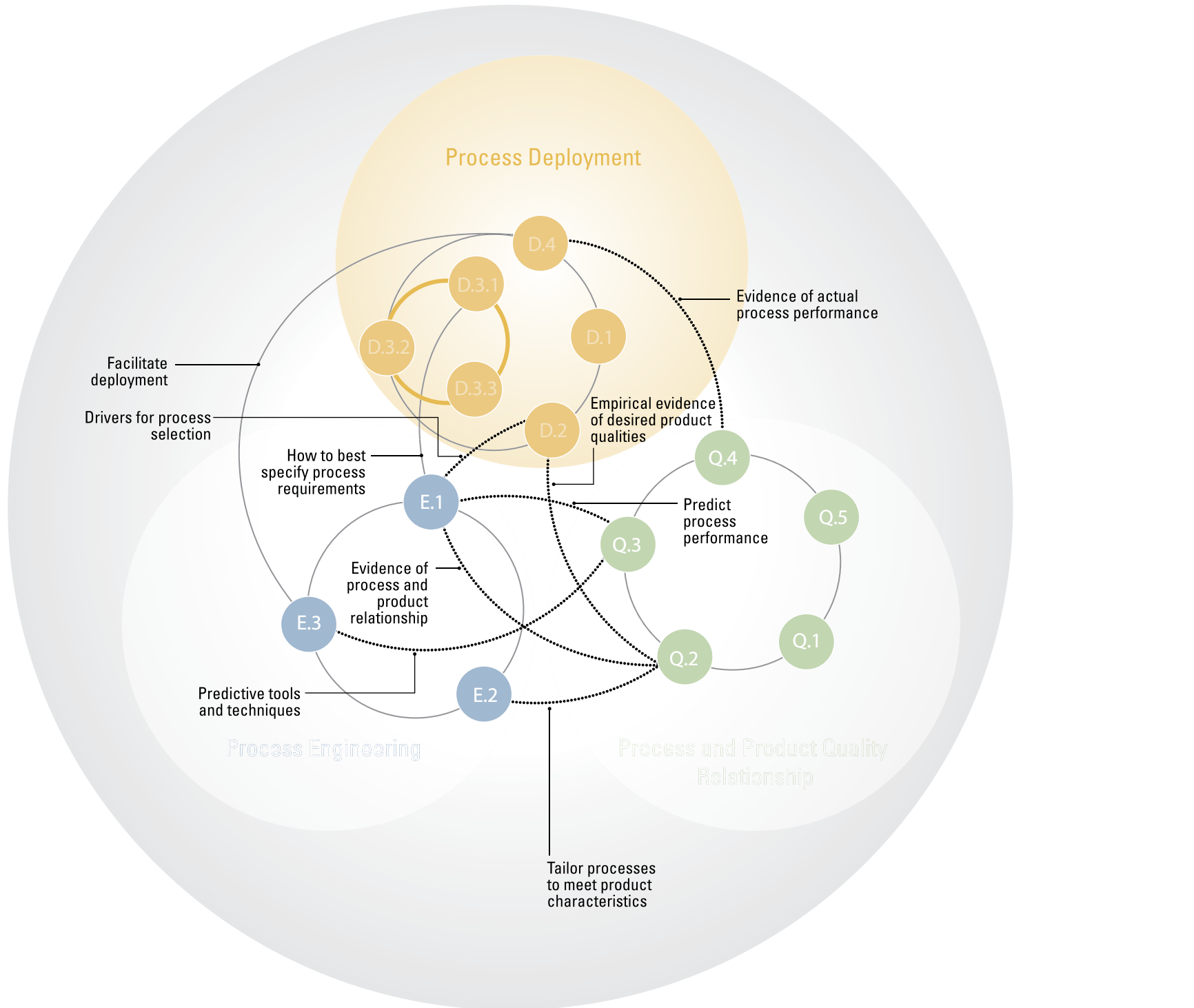


◀ *Figure 3: People Use Processes on Projects to Create Products*

People, process, project, and product issues may all be considered in any research theme. However, people issues are most prominent in Theme D; processes are most prominent in Theme E; project issues are most prominent in Theme P; and product issues are most prominent in Theme Q.

▶ *Figure 4: Example Relationships Between Research Nodes in Multiple Themes*

<sup>1</sup> In our use, the term “products” includes the concept of services.





The product, process, people, and project organizational perspectives on the core process research themes encompass a general appreciation of the following nine driving forces:

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### Forces Driving Process Research Framework

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1. **Value Add:** the pushback from users and customers who are demanding more value-added solutions

---

2. **Business Diversification:** businesses changing—getting larger or smaller, adopting different structures and ways of working, or entering new markets

---

3. **Technology Change:** the impact of new technologies both on businesses and, particularly, on systems development operations

---

4. **System Complexity:** new and evolving system architectures

---

5. **Product Quality:** the need to enhance product quality levels

---

6. **Product Turnaround:** the speed and nature of delivery of software-intensive technological solutions

---

7. **Regulation:** new and emerging standards that business is or will be bound to follow; this could include standards for the business community at large or, more specifically, standards imposed on the development and evolution of software-intensive technological solutions

---

8. **Security and Safety:** aspects of security for the development and deployment of systems as well as both the security and safety associated with the operation of software-intensive systems

---

9. **Globalization:** global markets, global work forces, and cultural diversification

---

In developing your instantiation of research in one of the themes, you may select from the set of research questions presented in the research nodes in Sections 3–6 those that are pertinent to your organizational or project environment. Alternatively, you may choose to apply particular driving forces that are important in your domain to any and all of the research nodes in order to develop a set of research questions that are tailored to your specific needs (previously referred to as creating an instantiation). Figure 2 includes driving forces with the core process research themes.

## 2.3 Overview of the Core Process Research Themes

As Figure 4 illustrates, each research theme has been given its own thread through the architecture, with varying concentration of product, process, people, and project organizational issues. Research nodes within each theme are connected by lines to denote broadly how knowledge in one node assists research associated with the next node. Some lines also cross research themes, connected with lines to indicate where there are strong relationships between research nodes. However, in principle, there could be important relationships between any two research nodes across the entire map, depending on the reader's areas of concern.

In some cases, a theme has a strong operational view (this applies in particular to the Process Engineering and Process Deployment themes). For such themes, traversing the nodes roughly clockwise will help in understanding the operational progression implied through the connecting lines.

For the other themes, The Relationships Between Process and Product Qualities and Managing Project Processes, there are also connections among the associated nodes. However, in these themes, the progression of connected nodes suggests an evolution of knowledge associated with increasing complexity rather than any form of an operational concept.

The Managing Project Processes theme also cuts across all three of the central themes. For this reason, it is separated from the others.

A description of each of four core process research themes follows.

### 2.3.1 Research Theme Q: The Relationships Between Process and Product Qualities

This research theme provides the *product* perspective. It is concerned with understanding if and how particular process characteristics can affect desired product (and/or service) qualities such as security, usability, or maintainability. Research nodes in this theme can be seen as projecting an expected evolution of knowledge, as research is conducted.

1. The first evolutionary phase will move the practice from an understanding of how best to define and specify product qualities (the first research node, Eliciting and Specifying Product Quality Requirements) to the need to determine if and how particular processes and variations in processes affect the level of desired product qualities that can be achieved (the second research node, Establishing Process—Product Quality Relationships).

2. These advances will be followed by the need to understand how to confirm achievement of quality requirements (the fourth research node, Verification and Validation of Product Qualities).
3. Knowledge gained from research activity associated with these three nodes can then be used to construct models of product-quality/process relationships which can be employed as support tools during process selection (the third research node, Modeling Product Quality-Process Relationships).
4. The fifth research node in this theme is concerned with how to select processes that sustain and evolve desired product qualities throughout the full product life cycle (Sustaining Product Qualities).

The relationship between an end-product quality and a process is important because process selection and general adoption by systems and software engineering companies requires staff to understand the achievable benefits. People will only adopt and follow processes that provide proven benefits. Those benefits may be in terms of (a) creating a better end product (or service), (b) making things happen faster, or (c) making people's jobs easier. Point (a) is covered throughout this research theme, notably in Node Q.2 (Establishing Process—Product Quality Relationships). Point (b) is addressed by research Node E.2 (Organizing Processes for Reuse) in the Process Engineering theme. Point (c) is covered by research Node P.1 (Motivate Process Use) in the Process Deployment theme. Hence, Figure 3 shows linkages among those nodes and themes.

### 2.3.2 Research Theme E: Process Engineering

This research theme provides the *process* perspective. It is concerned with how to define and build processes and understand their performance. The research nodes for this theme consequently follow an operational progression of how to

1. specify processes with adequate empirical evidence of their performance or performance impact in light of requirements
2. engineer, assemble, combine, and reuse process components to meet required performance targets
3. determine the infrastructure needed to best support this process engineering environment

This theme naturally draws upon knowledge and understanding developed in the first theme, since all processes are enacted in support of some product or service. Likewise, this second theme draws upon knowledge and understanding from the Process Deployment theme; after all, there is no point in making processes that people cannot or will not use.

### 2.3.3 Research Theme P: Managing Project Processes

This theme provides the *project organizational* perspective. It is concerned with the environmental and stakeholder values that drive the organizational structures used to undertake project work. These values may be political, economic, or social. They may be internal or external. They may be driven by particular business domain concerns, market conditions, or the nature of competitive environments. Stakeholders may include senior managers, shareholders, project staff, and project customers. The theme cuts across all three of the other core research themes, drawing from and having an influence on all of them. It is therefore presented separately from the other three in Figure 2.

### 2.3.4 Research Theme D: Process Deployment

This research theme strongly provides the *people* perspective.<sup>2</sup> It is concerned with getting the right processes effectively deployed into suitable organizational structures, so that people are motivated and prepared most efficiently to meet the goals of their organizations. The research nodes in Process Deployment theme follow this operational progression:

1. establishing the deployment infrastructure (e.g., software engineering process group) that will be the focal point for deployment
2. motivation for process use, selecting the appropriate deployment technique, and then planning for deployment
3. process deployment through formulating process requirements, adopting engineered processes, and assessing process adoption—while constantly monitoring and controlling the ongoing process deployment activities

This theme must therefore interact with the Process Engineering theme to ensure that appropriate processes are engineered that can be deployed and will be used and the Managing Project Processes theme, which is concerned with project organizational issues, to ensure that process deployment suitably facilitates the varying needs of different organizational project structures.

<sup>2</sup> “People issues” are, of course, crucial and pervade all the themes, not just this theme.

## 2.4 How Each Theme Presentation is Structured in this Document

In the presentation of each research theme, we have included

- **an introduction of each research theme that includes its rationale and focus**
- **a description of the state of the practice today with respect to the theme**  
If the description we provide of the current state of any of the core research theme does not match your situation, then you can use this document to create your own description of where you are today—and where you need to go.
- **a description of an idealized state of the practice for tomorrow with respect to the theme**
- **a description of each research node within the research theme**  
Each of the identified research nodes within the theme addresses one aspect of the theme’s focus and is described in terms of the process objectives that practitioners would seek to achieve. Singly or in combination with the objectives of other associated research nodes, each node’s objectives contribute to the progress of the research theme. For example, the focus of the Process Deployment research theme is on “getting processes into actual practice.” One of the research nodes associated with this theme is called Managing Ongoing Process Deployment, which has the objective to ensure that deployment of processes is planned, monitored, controlled, and appraised for effectiveness.
- **lists of research questions associated with each research node**  
These questions, the base constituents of the themes, are intended to be ones for which adequate answers are not currently available. Depending upon your environment, however, you may find answers to some questions to be relatively straightforward; for many other questions, finding answers will require that you add your context. For example, in the research node named Managing Ongoing Process Deployment, research question D50 asks: “How can we best monitor the ongoing returns on investment on process deployment and improvement? Is ROI an important measure?” These questions will certainly result in a series of related specific questions posed in the context of your environment, such as
  - How do we demonstrate that adopting a prototyping cycle will result in significant cost savings during post-validation life-cycle activities?
  - What is the cost of introducing prototyping tool support?
  - What is the cost of training staff and users on the tools and techniques involved?
  - For a given size of project, what is the current cost of rework resulting from validation failures?



# 3

## Theme Q: The Relationships Between Processes and Product Qualities

**This theme was developed by Julia Allen and Barbara Kitchenham, with additional contributions from Mike Konrad.**

Research Nodes and Questions in this Theme

- Research Node Q.1:  
Eliciting and Specifying Product Quality Requirements  
(Q1-Q5)
- Research Node Q.2:  
Establishing Product—Process Relationships  
(Q6-Q9)
- Research Node Q.3:  
Modeling Product Quality—Process Relationships  
(Q10-Q18)
- Research Node Q.4:  
Verification and Validation of Product Qualities  
(Q19-Q23)
- Research Node Q.5:  
Sustaining Product Qualities  
(Q24-Q26)

### 3.1 Introduction of Theme

This research theme is concerned with research needed to understand the relationship between process selection, project constraints (e.g., lead time or effort), and product<sup>3</sup> quality requirements<sup>4</sup> (e.g., usability or security requirements). The responses to the research questions we present here are most likely going to ensure that product qualities are effectively addressed in process definitions and their instantiations—meaning that the products developed and operated using specific processes are able to achieve their required product qualities. The scope of these questions includes reaching an understanding of the degree to which processes support the achievement of specified product quality requirements.

The theme addresses the following aspects:

- eliciting and specifying product quality requirements in the context of process (research Node Q.1)
- investigating the relationship between process and quality in the context of different process maturity levels (research Node Q.2)
- modeling product quality and process relationships (research Node Q.3)
- selecting a process to deliver specific product qualities (research Node Q.3)
- assessing the extent or degree to which the product quality is present (research Node Q.4)
- verifying and validating product qualities (research Node Q.4)
- making a product quality tradeoff analysis (including tradeoffs between product qualities and business requirements such as cost and schedule) (research Node Q.3)
- sustaining product qualities in operation and product evolution (research Node Q.5)

This theme description is generic; that is, our discussion and research questions are meant to be applicable to most product qualities. Research questions can be specialized to address issues related to specific product qualities; see the Appendix for an example of research questions specialized for “security.” Specific product qualities that may be of interest include those below. They are not an exhaustive list, but are those that arose often in our deliberations.

3 In this description, product is synonymous with systems of systems, system, and software.

4 The term product qualities refers to nonfunctional requirements such as security as well as behavioral requirements such as performance or reliability.



- security
- usability (human-machine interfaces)
- reliability
- dependability
- safety
- interoperability
- maintainability

With respect to tradeoffs and processes specifically intended to accomplish improvements in cost and schedule (such as processes for software product lines), product qualities that embody these include affordability and timeliness. These qualities need to be included within the scope of all product qualities when considering the research nodes, objectives, and research questions that follow.

### 3.2 Theme Rationale

This research theme is concerned with understanding process characteristics that address product qualities. The motivation behind this theme is one of demonstrating a more direct linkage between processes and end-product characteristics.

Currently, we see no general agreement about the relationship between process and product quality. The lack of agreement is visible in the variety of different approaches to product quality adopted by different researchers and research groups:

- ISO/IEC 9126 takes a “product” view. It provides a hierarchical model based on defining six high-level quality characteristics (functionality, efficiency, portability, maintainability, reliability, usability) and decomposing them into subcharacteristics and finally into measurable attributes. This approach has many problems, not the least of which is the inconsistencies in the standard itself [Al-Kilidar 2005].
- Software metrics researchers concentrate on internal quality assessment and investigate measures of “complexity,” “coupling,” and “cohesion” of software components [El-Emam 1999]. ISO 9126 is incompatible with this approach.
- Reliability modeling and performance modeling research concentrate on the properties of a system in its operational environment (or simulated operational environment). This research uses definitions of quality that differ substantially from those of ISO 9126 and are more suitable for requirements specification. Reliability research is part of a wider research community interested in the dependability of software systems where dependability includes concepts such as availability, reliability, safety, and security.

*Current research results make little attempt to provide an integrated approach to product quality requirements.*

- Usability design and testing (via usability laboratories) takes a different approach to usability than ISO 9126, referencing completely different standards:
  - ISO 9241: Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: Guidance on usability
  - ISO/TR 16982: Ergonomics of human-system interaction; usability methods supporting human-centered design
  - ISO 13407: Human-centered design processes for interactive systems
- Current software architecture research considers quality from the viewpoint of assessing appropriate architectures for new products. One approach is to develop scenarios that define quality requirements and (design and architectural) patterns that help to achieve these requirements. Stakeholders are expected to define quality requirements in terms of concrete scenarios defining system behavior or use. However, until recently, the assessment of the quality levels that will be achieved by design patterns has been qualitative (e.g., a specific pattern might “increase” reliability and “slightly decrease” maintainability). See, for example, Buschmann et al. on pattern-oriented software architecture [Buschmann 1996] and Bass et al. *Software Architecture in Practice* [Bass 2003].

These approaches use inconsistent terminology and incompatible methods. ISO 9126 defines each quality as “a set of attributes that bear on...” (For instance, “Reliability is a set of attributes that bear on the capability of software to maintain its level of performance under stated conditions for a stated period of time.”) The dependability definitions define the quality directly (e.g., reliability is “continuity of correct service”). (Note that this definition is often operationalized as “the probability of failure-free software operation for a specified period of time in a specified environment”). There is a substantial difference between regarding reliability as a set of attributes and regarding it as a property of software in its own right.

Victor Basili suggests viewing quality characteristics not by name but by user issue (e.g., what failure will I not abide, what hazards are unacceptable). His view eliminates the need for a particular product quality definition and aims at the needs of the user. We may not need to define a quality but only specify what is not allowable. For views on dependability, see recent articles by Basili and Donzelli [Basili 2004, Donzelli 2005, Donzelli 2006]. For another perspective on defining product qualities, see Voas’ “Software’s Secret Sauce: The ‘-ilities’” [Voas 2004].

Current research results make little or no attempt to provide managers and engineers with an integrated approach to specifying, achieving, and validating product quality requirements. We need a coherent research

plan to address the underlying issues facing software producers (i.e., how to design their development processes and manage their software projects in order to achieve specified product quality requirements).

### 3.3 Characterizing the Current State of the Practice

In this section, we describe the current state of the practice with respect to product qualities, their presence or absence at desired levels in developed and deployed systems, and the extent to which process is viewed as necessary to achieve a given product quality.

Until recently, little strong evidence has linked software processes to quantitative quality achievements. For example, a fairly substantial amount of research has linked module or component fault rates to internal software component measures. However, these studies have not related module fault rates to reliability. Furthermore, the models only seem (even moderately) useful in the context of evolving systems (i.e., predicting fault rates of modules across consecutive releases of a specific system [Ohlsson 2001]). Attempts to measure internal properties of a system during software development—measurements that can be used as surrogates for software product qualities as proposed by ISO 9126—have proven to be unsuccessful.

Since the 1970s, considerable research has been done in the area of reliability and performance modeling. This research has been successful in modeling self-standing software systems at the end of development (i.e., during system testing and acceptance testing) if the operational profile of the system is well understood.

Recently, a good deal of research has investigated the quality impacts of architectural decisions. Although much of this research is essentially qualitative [Svahnberg 2003], some major advances have been made in quantitative prediction of both performance [Liu 2005] and reliability [Wang 1999] during architectural design in the context of component-based system development. However, tradeoff models, although sophisticated, are still qualitative [Al-Naeem 2005].

Some qualities map readily to measurable concepts; others do not. Properties such as safety and security are usually decomposed into non-functional requirements; they are not considered “measurable” properties. This circumstance makes it difficult to assess the level of safety or security achieved other than qualitatively, even after system delivery. For example, safety cases are assessed by argumentation, not measurement [Weaver 2005].

*In an ideal future state, the use of processes is part of accepted practice to ensure that acceptable levels of product qualities are in place during all stages of the software and system development life cycle.*

Overall, progress in predicting quality characteristics (and thus validating quality requirements) early in the development process is mixed. An approach based on measuring internal software metrics was first proposed in the 1970s [Boehm 1978] and has been the object of many research projects (e.g., the method reported by Boegh et al. [Boegh 1999]). However, no effort based on measuring internal software metrics has delivered any major benefits. It is time to recognize that this approach does not work. Recent advances in quantitative performance and reliability prediction are extremely promising. They confirm the value of reusing architectures and component-based software development. However, other characteristics such as usability, maintainability, security, and safety can only be measured and predicted qualitatively. Tradeoffs between qualities are only possible using qualitative models. The challenge remains to construct quantitative tradeoff models incorporating most (if not all) qualities along with cost (affordability) and schedule (timeliness), as does the need to model and predict quality characteristics of complex systems of systems.

### **3.4 Characterizing the Desired State of the Practice**

In this section, we describe the desired state of practice with respect to product qualities when all questions posed in this core roadmap segment have been satisfactorily addressed and solutions adopted.

In this ideal future state, processes are accepted as one means by which specified levels of product qualities can be demonstrated and achieved. The use of processes is part of accepted practice to ensure that acceptable levels of product qualities are in place during all stages of the software and system development life cycle. The relationship between process and specific product qualities is known and can be quantitatively or qualitatively demonstrated (based on the nature of the product quality).

Further, processes are effectively used to elicit and capture product quality requirements including their specified levels for given products, markets, types of systems, and the like. The process disciplines and methods are sufficiently mature to provide confidence that expressing product quality requirements using process methods will produce the desired result in the deployed product.

Processes are also effectively used to assist in analyzing and making informed tradeoff decisions among all product quality attributes and between given product qualities and business requirements (such as cost, schedule, team competence, risk). Some business requirements can be considered as product qualities, such as affordability as an expression of cost and timeliness as an expression of schedule. Modeling methods exist for guiding these tradeoff analyses.

In addition, processes are effectively used to test, verify, and validate that product quality acceptance criteria and acceptance cases are met. Processes exist to assess and audit systems for aiding in making this determination. Measurement processes and defined measures are regularly used to demonstrate that product qualities continue to be present at the required level throughout the product life cycle, and in the face of product changes. (See Bollinger, Voas, and Boasson on persistent software attributes [Bollinger 2004].)

All categories of process described in this section have automated support to ensure their continued use and ease of use. In the state of the practice tomorrow, we fully expect that the relationship of process to some product qualities will be more mature than for others.

## 3.5 Description of the Research Nodes

### 3.5.1 Research Node Q.1: Eliciting and Specifying Product Quality Requirements

The objective of this research node is to determine how best to elicit quality requirements (criteria) for a product and how to properly specify these.

Research questions associated with this node include<sup>5</sup>

- 
- Q-1** How can a consumer with limited expertise be facilitated to express their needs in a sufficiently prescriptive way?
- 
- Q-2** How do we specify product quality requirements in general and such that they reflect business requirements?
- 
- Q-3** What levels of product quality are required for specific types of products? For specific markets? How are levels expressed?
- 
- Q-4** How do we specify product quality requirements in a quantifiable, measurable manner? (How will we know it when we see it?)
- 
- Q-5** Does the level of need for each ‘-ility’ vary by business domain? If so, how?
- 

<sup>5</sup> We’ve given each research theme a letter identifier so that the questions associated with each theme can be more readily identified. We’ve identified this theme on the relationships between processes and product qualities with the letter Q. Other themes on process engineering (identified with E), managing project processes (P), and process deployment (D) feature the same treatment. In addition, questions associated with the effects of emerging trends are identified with a T and those in the example instantiation for security with an S.

### 3.5.2 Research Node Q.2: Establishing Product–Process Relationships

The objective of this research node is to establish whether there is a direct relationship between a given product quality and the processes used to develop the product.

Research questions associated with this node include

- 
- Q-6** Is there a direct relationship between desired product qualities and the processes used to develop the product? If so, how is this relationship expressed and how does it differ based on the maturity of the process used?
- 
- Q-7** How do we determine the relationship between process and product qualities?
- 
- Q-8** What is the evidence that better processes are instrumental to delivering better products?
- 
- Q-9** Do the issues for product quality and process relationships change for composable components and for products assembled from composable components?
- 

### 3.5.3 Research Node Q.3: Modeling Product Quality– Process Relationships

The objective of this research node is to enable managers to select processes that result in the desired product qualities at the required level and degree given the maturity level of their organization. They can make informed tradeoffs between product qualities and other project and business requirements as well as among product qualities. They understand the risks and uncertainties inherent in their choices.

This research node also supports (re)negotiating product quality requirements in terms of what is actually possible, given constraints throughout the project and product life cycle.

Research questions associated with this node include

- 
- Q-10** How do we model and predict product quality—process relationships in the context of different maturity levels?
- 
- Q-11** How do we model and identify the tradeoffs between business requirements, process, and product qualities (such as degree of quality, cost (affordability), schedule (timeliness), team competence, risk)?
- 
- Q-12** How do we model and identify tradeoffs among required product qualities?
-

- 
- Q-13** How do we make well-informed decisions using the results of trade-off analyses?
- 
- Q-14** How do we select processes to meet specific product quality requirements?
- 
- Q-15** What process steps significantly influence the achievement of a specified level of product quality?
- 
- Q-16** When composing systems of individually certified components, how do you ensure that the non-functional product quality attributes such as security are achieved in the composed system?
- 
- Q-17** Can quality attributes associated with intermediate work products be used as indicators for quality attributes in the final work product?
- 
- Q-18** If not in absolute terms, can intermediate work products be used to inform the risks of failing to achieve final product qualities?
- 

### 3.5.4 Research Node Q.4: Verification and Validation of Product Qualities

The objective of this research node is to enable managers to select appropriate verification and validation processes to confirm the achievement of quality requirements. Process selection is guided by the nature and complexity of the system being constructed and operated.

Research questions associated with this node include

- 
- Q-19** How do we determine and specify product quality acceptance criteria?
- 
- Q-20** How do we test, verify, validate, assess, and audit that product quality requirements are met in the product?
- 
- Q-21** Using product quality and process measures, how can we determine that we are on track to achieve the desired level of product quality during each life-cycle phase?
- 
- Q-22** Do product quality verification and validation approaches scale up and/or change in the context of different product architectures (e.g. complex systems and systems of systems)?
- 
- Q-23** What is the role of automation in product quality verification and validation?
-

### 3.5.5 Research Node Q.5: Sustaining Product Qualities

The objective of this research node is to enable managers to select processes that best facilitate establishing, sustaining, and evolving product qualities throughout the full product life cycle.

Research questions associated with this node include

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**Q-24** How do we sustain product qualities in the face of product operations, product requirements change (both functional and non-functional), and product evolution?

---

**Q-25** How do we measure (assess, audit) that product qualities continue to be present at the required level and degree throughout the product life cycle?

---

**Q-26** What is the role of automation in product quality sustainment?

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# 4

## Theme E: Process Engineering

**This theme was originally developed by Dieter Rombach, Ross Jeffrey, Bill Peterson, Michael D'Ambrosa, Mario Fusani, Ho-Won Jung, and Stefan Ferber. Jurgen Münch and Alexis Ocampo made additional contributions.**

Research Nodes and Questions in this Theme

- Research Node E.1:  
Specifying Processes Using Evidence  
(E1-E21)
- Research Node E.2:  
Organizing Processes for Reuse  
(E22-E43)
- Research Node E.3:  
Providing Process Engineering Infrastructure  
(E44-E60)

## 4.1 Introduction of Theme

This theme primarily looks at processes from a process engineering perspective. Incorporated in this theme is the allied topic of integrating systems development processes with domain-specific processes. The focus of the previous theme (relationships between process and product quality) is on product qualities, their definition, and the characterization of processes that promote particular product qualities. The focus of this theme is on processes *per se*—how to define a process, construct a process from process components, and then understand and model process performance with a view toward building predictive capabilities based on experimenting with process models.

## 4.2 Theme Rationale

This theme is concerned with providing a set of process artifacts and mechanisms for effective (re)use by activities described in the process deployment theme. This objective includes

- **specifying processes using evidence** (e.g., defining scope of process, deriving process goals from business needs, technology, socio-political environment, and domain; providing quantitative process or product relationships for relevant goals) based on results from “relationships between processes and product quality” and “deployment and use”
- **organizing processes for (re)use** (e.g., identifying process families, engineering processes from process components) with process lines as an optional architecture for process components
- **providing process engineering infrastructure** for selection, integration, tailoring, and learning (e.g., providing methods and tools, applying existing process frameworks)

## 4.3 Characterizing the Current State of the Practice

The current state of process engineering is based upon ad hoc selection, tailoring, and integration without credible evidence of process impact. While companies with processes operating at CMMI<sup>6</sup> framework level 3 or above do have organizational standard<sup>7</sup> processes they tailor to

6 <sup>©</sup> CMMI is registered in the U.S. Patent and Trademark Office by Carnegie Mellon University.

7 This meaning uses the CMMI definition of a “standard” process: “A standard process describes the fundamental process elements that are expected to be incorporated into any defined process. It also describes the relationships (e.g., ordering and interfaces) among these process elements.”

create defined<sup>8</sup> processes for specific projects, we know of little commonly agreed upon evidence to support the “goodness” of these processes.

We also have no commonly acknowledged way to build processes from process components and no clear understanding of how to define process component interfaces or to assess the compatibility of linked process components. Processes are constructed often by crafting than by applying engineering principles.

In summary, with the current state of knowledge, we are unable to

- specify accurately the elements of a process having desired characteristics (functionality and capability or repeatability)
- confirm that a process model, if correctly implemented, will meet the requirements defined for its purpose (including business objectives)
- confirm the fidelity and suitability of a process from an analysis of its specification
- determine a strategy for constructing a process model from known or proven elements (subprocesses)

#### 4.4 Characterizing the Desired State of the Practice

Process line engineering combines process engineering with the concept of product line engineering. Variant-rich processes contain process elements (e.g., activities, inputs, outputs, or roles). Process elements that contain variation points are called variant-rich process elements. They are organized in a process line infrastructure that is designed with strategic business goals in mind. Concrete processes are derived from the process line infrastructure (i.e., instantiating the process line and resolving the variation points contained in variant-rich process elements). Intelligent support increases the efficiency of evidence collection, process selection, tailoring, and integration.

*Today, we have no commonly acknowledged way to build processes from process components and no clear understanding of how to define process component interfaces.*

8 Again, we’re using the CMMI definition of a “defined” process: “A managed process that is tailored from the organization’s set of standard processes according to the organization’s tailoring guidelines; has a maintained process description; and contributes work products, measures, and other process improvement information to the organizational process assets.”

## 4.5 Description of the Research Nodes

This theme has three research nodes:

- specifying processes using evidence (E.1)
- organizing processes for reuse (E.2)
- providing process engineering infrastructure (E.3)

The focus of this theme is on those processes for developing software-intensive systems or pure software systems.

### 4.5.1 Research Node E.1: Specifying Processes Using Evidence

The objective of this research node is to provide the abilities to specify, select, and evaluate processes based on evidence.

The first step in process specification is to identify needs for credible evidence. This step draws upon business goals, as well as linkages to evidence from process and product quality relationships and motivations from process deployment and use. The first of these linkages provides evidence of the applicability of a process to the needs for one or more specific product qualities. The second linkage provides feedback on process deployment and use and considerations of people competency issues. This research node, specifying processes using evidence, then integrates these sources of evidence and understanding so that we can reason clearly about the requirements or selection criteria for processes.

Research questions associated with this node include<sup>9</sup>

#### Scope of Specification

<b>E-1</b>	How can usable best practices be identified?
<b>E-2</b>	What kinds of processes are needed for value-creating networks; virtual teams; partnering; outsourcing, multi-site development, end-user development?
<b>E-3</b>	How can we align processes with business goals?
<b>E-4</b>	How to perform a gap analysis between today's state and a desired future state?

<sup>9</sup> We've given each research theme a letter identifier so that the questions associated with each theme can be more readily identified. We've identified this theme on process engineering with the letter E. Other themes on the relationships between processes and product qualities (identified with Q), managing project processes (P), and process deployment (D) feature the same treatment. In addition, questions associated with the effects of emerging trends are identified with a T and those in the example instantiation for security with an S.

**Mechanisms for Specification**

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- E-5** How can we best specify a process?
- 
- E-6** How can process definitions be packaged together with a quantitative/qualitative model describing their behavior?
- 
- E-7** What are appropriate process notations?
- 
- E-8** Can a process be analyzed to determine if it is implementable?
- 
- E-9** What process evidence is required?
- 
- E-10** What evidence is required with respect to process risks?
- 
- E-11** How can this evidence be specified and applied to the selection, tailoring and integration of processes?
- 
- E-12** How to combine evidence and “context”?
- 
- E-13** How does the context of a process (e.g., organization size, culture, process distribution) influence process selection criteria?
- 
- E-14** How can acquired process components be evaluated and certified (so that they can be trusted)?
- 
- E-15** How can knowledge from the related areas of organizational and behavioral studies be incorporated into the definition and specification of processes that can be effectively implemented?
- 
- E-16** How can we assure that a process will meet product/project requirements and standard compliance?
- 
- E-17** What does it mean to certify a process component and how could this be achieved? (For example, what criteria could such certification be made against?)
-

## Process Specification Improvement

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**E-18** How can we improve process specifications based on feedback from deployment and use?

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**E-19** How can the value of a process be determined and monitored?

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**E-20** How can the quality and cycle time performance implications of process decisions be evaluated?

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**E-21** What effects do different domains have on the selection criteria for processes? The critical issue here is the need for a clearer schema for classifying and categorizing “domains.” There is confusion between business domains, application domains, and industry domains, as well as with factors incorporating cultural issues. Identification of critical domain characteristics is crucial. Once these are known, the process and systems engineering issues can be addressed.

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### 4.5.2 Research Node E.2: Organizing Processes for Reuse

The objective of this research node is to engineer processes from reusable process components and other artifacts to meet specified process requirements. One approach is to frame the issue in the context of process lines.

Leveraging the business investment in processes for reuse in multiple projects, business units, and sites is a critical issue for process engineering. The multiple mechanisms to support reuse include process libraries, process tailoring, process standards, best practices, and expert experience-exchange networks. *Software product lines* target at strategic reuse in products linked to the business advantage instead of reuse as a goal by itself. Transferring the concept to process engineering is the key idea behind process line engineering:

- Generic process elements containing commonality and variability are organized in a process architecture that is designed with strategic business goals in mind.
- Concrete processes are derived from a process architecture, instantiating the process architecture and binding variation points of generic process elements.

Typical variation points of generic process elements are the application domain, project goals, and team competence. *Tailoring* of processes in a process line becomes mostly a variant selection activity. The process architecture and process component *integration* are the critical mechanisms to guarantee that tailored processes fit together and form a smoothly operational process landscape. Finally, the reusable process components of a process line require ongoing improvement and *evolution*.

Research questions associated with this node include

### Process Lines

- 
- E-22** How can we define the scope of process lines?
- 
- E-23** How can we define the value of process lines?
- 
- E-24** How can we organize processes and evidence into one or more process lines (similar to the concept of product lines)? This includes domain-specific issues.
- 
- E-25** What is the appropriate degree of commonality of processes/procedures (e.g., across multiple sites, disciplines, and cultures)?
- 
- E-26** How to understand the difference between different domains with respect to processes and measurement?
- 
- E-27** What effects do different domains have on the selection criteria for processes?
- 
- E-28** How can process line engineering be aligned with product line engineering?
- 
- E-29** How should a process architecture be constructed for a process asset base?
- 
- E-30** How can the right process elements be identified in the asset base for a specific project as a function of product requirements and team competence?
- 

### Tailoring

- 
- E-31** Can a formal approach, based on a sound theoretical basis, be developed to address the tailoring of processes for specific implementations?
- 
- E-32** What are the organizational and environmental factors that affect tailoring choices (e.g., tailoring for small enterprises or for agile development)?
- 
- E-33** How can we tailor processes with predictable effects on efficiency?
- 
- E-34** How can processes be designed for easy tailoring?
- 
- E-35** How to specify processes including variability?
-

### Interoperability

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- E-36** To what extent is it possible to integrate different processes, in particular when they are based on different paradigms, for example, agile processes versus more waterfall-like approaches?
- 
- E-37** How can we harmonize the mental model of sequential development with the reality of continuous iteration?
- 
- E-38** How can processes be packaged together with a quantitative/qualitative model describing their behavior?
- 
- E-39** Are there mechanisms for understanding and improving interoperability between processes (composability analysis: pre/post conditions, inputs/outputs, styles, assumptions)?
- 
- E-40** How can domain-specific development processes (product dependent) and software/systems development processes be synchronized?
- 

### Evolution

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- E-41** How does the context of a process (e.g., organization size, culture, process distribution) influence process evolution?
- 
- E-42** How can we evolve process lines based on deployment feedback?
- 
- E-43** How can processes be made sufficiently adaptive to provide effective support in responding to domain-specific change?
- 

#### 4.5.3 Research Node E.3: Providing Process Engineering Infrastructure

The objective of this research node is to provide infrastructure to support process engineering. This infrastructure includes the appropriate support organization and integrated support for all the activities for specification, integration, tailoring, and learning.

The research questions are divided into two areas: (1) organization and training and (2) technology. The organization questions focus on defining organizational hierarchies that reflect the advances being proposed. In parallel the training questions focus on the related people skills. The technology questions focus on process lines and other technology approaches to support organizing processes for reuse.



Research questions associated with this node include

### Organization & Training

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- E-44** What process infrastructures are appropriate to support the new technologies and concurrent engineering?
- 
- E-45** How do we create easy to use “experience bases” that allow knowledge to be stored, updated, and accessed by developers at varying levels (to facilitate the continuous evolution of problem domains and technical skills required as businesses move into new hybrid domains, for example)?
- 
- E-46** How do the team competencies affect the engineered development processes?
- 
- E-47** How do we educate people for process engineering in general and the use and/or development of process lines in particular?
- 
- E-48** How do we educate people in the need for and the use of evidence?
- 

### Technology

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- E-49** Which activities related to evidence creation, process line engineering, and usage can or should be automated?
- 
- E-50** What automated decision support is useful and how can automation and human (educated) creativity be balanced?
- 
- E-51** How do we perform process model configuration management?
- 
- E-52** How could “process patterns” be best used?
- 
- E-53** What is the role of process simulation in providing trust, scaling, and supporting process prediction, selection, tailoring, and integration?
- 
- E-54** What visualizations can support process management (including different views for different stakeholders and different business domains)?
- 
- E-55** What level of statistical analysis is feasible and reasonable to apply to process management?
- 
- E-56** What is appropriate support for automated metrics collection?
- 
- E-57** How can an inference engine for effective display and retrieval of processes be constructed?
- 
- E-58** How can we use process evidence to derive theories about process, product, and resource dependencies?
- 
- E-59** How do we define intellectual property for a process?
- 
- E-60** How can we integrate process engineering and workflow management tools?
-



# 5

## Theme P: Managing Project Processes

**This theme was developed by Claes Wohlin, Gonzalo Cuevas, Nidhi Srivastava, and William Peterson.**

Research Nodes and Questions in this Theme

- Research Node P.1:  
Operating Under Autonomous Control  
(P1-P16)
- Research Node P.2:  
Managing Through Centralized Cooperation  
(P17-P27)
- Research Node P.3:  
Agreeing Under Federated Collaboration  
(P28-P32)

*A large number of companies practice distributed or global development that could most likely be done more effectively and efficiently; hence, applied research is needed.*

## 5.1 Introduction of Theme

This theme is primarily concerned with the evolution and impact of organizational control structures on the management of project processes. This theme is therefore a filter for the other core research themes in so far as it provides context against which to consider the research questions in each of the other themes. In addition, this theme adds research questions related to managing specific project processes.

## 5.2 Theme Rationale

This research theme is concerned with the formulation and evaluation of processes that specifically address the challenges related to organizational control structures and in particular their effect on projects. The theme is motivated by the increased use of distributed development. For example, distributed development may be within one or several companies, at one or multiple locations, with one decision authority, centralized cooperation or federated collaboration, and with shared or different organizational goals. The distributed development may include different time zones and different cultures. Such globalization will continue. However, it may take different shapes depending on developments in the world. It may include more traveling or less travel, but the requirements to be able to co-develop from separate sites toward a joint development base will keep increasing. Development “24/7/365” (or at least 24/5+, assuming that all sites have a weekend) may become more and more common.

This research theme differs from the others in the sense that research has not been sufficiently translated to industry practice, and consequently research is not, or at least not yet, driving progress. A large number of companies practice distributed or global development, within their own organizations or using outsourcing. Companies have managed to “get by” so far, but distributed—and especially global—development could most likely be done more effectively and efficiently; hence, applied research is needed.

Thus, researchers have to understand research in related fields and the current industry practice and start to improve on it, taking on some of the key challenges with global software development. This is particularly true of free and open-source software. Research in related fields includes work on virtual teams and cultural issues. This research has not yet been fully integrated into the research in software engineering, which may be exemplified by a new conference that has been launched in the area: the International Conference on Global Software Engineering (ICGSE).<sup>10</sup> The conference presents the challenges as follows:

10 More information can be found at <http://www.inf.pucrs.br/icgse2006/>.

*Developing software across borders is becoming an important competitive advantage in today's software industry. However, the increased globalization of software development creates software engineering challenges due to the impact of time zones, diversity of culture and communication, or distance. This requires novel and effective techniques and behaviors to achieve intended productivity and quality targets.*

*ICGSE 2006 is the first International Conference that aims at bringing together researchers and industry practitioners to explore both the state-of-the-art and the state-of-the-practice in software engineering for global software development.*

Research papers are published in the area, but they are too few and several of them are pointing to the challenges and problems rather than presenting solutions. A search in the ISI database, which contains the major journals, on “global software development” results in 17 papers being identified, and a search on “outsourcing” AND “software development” resulted in 16 papers, with a small overlap between the two searches.<sup>11</sup> The two lists are provided in the Further Reading and References section at the back of this book. Several things may be noted. The oldest paper is from 1996, and several of the papers belong to Lecture Notes in Computer Science or the special issue of *IEEE Software* devoted to global software development. In summary, relatively little research into global software development has so far been published in journals.

It is also noteworthy that only a few papers are published a year in the international journals on this topic. Although the information is not included in our results lists, it is interesting to note that no paper from the first list (from a search on “global software development”) had been cited more than six times as of February 2006, the time of our search. This in itself is an indication that little research is being done in the area.

In addition to the articles found in the citation database, we note that the journal *Software Process Improvement and Practice* devoted a special issue to global software development in 2003.<sup>12</sup> The journal *Information and Software Technology* planned a special issue on global software development in 2006. However, the number of submissions was rather low and finally only two papers were judged to meet the quality standards. The Association for Computing Machinery (ACM) published a report on global development and outsourcing in March 2006 [Sapray 2006].

11 It should be noted that the ISI database is normally used in library research, and hence it is a good source for sampling research articles.

12 See, for example, the following article: Damiam, D. E. “Global Software Development: Growing Opportunities, Ongoing Challenges.” *Software Process Improvement and Practice* 8, 4 (October/December 2003): 179–182.

Also, *IEEE Software* published a special issue in September/October 2006 on global software development and began a regular column on free- and open-source software in 2005.

Global software development provides some opportunities but also a vast number of challenges (some of which also exist for single-site development), including

- Process is often documented, but in many instances another process is practiced. How should we be able to coordinate the actual processes used?
- How do we manage time zones and different cultures?
- Is it at all possible to work with a common development base, where software is checked in and checked out by different development sites?
- How do we manage integration of software developed at different sites?
- How do we divide software development among sites?

The list of challenges can be made very long. The objective of this research theme is to try to structure some of the challenges and formulate research needs based on them.

### **5.3 Characterizing the Current State of the Practice**

Today we have many small companies operating on only a single site. Some of these companies operate collaboratively with others, possibly to enhance capacity or to avail themselves of specialist skill sets. These collaborations may involve several companies in one country or companies distributed across international borders, where the cost base or political considerations may be important drivers. Such collaborations tend to be managed through subcontractor relationships.

Many larger companies are split across multiple sites, again either in one country or across several countries. In such circumstances, there may often be a greater tendency to have collaborative working arrangements without the notion of a subcontractor management structure. These projects may be considered more integrated than is often achieved through a contractual relationship.

The level of process integration across split sites tends to be very low (“geography is destiny”). This is particularly true where cross-site management is achieved through subcontractor relationships. Each site often deals with the other sites as “black boxes,” this being the easiest structure to handle given the current lack of process culture that pervades.

Where higher levels of integration have been successful, integration is, nevertheless, normally organized around development life-cycle stages. For example, requirements development and design are completed on the same site. Then implementation and testing are accommodated on different sites. True blending of team members across split sites is very much in the minority.

Many companies run projects across sites in different countries. Research is being conducted, but it is still quite limited in comparison to the wide use of global development today, based on the searches mentioned of the ISI database. Some key areas of research may be identified and exemplified with some of the articles found. Research areas include

- coordination of global development (e.g., [Carmel 2001, Hersleb 2003, Smitte 2004, Smitte 2005])
- virtual teams (e.g., [Jacobs 2005, Sakthivel 2005])
- agile development (e.g., [Reeves 2004, Rottman 2006, Tiwana 2004]).
- a number of articles were identified when searching for “outsourcing” (e.g., [Kishore 2004, Dayanand 2001, Bhatnagar 1997])

Global software development and outsourcing is a worldwide trend, and research is catching up with it. Evidence to support this conclusion include the inception of a new conference devoted to global development (ICGSE), ACM’s report on the topic, and the increasing frequency at which articles on the topic are published (much more frequently than 10 years ago). Having said this, the amount of research into global software development and outsourcing is still low in comparison to the extent in which it is practiced in industry.

## 5.4 Characterizing the Desired State of the Practice

In this state, small and large organizations live together in harmony and have culturally infused process awareness. Federations of small organizations tend to grow in response to project needs. As the projects complete, the federations reduce in size. Even large organizations tend to manage themselves around a federated system. The need for process in this environment is unquestioned. In fact, process compliance is a mandatory requirement for entry onto the “register of suppliers.”

Continuous process improvement is a regular practice at organizations. Education, training, and professional awareness support the above concepts. Integrated process standards, including other disciplines and business processes for different domains are common. Emerging processes for systems engineering of global-scale complex and adaptive

systems are aligned with stakeholder values. The use of process simulations based on various parameters to reduce risks is common. Process is viewed as an enabler for cooperative working.

Not only do organizations evolve rapidly in this environment to meet business needs, but so too do their individual staff complements. The notion of a job for life has almost completely gone. Now people are brought in on personal, short-term contracts, according to project work demands. People are certified against processes or process components. This means that employers can ramp-up teams much more efficiently in response to business needs.

## 5.5 Description of the Research Nodes

The focus of this theme is from a “project” perspective. The three research nodes in this theme are

- operating under autonomous control (P.1)
- managing through centralized cooperation (P.2)
- agreeing under federated collaboration (P.3)

The nodes represent progression from a research perspective and an organizational complexity perspective. Most development organizations would move through the three nodes as a progression. Very few development organizations are expected not to pass through those stages of growth. Moreover, the research issues become more complicated as we progress through the nodes. Thus, it is reasonable to believe that good solutions are needed for one node before moving onto the following nodes. For example, if someone would like to address research for Node P.3, the research questions in nodes P.1 and P.2 are most likely also relevant. (However, in presenting the nodes in this document, we do not repeat research questions for nodes with a higher number.)

For each of the three nodes, research has to address how open-source, multidisciplinary competence provisioning and experience bases are handled. Furthermore, the processes need to be flexible and tailorable to the needs and the size of the development (in terms of partners involved and number of people involved). Moreover, different processes at different parts of a company or across multiple companies must be able to interact. The interfaces between process parts become crucial. Results from research questions could help us in structuring project work appropriately for projects of varying sizes and distribution.

For the nodes below, we are assuming process-inclined or process-savvy organizations. We do not know how process maturity of an organization correlates to its ability to move and progress through the nodes.



### 5.5.1 Research Node P.1: Operating Under Autonomous Control

The process objectives of this node are to focus on projects with autonomous control to achieve predictable outcomes in terms of functionality, cost, schedule, and quality attributes when developing, evolving, and maintaining software. Autonomous control refers to situations where there is one decision authority and everybody works according to the same project process and joint organizational goals. However, it does not exclude distributed development, working across cultural boundaries, or having different companies involved. The key issue is that one prime has the decision authority and that anyone involved in the project uses the same project process instantiation. Some examples of this situation include the following:

- one company at one or several sites
- “body shopping” with a requirement to use the same project process instantiation
- several companies with one prime and everybody uses the same project process instantiation

In this node, organizations may have established their process assets (process repository) and their improvement program. Also, they may have established the competency roles and profiles, which allow them to know the talents of the people and thus to establish the most effective structure and staffing in each project. In addition, the process models are extended to cover all life-cycle aspects: products and services. Finally, in this state the results of a project in terms of cost, functionality, schedule, and quality should be predictable.

The motivation for operating projects with one decision authority and using the same project process instantiation comes from several sources:

- reduction of overhead for communication and interaction due to the use of the same project process instantiation for different working parts of the team
- the ease of communications and enhanced ability to share process understanding, though in this environment there may be a lower motivation for process adoption
- other motivations for this organizational structure include the ability to react more quickly to market demands and also the ability to be close to particular clients

Research questions associated with this node include<sup>13</sup>

### Process Type (including scale)

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- P-1** How do we select the best possible project process or set of processes to use? The latter is particularly relevant when having different processes. Selection of the project process is a key issue to be able to achieve project goals. Moreover, it must be possible to adapt the process to different types of applications, project size, and so forth.
- 
- P-2** How do we scale processes to our needs? How does a subject matter expert (SME) know when it is time to have more formal procedures in place? SMEs cannot be expected to have well-defined processes in place. It is hence important to be able to have as little overhead as possible, but still sufficient to enable the delivery of high-quality software. As a small company grows, it is important to realize that the processes used have to change. The questions are when to change them and how to change them. It is easy for a company to grow out of its process support.
- 

### Competency

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- P-3** What are the needed competencies for the required tasks on a specific project? How is the relation between competence profile and development process handled? It is a challenge to have the right mix of competencies in a given project, in particular when certain type of competence may be needed in too many projects at the same time. It is also a particular problem for small companies where often the same person must take on multiple roles. This issue becomes an even larger challenge when looking into successive nodes within this theme. Furthermore, how do you “process-bond” teams that are brought together from outside the company for specific projects?
- 
- P-4** How do individual competencies sum up in the team? The distribution across site means on the one hand that competencies at different sites become available, but on the other hand it may be difficult to get what one wants from a project perspective. This may be because the site manager has many projects and would like to staff them according to an optimization for the site and not for a project.
- 
- P-5** How do we make optimal use of available competencies? Different companies mean different competencies. How do we effectively combine competencies that are available in different companies?
- 

<sup>13</sup> We've given each research theme a letter identifier so that the questions associated with each theme can be more readily identified. We've identified this theme on managing project processes with the letter P. Other themes on the relationships between processes and product qualities (identified with Q), process engineering (E), and process deployment (D) feature the same treatment. In addition, questions associated with the effects of emerging trends are identified with a T and those in the example instantiation for security with an S.

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**P-6** How do we capture and share experiences across sites? Project work means building experience, which is difficult to share in general, but becomes even more complicated when the team is distributed across sites. A certain understanding or experience may come at a site internal meeting, but how is this experience communicated to others not at the meeting, and in particular if they are at another site?

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### Distribution

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**P-7** How do we manage development between different locations? This includes managing, for example, responsibilities and risks between locations (including risks inherent in distributing in the first place). Development across locations is in many cases a necessity for large project and large companies. This means that the actual distribution of the development must be managed. What management procedures are needed to manage a distributed project? How is time reporting done? To what extent do things have to be done in the same way at the different locations?

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**P-8** How do we divide the work effectively and efficiently between locations? The work should not only be divided between the locations, it should be divided in an effective and efficient way. This includes taking the current architecture into account

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**P-9** How do we distribute quality requirements? The distribution of work often means that functionality is distributed, but how do we handle non-functional requirements? The customer or market has expectations on certain quality aspects for the whole system, but when distributing the work it may mean that quality requirements are forgotten or it is very difficult to break them down to parts of the software. A typical example is how to handle performance.

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**P-10** How do we handle different time zones? Time zones are obstacles for communication, but also an opportunity for having development 24 hours a day. This includes challenges related to

- How do we handle time zones and how do we effectively communicate the results from one site to another? How do we make use of differences in time zones? This question is about the opportunities. How can different time zones help us develop software more efficiently? Is it possible to work 24 hours a day with development and pass assignments around? Can technologies such as Instant Messaging and Voice over IP make the world one global workplace?
- What is the productivity drag, if any due to time zone differences? Is the productivity different in different sites? Why? How can we leverage from the best? Do people in different cultures make different types of mistakes?
- How do we work toward a joint base (configuration management)? Many configuration management tools exist, but are they able to cope with potential issues such that developers in different sites wanting to work on the same component at the same time?
- How do we manage different cultures and time zones between different companies? Different companies imply different processes. Distributed development around the globe also implies different cultures. How do we handle the mix of cultures and mix of processes?

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## Cultural

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- P-11** How do we handle cultural differences? Cultural differences are a fact. The challenge is first to be aware of them and then to use them to our advantage. Can formal training deal with the above challenge? How do we educate people to work in global software development? What additional knowledge is needed to ensure that developers can work in a global environment? It does not only require knowledge about software development, but also a good understanding of the challenges with global development and with other cultures.
- 
- P-12** How do we ensure the same process interpretation in different cultures? Can Enterprise Process Frameworks address the issues of multiple process styles? How heavy or light should an enterprise framework be to meet business objectives? Even when having the same process across sites, there is no guarantee that it is interpreted in the same way. The likelihood is higher if being within one country and with people with a similar educational background, but it becomes much more a challenge when having people from different cultures.
- 
- P-13** How do we make use of experiences in one culture in another place? It is well-known that it is difficult to share experiences effectively. However, it becomes even more complicated to share and use experiences in one culture with another culture. How can this be done? It is probably insufficient to publish experiences; they have to be transferred, but what is the best, most effective way?
- 
- P-14** How can the end-user perspective be captured in global software development? The end-user comes further away from the development when the development goes global. Thus, it may become even more difficult to include the end-user perspective into the development.
- 

## Standards and Regulations

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- P-15** How do we make processes that are compliant with accepted standards? Different companies in different countries may have different standards or they may even be required to follow different standards due to legislation. How can global software development be conducted with different standards?
- 
- P-16** Are global standards an imperative for this model to succeed? Is it possible to succeed with global development without having common standards? Can global process interface standards be developed?
-

## 5.5.2 Research Node P.2: Managing Through Centralized Cooperation

The process objectives of this node are to focus on projects with one main decision authority, but using different project process instantiations. These projects are most likely decentralized and made up of a possible mix of mature and immature organizations, but having joint organizational goals. Some examples of this situation include: one company in multiple sites, divisions and so forth; and subcontracting with one prime.

Scenarios within this node could be large projects in one company with multiple development locations or multiple companies. The reasons for having development in multiple locations are many: access to labor, cost-reduction, presence in a specific country or region, tax incentives to establish work based in economically disadvantaged parts of a country, or where there are pockets of expertise (e.g., in regions surrounding a University with a good reputation in certain fields). Even the need for a sufficient number of people can cause companies to establish themselves at multiple locations or to cause subcontracting to other companies. Other reasons include having locations near major clients or near important suppliers.

The objective is to support companies in being able to divide projects into suitable parts that can be developed on different locations and then, as easily as possible, be integrated into a system. This is a challenge, and it will make more demands of process than perhaps a single location operation, however it has a better chance of succeeding where the processes and culture support a joint understanding.

Research questions associated with this node include

### Different Processes

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**P-17** How do we handle the use of different project processes? Different locations may have different project processes or at least different flavors of the same process. This poses some challenges that are reflected in the remaining questions in this group.

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**P-18** Is the output from one process producing the input needed in another process, or are the differences between processes at different locations a problem?

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**P-19** How do we handle interfaces between processes? The interface between different processes in distributed development must be well specified and the output from one process should be the input to another process.

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- P-20** How are the abilities to deal with multiples process style managed? For example, is it possible to combine a waterfall approach in one location with a much more agile approach in another location? What requirements have to be put on the development to ensure that we obtain one integrated system at the end of the day?
- 
- P-21** How can we handle companies with different process capability? How do customers, suppliers, and vendors with different process capabilities work effectively? Is the process capability determined by the lowest common denominator?
- 
- P-22** How do we integrate open source code in company-specific products? Open source is often used as “good example.” How can software from open source be used in commercial context? How can we learn from how open source development is conducted?
- 

### **Team issues and Competence**

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- P-23** How do we manage virtual teams? How are virtual teams formed? How are competencies found and combined? A virtual team is here defined as a team of individuals working together in a specific role, for a specified time and with a specific goal, however without any supporting organizational structures.
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### **Central Authority**

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- P-24** How do we identify suitable partners/subcontractors? How are the relationships between different roles managed? The problem here is about identifying the most suitable partners to meet our goals. This includes identifying suitable collaborative partners and subcontractors. What is the role of SMEs in these relationships?
- 
- P-25** How do we put requirements on subcontractors? What is a minimal set of requirements when subcontracting internationally? This includes both functional and non-functional requirements.
- 
- P-26** How do we accept components delivered from a subcontractor? Delivered software must be accepted. How do we perform acceptance testing? This may be particularly difficult when only part of a system is delivered. How do we certify a specific quality level for a component or subsystem of the final system? Particularly where the overall product qualities may not be directly traceable to that ‘component’?
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- P-27** Do locations need a primary and secondary role based on competencies within a company too? Should one location act as the primary location and other work as subcontractors? The actual roles and responsibilities must be clearly defined. Should sites be structured for growth as “Centers of Excellence”?
- 

### 5.5.3 Research Node P.3: Agreeing Under Federated Collaboration

The process objectives of this node are to focus on projects with shared decision authority and project goals but with different organizational goals and processes. These projects are most likely decentralized made up of a possible mix of mature and immature organizations. Furthermore, the objective is to create effective and efficient systems development independent of times zones, cultures, and other differences (for example, development processes). To truly harness the possibilities from global development, the best companies around the globe must be involved. The objective must be to create strategic alliances with the best players to be competitive. Some examples of this situation are joint ventures and independent development with one integrator.

One scenario of this node is to make use of different expertise at different companies. For example, there could be a split between domain knowledge or expertise (provided by one partner) and systems and software engineering skills (provided by another partner). The objective could be to create virtual value-added networks by combining the expertise of different companies. In other words, several companies jointly develop a product, where there is an agreement about how to divide income from the sales.

Research questions associated with this node include

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- P-28** How should relationships between partners be formulated? Joint development of a system means having some explicitly agreed-upon relationship. The relationships include other sites, outsourcing, partner development, and networks of partners. The networks may be formed for a specific project or may be more long-term and go beyond the scope of any one project. It is important to decide what the core assets are and what is suitable to let others handle.
- 
- P-29** How can we handle interfaces among several small companies? To compete with larger companies we may see networks of small companies working together. They are often less mature and they may not have well-documented processes. How do small companies together become mature and able to handle larger projects?
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**P-30** How should a process for collaborative development be formulated? The development at different companies requires some process for the actual collaboration. How should it be handled?

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**P-31** How do we handle change? Requirements change during development. This becomes much more cumbersome when a change may affect not only one company, but several. What routines need to be in place to handle change across companies in distributed development?

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**P-32** How do we create value-based networks of partners to work as peers in projects? How do we establish shared goals? Different companies may have different goals, but to be successful shared goals are needed. Is it possible to agree on common goals?

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# 6

## Theme D: Process Deployment

**This theme was originally developed by Terry Rout, Hanna Oktaba, Hans Juergen Kugler, and John Goodenough. Stan Rifkin, Suzanne Garcia, and Eileen Forrester made additional contributions.**

Research Nodes and Questions in this Theme

- Research Node D.1:  
Establishing the Infrastructure (D1-D6)
- Research Node D.2:  
Motivating Process Use (D7-D19)
- Research Node D.3:  
Effective Adoption and Deployment
  - D.3.1: Formulating Process and Deployment Requirements (D20-D30)
  - D.3.2: Supporting Effective Adoption (D31-D35)
  - D.3.3: Assessing Effectiveness (D36-D45)
- Research Node D.4:  
Managing Ongoing Process Deployment (D46-D60)

## 6.1 Introduction of Theme

Process deployment, at its heart, is about getting processes into actual practice. There is no shortage of good software engineering ideas, but few are in practice.

The process deployment theme has many interrelationships with both the product and process themes already described. The main interrelationships are depicted in the core framework structure (Figure 3) presented at the beginning of this document. Process deployment draws heavily on process engineering. Process engineering provides the processes and process performance models that process deployment is responsible for getting into practice. Process deployment can capture empirical evidence and patterns of experience from the deployment and use of processes. This evidence and experience base is fed back into process engineering and product quality to maintain and refine process engineering. In fact, it is an open research question about the cause and effect relationship between process engineering and deployment: which informs the other?

The scope of process deployment is worth exploring. In essence, we are suggesting that it is “deploy  $x$ ,” where  $x$  is any software engineering related process or product. The reason for the wide scope is another open research question: how is software engineering deployment informed by the extensive information available about deploying processes and products outside of software engineering?

## 6.2 Theme Rationale

This theme is centered on people at all levels of analysis: individuals, teams, groups, organizations, countries, and cultures. We are focusing on the organizational level of analysis here. Specifically, we are concerned with how collectives become aware of, make sense of, and use processes in their daily work; how to ensure processes get followed, and how to measure relevant aspects of the usage. It incorporates issues dealing with education and training to develop collective competencies; motivation of process performers to use and faithfully adhere to the agreed process; actual usage of a developed or standardized process into an organization’s projects and operations; setting and measurement of the achievement of process adoption goals, and appraisal of the deployed processes to determine their fidelity and capability, as well as to evaluate whether the usage achieved the goals of adding value promised by the process or product.

Readers need to recognize the critical difference between process *implementation* and process *deployment*. The concept of deployment goes beyond the single instantiation of an implemented process, to address the effective deployment of a process specification to achieve multiple implementations of the process across an organization, each tailored to suit its specific organizational context. The successful implementation of a process instance establishes its basic functionality; its effective deployment establishes its true value to the implementing organization.

*Process deployment extends beyond the single instantiation of a process specification.*

Note also that the viewpoint taken here is primarily that of the transition agent, the role which is responsible for understanding the adoption context, for creating or obtaining relevant transition mechanisms to support that context (including establishing the infrastructure in which the transition agent “lives”) and for establishing and measuring progress toward adoption goals.

### **6.3 Characterizing the Current State of the Practice**

Almost nothing is known empirically about the most effective ways to deploy software engineering processes. Even the most rudimentary questions cannot be answered: how much change can we introduce and how fast? Nor do we know how to estimate the duration and resources required to convert an idea to use. We know almost nothing about how to set transition goals and we are at the beginning of our knowledge about how to measure adoption, that is, the taking up of new ideas and adapting them into practice.

We do not know how to take the knowledge of adoption in one organization and adapt it to others. We do not know what of the technology to be introduced has to be altered to make it fit better with the organization into which we desire to insert it; we do seem to know more about the changes we need to make to the organization in light of the demands of the new technology.

As a practical matter, we do not agree on how software engineering organizations and their surrounding internal and external structures work and interact (in a way that is relevant to adoption).

We do not agree on what motivates organizations to change, so we see work on quantifying benefits, sharing details (stories) of implementations, and models or roadmaps of specific implementations, and we do not know if they are necessary or even beneficial.

Current methods to measure process adoption, such as standardized assessments, appraisals, and evaluations, are disruptive and highly invasive. They are heavily reliant on staff and are consequently costly both in terms of external consultants and, more importantly, in terms of internal disruption to day-to-day operations. The still-heavy reliance on human judgment for most appraisal types also makes conducting consistent and reliable appraisals challenging.

For those organizations that do make the leap of faith, or that have been motivated by business drivers such as perceived marketing advantage or the ability to increase their customers' confidence levels in their performance, process deployment has often been an ad-hoc procedure, offering little opportunity for insight into the reasons why the deployment was successful, or conversely, a poor understanding of why the initiative failed. Although techniques and models have been promulgated to support understanding of organizational, group, and individual behavior during a process adoption, research in these approaches is sporadic and significant gaps in knowledge of effective approaches is seen in different system domains.

We do not know the best infrastructure for process improvement. Software engineering process groups (SEPGs) have been part of the dictum [Fowler 1990], but their effectiveness has not been objectively measured. Further, alternatives to SEPGs have not been systematically proposed and evaluated. In particular, we do not have an adequate contingency view: Under what conditions do the various infrastructure alternatives perform best and why?

## **6.4 Characterizing the Desired State of the Practice**

We would understand how organizations work and what motivates them to change, to improve. We would be able to assess how much change is reasonable and how quickly it could be introduced. And we would be able to estimate the resources and duration to accomplish the targeted level of adoption.

We would know what we would have to tailor, both with respect to new the process technology and the organization. Our tailoring guidelines would be sensitive to a range of contexts, including, but not limited to, competitive landscape (e.g., time-to-market pressure), national culture, organizational culture, professional culture, external and internal drivers, organizational strategy, and rewards and reinforcement.

Accordingly, processes will be deployed effectively and flexibly, employing empirically confirmed tool support to implement flexible and responsive tailoring of process models. The performance of processes will be enhanced by capturing and analyzing performance data and by improving processes based on that data and analysis. We will have the capability to define a common basis for capturing, storing, comparing, and sharing experiences in implementing processes that links to common approaches to process, organizational, and implementation modeling. We will have frameworks, grounded in appropriate theory, for knowledge acquisition from process implementation experiences and a theoretical basis for relating results of process implementation to the formal specifications and organizational context into which the processes are being deployed.

And we will know which kind(s) of deployment infrastructure is appropriate and how much investment would be necessary to achieve the desired level of adoption.

## 6.5 Description of the Research Nodes

There are six research nodes in this theme:

- establishing the infrastructure to be the focal point for deployment (D.1)
- motivating process use (D.2)
- formulating process and deployment requirements (D.3.1)
- supporting effective adoption (D.3.2)
- assessing effectiveness (D.3.3)
- managing ongoing process deployment (D.4)

The research in this theme supports several activities needed when deploying processes and measuring their effectiveness in an organization:

- Establish the desire, need, and fit for the new process, for the change. Then establish sponsorship for deploying those processes, aligning processes to business goals, and investing in process infrastructure and process improvement (relates to research nodes “establishing the infrastructure” and “motivating process use”).
- Establish the process needs within the organization context. These needs are satisfied by the capabilities of the process engineering theme in the framework (relates to research node “formulating process requirements”).
- Adopt the engineered processes based upon the adoption infrastructure (relates to research node “supporting effective adoption”).

- Evaluate the processes currently implemented within the organization and apply the results to characterizing the success of adoption, as well as diagnosis and improvement of processes to better support the business goals (relates to research node “assess effectiveness”).
- Manage the ongoing deployment of the processes within the organization ensuring that performance and capabilities satisfy the organization's process needs (relates to research node “managing ongoing process deployment”).

### 6.5.1 Research Node D.1: Establishing the Infrastructure

Transition agents are responsible for establishing the mechanisms to search for potential process improvements and process improvement models, translate those potentials into solutions for their own organization's problems, find sponsors to tailor the solution and tailor organization to the new process, pilot test the new process, collect performance adoption information, and improve the deployment process going forward. What is the best infrastructure with which to accomplish those goals?

SEPGs have been proposed, and research needs to be conducted to identify and validate the best forms of SEPGs or alternative infrastructures.

Research questions associated with this node include<sup>14</sup>

- 
- D-1** What infrastructures have been tried and what are their relative merits?
- 
- D-2** What is the best advice, then, on which infrastructure fits which (contingent) context?
- 
- D-3** Where should the infrastructure sit inside the served organization? What is the best governance model?
- 
- D-4** How much responsibility for the adoption cycle is it appropriate and effective for it to take as its charter?
- 
- D-5** What is the profile of the best-suited people to staff the infrastructure roles?
- 

<sup>14</sup> We've given each research theme a letter identifier so that the questions associated with each theme can be more readily identified. We've identified this theme on and process deployment with the letter D. Other themes on the relationships between processes and product qualities (identified with Q), process engineering (E), and managing project processes (P) feature the same treatment. In addition, questions associated with the effects of emerging trends are identified with a T and those in the example instantiation for security with an S.

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**D-6** What is the quantitative relationship between investment in infrastructure and the achievement of adoption goals?

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### 6.5.2 Research Node D.2: Motivating Process Use

We have swept into this node most of the fundamental questions related to adoption because absent their answers we cannot hope to address the questions of how to motivate a change in what we do every day in a software engineering organization. We are particularly cognizant that we have to keep the unit of analysis (organizations) in mind as we propound our questions, as there is already an abundance of work at, say, the individual (psychological) level. It is well settled that the psychological level does not scale to the collective, so we have to be careful to formulate appropriate questions and be attentive to the sources and methods we use to answer them.

Research questions associated with this node include

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**D-7** How do organizations work (in the ways relevant to adoption)?

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**D-8** How do organizations change and improve?

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**D-9** Assuming there is more than one answer to the first question and to the second, how do we map the ways in which organizations work to the ways in which they change?

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**D-10** How do we estimate the resources and duration needed to make planned change?

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**D-11** Is there a way to assess the degree to which an organization is ready to make a change to an extent we specify, both in depth and rate (how much, how soon)?

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**D-12** What is the best way to characterize the environment of the organization that is relevant to understanding and tailoring the deployment?

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**D-13** Is there a difference in deploying process vs. product?

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**D-14** What is the best way to align and increase the motivation and ability of personnel to adopt new processes? In fact, what motivates change for each type of change target? For example, are business cases relevant?

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**D-15** What is the best way to plan the tailoring of the new processes in light of the answers to all of the questions above? To tailoring the organization?

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- D-16** What organization-based confidence or acceptance criteria ensure that when defined processes are adopted, the desired results will be produced? (These criteria are used to decide when the engineered processes produced by the Process Engineering layer are worth deploying in the organization.)
- 
- D-17** How do we determine and coherently express understanding of the cause and effect relationship among processes/process changes, deployment, and product outcomes?
- 
- D-18** What explains the difference in the rate and success of deployment (i.e., small vs. large, government versus commercial, business sector differences, etc.)?
- 
- D-19** What are the key strategies and tactics to motivate process use in settings where process adoption has failed in the past?
- 

### 6.5.3 Research Nodes D.3: Effective Adoption and Deployment

The objective of this group of three research nodes is to provide structure and insight into effective process deployment activities. Process deployment includes identification of process needs for a given context; specification, engineering, and refinement of processes through modeling and simulation (as expressed in the Process Engineering section); deployment of processes through a variety of adoption support mechanisms and structures; and measurement of both the effectiveness of the process in meeting the organization's business goals, as well as measurement of the progress and success of the adoption itself.

Deployment includes two facets. The act of deploying selected technical and management processes to an organization or project is the first, and deciding which deployment processes should be used to facilitate the adoption of the selected processes is the second. These facets break into three activities:

- **Formulate**  
This activity determines the technical and management process and transition needs, as well as the competencies of the human resources, since these competencies affect the ability of the organization to successfully adopt selected processes.
- **Adopt**  
This activity introduces the selected processes into the organizational context.
- **Assess**  
This activity provides evidence showing to what extent the selected processes are being adopted (i.e., used and followed accurately), and if followed, whether the process is achieving its expected results.



The “assess” activity identifies the effectiveness of the adoption (e.g., the breadth and depth of deployment) as well as the effectiveness of the deployed processes in achieving the expected organizational benefits.

The research nodes below elaborate research needed in each of these areas to be able to achieve the future state described in section 6.4.

#### 6.5.4 Research Node D.3.1: Formulating Process and Deployment Requirements

The process research objective associated with this node is two-fold: (1) improved methods are available to provide a high-level description of an organization’s process needs and the relationships among these needs; and (2) improved methods are available to efficiently determine requirements for successful deployment.

The business needs and organizational context (e.g., barriers and enablers for deployment) determine the requirements that deployed processes should satisfy. This node in the deployment cluster deals with research issues associated with determining the requirements for processes to be deployed, as well as understanding and expressing the requirements for successful deployment of the selected processes. The process requirements are to be satisfied by the technology called for by process engineering. Process engineering provides the technology for selecting and tailoring processes that satisfy an organization’s process needs.

In addition to deciding what processes need to be deployed, an organization needs to decide which deployment processes should be used, again based on requirements. This node also addresses research questions related to improving understanding of the requirements for different deployment approaches for different organizational and business contexts.

Research questions associated with this node include

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**D-20** How can we best formulate process needs related to business goals?

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**D-21** How should value-based processes be deployed?

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**D-22** How can we best construct sets of processes that when deployed will deliver desired business outcomes?

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- D-23** How do we express process needs so as to ensure that an organization is able to adopt processes meeting its needs, e.g., by taking into account the relationship between process capability and organizational maturity? (Depending on an organization's process maturity--and many other factors--it may be able to adopt some processes better than others. This needs to be taken into account when selecting and tailoring processes, i.e., these constraints need to be expressed when stating an organization's process needs.)
- 
- D-24** How do we express process needs so as to ensure that deployed processes will be able to respond effectively to changes in the organization and/or the business environment?
- 
- D-25** Do current models for process capability and selection reflect the linkage to risk appetite and risk tolerance in the organization or project?
- 
- D-26** What are enablers and barriers for process adoption?
- 
- D-27** How does the level of team competency affect the deployment of processes?
- 
- D-28** How do we ensure that required competencies can be rapidly developed and applied in the deployed processes?
- 
- D-29** What are the key factors influencing the successful deployment of engineered processes?
- 
- D-30** How do the processes for expressing deployment requirements affect the need for transition infrastructure? Are some processes cheaper or faster than others? Do some require less infrastructure and, say, more active participation by those who are affected by the changes?
- 

### 6.5.5 Research Node D.3.2: Supporting Effective Adoption

The objective of process research under this node is to improve the procedures used to deploy selected processes in an organization so that adoption spreads with appropriate speed to all appropriate structures and roles within an organization.

This node deals with research needed on methods for helping organizations adopt new processes. Such research includes research on determining which adoption support processes are most effective in different organizational circumstances.

Research questions associated with this node include

- 
- D-31** How do we ensure that required competencies can be rapidly developed and applied in the deployed processes (JIT Training)?
- 
- D-32** How can we support team performance versus individual performance?
- 
- D-33** What is needed to develop effective teams and team architecture (e.g., leadership and team motivation)?
- 
- D-34** How do you make the transition mechanisms of processes designed for one context easily and efficiently adaptable for a new context? (i.e., when an organization is acquired into another enterprise)?
- 
- D-35** How can CEOs and other management personnel be educated and trained for process deployment, and how can we best measure the effectiveness of training?  
In fact, does it matter how effective executive sponsorship is?
- 

### 6.5.6 Research Node D.3.3: Assessing Effectiveness

The objective of process research under this node is to improve the procedures used to determine the effectiveness of deployment processes and deployed processes.

The objective of process research under this node is to establish a sound theoretical and empirical basis for deployment evaluation and assessment. The knowledge gained from the experience of process deployment is routinely captured, analyzed and used.

The work of this activity results in assessment criteria and identified deficiencies, recommended improvements, strengths, and weaknesses in: the deployment process, the processes that were deployed, the stated process needs, and the effectiveness of the deployment.

Research questions associated with this node include:

#### **Assess the Deployment Process**

- 
- D-36** How do we define measures of breadth of process adoption in a particular context?
- 
- D-37** How do we define measures of depth of process adoption in a particular context?
-

### Assess Adopted Process Effectiveness

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- D-38** What are the appropriate success criteria upon which to judge deployed processes?
- Can we develop a generally accepted set of measures describing the effectiveness of deployed processes and the impact of improvement actions?
  - Process reality is different for different organizations; how does this affect our understanding of success criteria?
  - What is the difference between documented and practiced processes? Is the development performed according to the documented processes or how does the actual development differ from the documented process within an organization?
- 
- D-39** What level of automation can be introduced to facilitate the assessment process?
- 
- D-40** How can we best validate processes, to confirm fitness for purpose and return on investment?
- 
- D-41** What aspects of process capability are important and relevant for assessment?
- 
- D-42** How can we be sure that the results of process evaluation really reflect the ability to satisfy business needs?
- 
- D-43** What lessons can be learned from different forms of process evaluation?
- 
- D-44** How can we improve the efficiency and effectiveness of process evaluation approaches?
- 
- D-45** How do we convert process evaluation to a continuous activity that can be effectively automated?
- 

#### 6.5.7 Research Node D.4: Managing Ongoing Process Deployment

Activities under this node develop: goals and targets for process performance and capability, measures for monitoring performance and capability, analyses of collected data, identification of deficiencies between actual and targeted performance/capability, and actions to address these deficiencies (e.g., corrective actions and preventive actions).

This node deals with the research needed to ensure that the ongoing deployment of processes in the organization can be effectively monitored and controlled, and that feedback on process performance will reinforce continuing motivation and sponsorship.

The objective of process research under this node is to establish a sound theoretical framework that relates the results of process implementation to the process model being deployed. A sound theoretical and empirical basis exists for quantitative management of engineering, management and improvement processes.

Part of understanding the success of a process deployment must come from process appraisal. This aspect is also considered in this node.

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**D-46** Since all measurement is taken in a context, what is the best way to characterize the adoption context? What is the best way to measure that context?

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**D-47** How can adoption effectiveness be compared across organizations or between any two organizations? That is, how do we know which aspects of deployment to transfer from one organization to another? How do we know what we are supposed to learn from each other?

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**D-48** What is the impact of changes in the organization and the business environment on the process needs and capabilities of the organization?

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**D-49** How do we best monitor on a continuous basis the capabilities and everyday use of deployed processes?

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**D-50** How can we best monitor the ongoing returns on investment on process deployment and improvement? Is ROI an important indicator?

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**D-51** What is the most effective way of identifying and addressing changes in competencies driven by changes in the organization and business context?

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**D-52** How can we identify causes of variations in performance and capability so as to initiate effective process evaluation?

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**D-53** How do we create easy to use “experience bases” that allow knowledge to be stored, updated, and accessed by developers at varying levels?

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**D-54** How can concepts like network-centric knowledge management (could be social and/or infrastructure) be employed to leverage process knowledge across multiple contexts?

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**D-55** What kind of ontology would be useful for classifying process-based knowledge and the context of its acquisition and use?

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**D-56** How can we improve the design and use of process asset repositories to support effective learning from experience?

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- D-57** Can the full validity and usefulness of statistical process control be demonstrated in relation to software and systems engineering and management processes? If yes, how should it be used to aid adoption?
- 
- D-58** What are the limitations of applicability of statistical process control in this context?
- 
- D-59** Can the collection and analysis of process metrics be improved to reduce effort and increase acceptance?
- 
- D-60** How can we best identify gaps in the extent to which an organization's processes address its goals, and what is the optimal mechanism to address these gaps?
-

# 7

## Process Effects of Emerging Technology Trends

**The content for this section was developed by Suzanne Garcia, Eileen Forrester, John Goodenough, Khaled El-Emam, David Raffo, Lynn Penn, and Alan Lawson. Additional contributions were made by John Morley. This group considered all the emerging technologies and architectures identified through IPRC workshops.**

### Research Areas and Questions in this Section

- Technology Factor:  
Continuous Requirements Evolution  
(T1-T23)
- Technology Factor:  
Incomplete Knowledge  
(T24-T37)
- Technology Factor:  
Heterogeneous Component-Based Systems Integration  
(T38-T56)

## 7.1 Introduction

Can anyone define the technologies that will influence or, perhaps, guide our future? Does anyone know the effects a new technology will have on product qualities or process? IPRC members delved into speculation about the ways in which new technologies might affect the processes we use—witness the scenarios of the future described in Section 9 and the definition of driving forces in Section 2.2.

At the conclusion of that speculation and definition, however, what we have confirmed is that we cannot know with certainty what will be. We cannot project today's technologies into the future with any acceptable accuracy, because we cannot fully predict the course an innovation will take as it moves from concept through research to use. Likewise, we are hard-pressed to explicitly predict tomorrow's technologies because we cannot influence many of the forces that will cause them to be developed.

Yet despite those limitations, we do know something valuable about the trends we see with technology: we can identify attributes of technology that have significant impact on processes within a system life cycle. Because they affect a system or product's life cycle, those attributes—we call them technology factors—are important for process research. In this section, we have delineated three overarching factors that emerged from our considerations of the varying possible technologies of the future:

1. **Continuous Requirements Evolution**  
We must acknowledge that, for many system types of the future, we will need to initiate, manage, and evolve sets of necessarily incomplete requirements over multiple iterations of system evolution and reconfiguration.
2. **Incomplete Knowledge**  
Beyond continuous evolution and therefore incomplete knowledge about requirements, many systems will be evolving the technologies in use, and the stakeholders that are participating in evolution, at the same time that they are trying to deliver a usable system. This creates a development context of necessarily incomplete knowledge for a major part of a system's overall life.
3. **Heterogeneous Component-Based Systems Integration**  
We are moving away from hand-crafted, custom-developed solutions into a world of heterogeneous, component-based systems (systems of systems). The integration challenge in this environment extends beyond the technical integration (though that will be difficult enough) into the socio-technical aspects of process integration in particular.



If this sounds like Fred Brooks Jr.'s "No silver bullet," well it is! In that famous paper, Brooks drew attention to the inherent complexity of software. Here, we are simply observing that it is increasing, even though we barely could get intellectual control of the previous level of complexity. A recent observation by William Wulf, president of the U.S. National Academy of Engineering, is instructive. In an address at the convocation of the University of Southern California Center for Systems and Software Engineering on October 24, 2006, Wulf said

*The fact that physical systems are described by continuous mathematics is what enables thorough testing. It is possible to test a physical system for one input value and know that its behavior for small changes in the input will be very similar. Thus, if one tests a range of input values that are 'close enough,' you have exhaustively tested the system.*

*Not so for software. If one of the  $10^{10}$  bits of my laptop's memory is changed, a large, discontinuous change in behavior may occur. That, in turn, means that an 'exhaustive' test of a piece of software must consider all possible 'states' of memory.*

*Just to get a feel for what that means, each bit in memory can be in one of two states – so there are  $2^{10^{10}}$  (roughly  $10^{30}$ ) of them. That's 10 raised to a power that has a one followed by eight zeros. Just for comparison, I believe there are about  $10^{100}$  atoms in the universe. Ten raised to a power of 1 followed by two zeros. Thus, the number of atoms in the universe is an infinitesimal fraction of the number of states in my laptop's memory.*

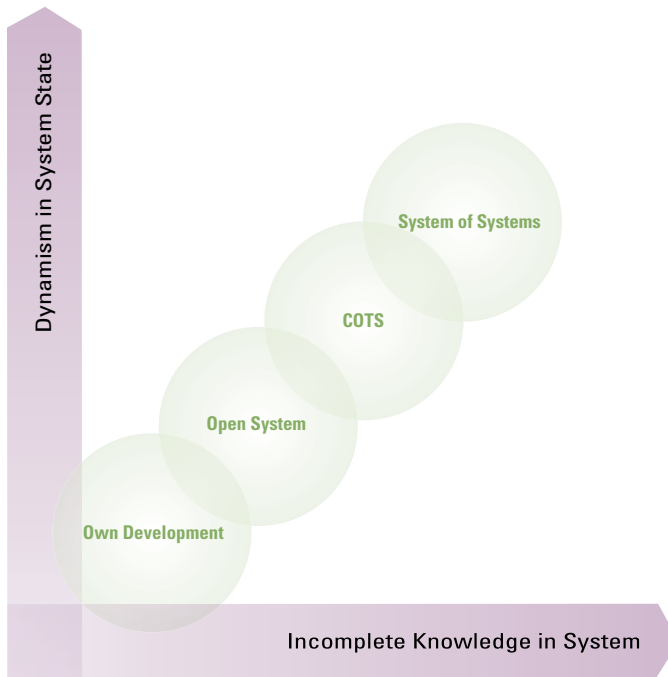
*Bottom line, except for trivial programs, exhaustive testing of software is impossible. The lack of mathematical continuity is the culprit.*

The purpose of our discussion of these factors is to propose an approach to forming research questions while acknowledging that the forces affecting process development for any particular environment may be unknown or not clearly understood. These are not the only factors that were considered, and it is easily conceivable that other factors will increase in importance to processes for system construction and evolution over time. Future IPRC content is likely to address adding additional technology factors.

In process terms, systems and software engineering has many problems for which adequate solutions have not been found. The research questions presented in earlier sections of this report provide testament to this fact. To be successful, any new technology or architecture will need either to solve an existing problem or open up new opportunities. Industry trends suggest that

- Systems are becoming ever more complex, both in terms of size and architecture—often involving a multidisciplinary approach—and reuse of open source components is increasing, along with the trend towards the dynamic trading of services between interoperating technological systems. This leads to systems that are built from heterogeneous components, often with diverse stakeholders. We characterize this as “heterogeneous component-based integration.”
- There is an increasing need to cope with very dynamic environments where systems are regularly upgraded to accommodate continually changing business requirements. We struggle with evaluating the impact of these changes, both on the systems themselves and on the environments into which these systems are placed. We characterize this as a state of “continuous requirements evolution.”
- As we move closer and closer to a virtual world, trust and assurance of system integrity is becoming a major concern, particularly where biological linkages exist. In these contexts, we are often faced with the dilemma of the need for high trust and assurance, while having incomplete knowledge of the constituents and the system’s state. A complicating factor is that more and more non software engineering professionals are building systems, taking us closer to a merger of the software engineering discipline with the target domains themselves. However, this is not yet providing an integration of software development processes with domain-specific processes. We characterize this as working in a state of “incomplete knowledge.”
- We operate in an increasing global domain, both for the procurement and provision of technological systems. This is one of the underlying causes of the heterogeneity that continues to increase in our systems and systems of systems. We treat this in our section on “heterogeneous component-based integration.”

Figure 5 provides a framing of three dimensions that we believe have impact when looking at how emerging technologies affect processes of system construction and evolution. As the degree of dynamism increases in the system state (e.g., constituents coming in and out of systems of systems), we also see a decrease in the degree of knowledge we can have about the system's state.<sup>15</sup> This might not be as much of a process issue if we weren't interested in greater and greater degrees of assurance for the systems that we construct, regardless of their conditions of construction. This tension among dynamism, knowledge, and desire for assurance underpins the three factors that we highlight in this section.



*The tension among dynamism, knowledge, and desire for assurance underpins the three factors that we highlight in this section.*

Figure 5: The Trend Toward Decreasing System Knowledge

These issues are also connected to the research themes presented earlier. In general, however, we can see that there are three broad areas where more research is required. These are concerned with how to handle (a) continuously changing requirements, (b) circumstances in which we necessarily have incomplete knowledge, and (c) the world of large-scale interoperating technological systems.

<sup>15</sup> Position of systems in Figure 5 are meant to indicate only notional relationships between dynamism and knowledge.

## 7.2 Method

We initially looked at technologies and what is driving their development in terms of a matrix (see Figure 6). This approach is concerned with the effects that new and emerging technologies related to information and communications technology might have on the processes used to conceive, build, deploy, operate, and evolve products and services that make use of them. In analyzing the many possibilities that may come up in the future, the approach has been resolved into three technology factors that cut across multiple technological possibilities and have significant process research implications. We examined these factors, rather than trying to build maps for specific technologies, because the process issues that arise for individual technologies will be more general than specific.

There will be exceptions to this statement; however, in looking at a process research framework, we need to deal with the general process issues that will be present in many of the emerging technologies, since they are the high leverage points. Users of the framework may find it useful to think about how the questions below modify some of the research questions in the four core process research themes (see Sections 3–6) if both the technology factor and the considerations of a particular research node are in play. See the Appendix for an example of considering technology factors and other research nodes together.

In the matrix shown in Figure 6, at the intersection of challenges and system types, we see some areas emerge in relief (see gray cells in Figure 6), such as the high acceleration of importance that complexity, dynamism, and emergent behavior have in a systems area that is still early in its evolution—self-organizing systems.

New technologies are highly likely to imply new process needs/capabilities. One of the interesting process aspects about new technologies is that we are typically trying to learn about them as we build them. This leads to a different learning process than is present later in their evolution. This difference will be reflected in process objectives and research questions that may be specific to a particular system evolution stage.

As an emerging technology factor is exercised from today's process capability to the future, depending on the characteristics of the technology, different process capabilities may be needed to succeed. The team created process objectives and research questions that cover a wide spectrum of system evolution contexts. Research users may wish to confine their process research focus to a narrower context than is expressed in these questions.

		Process Challenges									
Size	Complexity	Dynamism	Emergent Behavior	Non-Professional Developers	Multi-Disciplinary Systems	Open Source Processes (Theme P)	Trust & Assurance	Heterogeneous Organizational Operations	Integrated Or Heterogeneous Component-Based System		
<b>System Types</b> <b>Self Organizing Systems</b> - Self-protecting systems - Context-aware systems - Self-organizing development systems (ecology based)		C-2 S-0 D-4	C-3 S-0 D-4	C-1 S-0 D-0	C-1 S-2 D-0	C-1 S-1 D-1	C-3 S-1 D-1	C-4 S-1 D-1	C-1 S-0 D-1		
<b>Systems of Systems</b> - Ultra large scale systems - Systems of systems		C-3 S-1 D-2	C-4 S-4 D-0	C-1 S-0 D-0	C-3 S-2 D-1	C-1 S-1 D-0	C-4 S-1 D-3	C-4 S-2 D-1	C-4 S-1 D-3		
<b>Ubiquitous Systems</b> "Appliances" (need to be context aware)		No votes	No votes	No votes	No votes	No votes	No votes	No votes	No votes		
<b>Service Level Application-Based Systems</b> - Methodology to simulate system as risk mitigation approach - Service level based systems - Systems that introspect due to real use cases		C-1 S-1 D-1	C-1 S-3 D-0	C-0 S-3 D-0	C-2 S-1 D-1	No votes	C-1 S-3 D-0	C-1 S-1 D-1	C-1 S-2 D-0		
<b>AI/Robotic</b> - Robotic systems - AI systems		C-0 S-1 D-0 R- Metrics	C-0 S-1 D-0	C-1 S-2 D-0	C-0 S-4 D-0	No votes	C-0 S-3 D-0	No votes	C-1 S-1 D-0		
<b>Heterogeneous Component-Based Systems</b> - Open source - COTS		C-4 S-1 D-3 R- Metrics	C-0 S-1 D-0	C-4 S-4 D-0	C-4 S-4 D-0	C-4 S-2 D-2 R- OSS process	C-4 S-0 D-2 R- Dev Stds of OSS Developer experience	C-0 S-3 D-0	C-4 S-1 D-3		

Figure 6: Process Challenges

As a reminder, there are three technology factors encompassed in this section:

1. Continuous Requirements Evolution
2. Incomplete Knowledge
3. Heterogeneous Component-Based Systems Integration

## 7.3 Technology Factor: Continuous Requirements Evolution

The process objectives for this node are to initiate, manage, and evolve sets of necessarily incomplete requirements over multiple iterations of system evolution and re-configuration.

Whether it is the evolution of a system of systems or the integration of nanotechnology into the latest soft body armor, looking at requirements from anything except a continuous viewpoint will be less and less feasible, especially where emerging technologies are in play.

### 7.3.1 Characterizing the Current State of the Practice

Requirements changes within software that is specifically produced for limited users is a reality today and without constant attention and processes which support such an evolution, industry is often paralyzed and unable to meet the needs of the customer thus destined to fail. Although requirements are supposedly stabilized within the first phase of the life cycle, software methodologies, like agile, are calling for real time development and acceptance of requirements throughout a highly iterative product development life cycle.

The level of expected dynamism in requirements is not usually accounted for in life cycles in prevalent use today. It is a fact that requirements “popping in” are not handled well. We go out of our way to drive dynamism out of the life-cycle stages beyond requirements analysis for large, monolithic systems of systems.

Although methods with an emphasis on agility and flexibility are in some use today, there is considerable variation in how these methods are practiced. Agilists who have surveyed conformance of project practices to the principles and practices of particular methods have found that the agile terms are often used without applying the actual practices in the way they are intended.<sup>16</sup>

We try to minimize risk by minimizing variability. We go out of our way to drive dynamism out of the life-cycle stages beyond requirements analysis for large monolithic/systems of systems, leading to overly constrained systems that are unable to evolve as needed. Synchronization

<sup>16</sup> These insights are taken from a private conversation of Suzanne Garcia and Alistair Cockburn (developer of the Crystal Methods approach) in September 2006.

and management of stakeholder expectations with system requirements volatility is problematic. When we do deal with changes, we often limit our analysis of the change impact to local effects. This often leads to missing important system-level effects of local changes. Release cycles are ad hoc. We have little visibility into planned releases based on requirements. Systems are often looked at singularly versus part of the bigger picture.

### 7.3.2 Characterizing the Desired State of the Practice

In a future where we explicitly account for and embrace continuous requirements evolution, we would have a set of models, analysis techniques, and methods that allow us to characterize requirements dynamism both for build purposes and prediction purposes. We would have a set of validated (or at least useful!) metrics for characterizing the dynamism of a requirements set in its initial state. Using analyses and models to guide creation of the initial version of the system, we would be able to characterize it for adaptation and assurance purposes. We could effectively build an initial version of a system that is adaptable to a continuously evolving set of requirements. We would be able to characterize the level of known requirements satisfaction with an initial system build, and the level of dynamism expected in its future. One of the ways we would support evolution is by minimizing the constraints in the initial system so that the solution space for future versions would not be unduly constrained.

To achieve comfort with continuous requirements evolution, we would use modeling and simulation much more extensively, and these models would effectively express the relevant elements of multiple systems so as to be able to visualize change impacts across the different systems. These models would also effectively express the uncertainties and probabilistic aspects of requirements. When dealing in system of systems contexts, architectures would be designed to permit effective analysis across multiple system nodes, allowing us to:

- anticipate indirect and cascading effects due to different process choices
- predict the effects of system node interchange
- determine risk/reward ratios for different system-of-systems configurations

All of this would allow the impacts of changes to be modeled successfully across multiple system-of-systems elements in a timely manner.

Research questions associated with this technology factor include<sup>17</sup>

<sup>17</sup> The questions associated with the technology factors in this section are identified with the letter T. Elsewhere in this report, research questions for the theme on the

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<b>T-1</b>	How do you anticipate the pressures for change early in the system life?
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<b>T-2</b>	How do you anticipate requirements volatility and unknown, unidentified requirements early in the development life cycle? How do you adapt processes to allow for this?
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<b>T-3</b>	What metrics can we develop to characterize the level of known requirements satisfaction and the level of dynamism expected in future?
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<b>T-4</b>	How to you characterize the level of known requirements satisfaction with initial build and the level of dynamism expected in future?
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<b>T-5</b>	How do you support a requirements management system/process that accounts for both expected and unexpected change?
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<b>T-6</b>	How do you instantiate a life cycle that explicitly recognizes incomplete requirements as its basis for initial development?
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<b>T-7</b>	How do you instantiate development with partial requirements?
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<b>T-8</b>	How do we instantiate processes for verification and validation in initial build that account for high requirements dynamism?
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<b>T-9</b>	How do you keep verification and validation tightly coupled to requirements when the requirements are “a moving target”?
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<b>T-10</b>	How do you gather and filter the relevant data to support “the next evolution” in your requirements?
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<b>T-11</b>	How do you instrument the system to collect information that will permit appropriate requirements evolution?
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<b>T-12</b>	How do you model the eco-system the system will be a part of?
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<b>T-13</b>	How do you measure requirements volatility in a useful way?
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<b>T-14</b>	How do you sustain and evolve an eco-system model for the world the system lives in?
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<b>T-15</b>	What is important and essential to include in SoS requirements analysis models?
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<b>T-16</b>	What data about user behavior needs to be collected that will help infer the need for requirement changes?
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<b>T-17</b>	What information about new technologies needs to be collected to help infer the need for requirements changes and the impact of the new technology on the existing system
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relationships between processes and product qualities are identified with a Q, those for the process engineering theme with an E, for managing process processes with a P, and for process deployment, a D. The questions shown in the Appendix are labeled with an S.



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<b>T-18</b>	What replaces “quality = conformance to requirements” in a system where continuous requirements evolution is present?
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<b>T-19</b>	How do you instantiate an assurance strategy (a process for doing so) given that a subset of the requirements do not have to be met all the time? (i.e., in a SLA context)
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<b>T-20</b>	How do you establish a release cycle that balances environment change with user ability to integrate or deploy the new increment?
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<b>T-21</b>	How do you anticipate (determine) the pressures for change at a given point in the system life?
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<b>T-22</b>	What are the relevant utility functions for establishing release cycles?
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<b>T-23</b>	How do you recognize when to re-architect for future anticipated changes?
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## 7.4 Technology Factor: Incomplete Knowledge

The process objectives for this node are (i) to enable systems developers to make decisions effectively and efficiently throughout the life of a system while accommodating necessarily incomplete or uncertain system knowledge and (ii) to be able to define acceptable levels of incompleteness or uncertainty for developers in different system contexts.

Many of the technologies and architectures that are emerging (e.g., net-centric operations), operate in, and therefore are built in, a state of explicitly incomplete knowledge—about the context of use, the other constituents that are part of the product’s operational context, the effects of the other organizations involved in a development effort, system state, etc. This factor is particularly urgent to address in systems where failure would have severe negative consequences, so the real issue addressed is the incomplete knowledge in a state of continuing high need for performance, safety, security, etc.

While our focus here is on the knowledge of the developer of the system, another entire topic is the incomplete knowledge and skill of the user. For example, it is typical that as technologies mature there is pressure to “de-skill” their use. The de-skilling is sometimes communicated as “self-service.” De-skilling implies less knowledge than those who hitherto interfaced to or used technology (think of the help you get at call centers today regarding answers to technical questions), so there is an immediate implication that users of technology will know less, will have incomplete knowledge. Sometimes the de-skilling is liberating and makes technology

available to “the rest of us,” and sometimes it adds a level of complexity that we as professional systems developers cannot yet cope with (think of trying to de-skill nuclear power plant operations).

#### 7.4.1 Characterizing the Current State of the Practice

For system contexts in which incomplete knowledge is (or will be) prevalent, today’s component- and system-build approaches are a poor fit, because they force systems to drive to certainty. We often push for certainty before understanding an adequate set of contexts—for use, for test beds, or for configurations. We do not know what data is safe to ignore or simplify in different configurations or system states. We have trouble characterizing how much data is enough to collect in relation to making process and other choices. Processes that help to assess the probability that what is “known” is actually “true” are not in widespread use.

In addition, when faced with a set of data or an analysis result, techniques we currently use are insufficient for characterizing the completeness of our knowledge about the data. Many of the standard analysis techniques (e.g., FMEA, the failure modes and effects analysis) do not translate well into an environment of incomplete system knowledge (i.e., where you do not know if the component at the end of a fault tree is actually working or not working). Quantitative assurance with an explicit probabilistic focus is not an accepted mode in the test and evaluation community, even though it’s a necessary mode in systems of high uncertainty, especially where there is minimum tolerance for failure. Therefore, release processes based on quantitative assurance are neither sufficient nor adequately used.

#### 7.4.2 Characterizing the Desired State of the Practice

When we have systems that are characterized by continuing, incomplete knowledge, we would use system building approaches that effectively deal with low probability but high impact risks. We would consistently use processes that identify clearly the boundaries of complete and incomplete knowledge about operational scenarios, system state, and system configuration. Approaches would be well understood and used for collecting the “right” data (that which cannot be ignored or simplified) in different operational contexts. Quantitative assurance with an explicit probabilistic focus would be an accepted mode in the test and evaluation community. When making release decisions, we would use release processes based on quantitative assurance results. We would also have processes for managing configurations that effectively deal with unbounded and incomplete contexts.

Overall, we would have processes that drive to certainty only when the time is right, and the knowledge needed is available. And we would

have a comfort level with uncertainty and incomplete knowledge because we have processes that appropriately handle them.

Research questions associated with this technology factor include

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- T-24** What are key elements of the design or architecture that accommodate operating and evolving a system when there is, and will continue to be, incomplete system state knowledge?
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- T-25** For a given system type and operational context, can we characterize a framework of where and how incomplete knowledge can be tolerated or dealt with?
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- T-26** What are the processes for determining what is important to know or not know about system state and configuration?
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- T-27** What are the processes for using knowledge (complete or incomplete) about system state and configuration for system build and integration?
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- T-28** What are the processes for determining what is knowable and unknowable about the operational state or configuration of a system at different points in its evolution?
- 
- T-29** How do we determine what data will help us to move from “unknown unknowns” to “known unknowns” to “knowns”?
- 
- T-30** How do we determine the “shelf life” of data to be collected at various points in system evolution?
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- T-31** What are approaches for understanding which elements of your configuration can be ignored at any particular time?
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- T-32** How do we provide frameworks for eliciting more complete pictures of system context and data more effectively?
- 
- T-33** How do we effectively collect information about ambiguous data and data types to help reduce that ambiguity?
- 
- T-34** What kinds of modeling and analysis techniques for assurance help us to characterize the level of completeness of our assurance strategy in relation to the knowledge that is available?
- 
- T-35** How do we provide “data cleansing” to deal with data issues when we’re acknowledging incomplete data sets?
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- T-36** Given that conclusions from assurance activities are necessarily probabilistic in nature, what’s the decision process to use them for release decisions, etc.?
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- T-37** What kinds of processes can be used for relevant quantitative assurance when system state or context of use is unknown?

## 7.5 Technology Factor: Heterogeneous Component-Based Systems Integration

The overall process objective for this node is to establish effective processes for conceiving, orchestrating, constructing, deploying and evolving complex systems composed from heterogeneous components. In this context, we consider heterogeneous components to include both system components (some of which may be autonomous) and the organizations that construct and integrate them.

Many of the technologies that we envisage for the future move us away from hand-crafted, custom-developed solutions into a world of integrating heterogeneous, component-based systems. The integration challenge in this environment extends beyond the technical integration (though that will be difficult enough) into the socio-technical aspects of process integration in particular.

Many industries which have previously not relied on software (such as household appliances and automobiles) are becoming increasingly dependant on its utility. Their ability to produce inexpensive products with acceptable quality levels is critical to their success.

### 7.5.1 Characterizing the Current State of the Practice

One of the fallacies of our current approach to systems integration is the assumption that high quality, “best of breed” components will automatically lead to an easily integrable system solution. The emerging literature in system of systems interoperability highlights the many problems encountered when components of long-standing use individually are composed into a larger system context. The ultimate source of this issue is that systems of systems composed from heterogeneous, often autonomous constituents,<sup>18</sup> exhibit emergent properties—properties that are not present in the individual components, but are exhibited when the system operates as a whole.

When integrating systems from heterogeneous components, we have trouble understanding whether the components conform to agreed-upon standards, especially with “private” components that we must treat as black boxes. We often do not even understand what data is relevant to collect from components to analyze service quality across a system context. An exception to this is the open source movement, where standards conformance and other questions can be answered more transparently than with many privately built components.

<sup>18</sup> By constituents, we mean both the organizational elements involved in the building of a system or component and the components themselves.

When trying to integrate in a context where we're working with heterogeneous organizations, we often find a lack of trust among the constituents, increasing the overhead related to managing these types of efforts for all concerned. One source of this lack of trust is varying capability of engineering and project management processes among the constituents. From an SEI process maturity viewpoint, we have trouble resolving process maturity differences among the different constituents. A frequently cited observation is that, in CMMI math,  $ML3+ML1=ML1$ . In other words, higher maturity organizations are more often brought down to the level of process performance of their lower maturity partners than the opposite.

When it comes to verifying and validating heterogeneously constructed systems, we do not know how to validate systems against scenarios of use that have not yet been conceived, and even if we could envision all the scenarios of use of a particular system, the cost to test and evaluate the entire system across all the possible contexts of use is prohibitive. Some organizations have a risk-based approach to evaluating suitability of software for integration, but these practices are not widely used. We do not have validated techniques for analysis-based verification and validation in this space yet (although research in this area has begun). In general, when it comes to verification and validation, we're testing the strength of the bricks, not the strength of the building.

One of the benefits of systems integrated from heterogeneous components is the potential for beneficial emergent properties to manifest. However, we lack effective methods for analyzing and characterizing the emergent properties of a heterogeneously composed system, with regard to both beneficial and detrimental emergent properties. [Fisher 2006]

### 7.5.2 Characterizing the Desired State of the Practice

The overall desired state for integrating heterogeneous components into usable systems is to successfully achieve interoperability and other beneficial quality factors (e.g., security, privacy) in an environment of increasing dynamism.

We would use interoperable processes effectively for heterogeneous "planned" systems. Integration checklists would systematically allow risk-based choices for building initial heterogeneous systems. "Black box" integration would be consistently possible and we would treat components in a black box fashion for integration purposes. We would understand and articulate the inherited risks among components. Standard processes, interfaces, and technologies would support consistently achieving interoperability.

We would observe appropriate privacy and security practices when collecting and reporting data; this would improve the trust level of constituents in a heterogeneous system integration. Standards would be routinely used to specify the data to be published by components expecting to integrate into heterogeneous systems.

We would be able to accurately characterize and facilitate the manifestation of beneficial emergent properties, and minimize the incidence and impact of detrimental emergent properties.

Research questions associated with this technology factor include

<b>T-38</b>	Are there requirements approaches that will reduce integration and assurance challenges for heterogeneous systems?
<b>T-39</b>	How do we understand the indirect and cascading effects that are inherited from component systems when we try to initially integrate them?
<b>T-40</b>	How can we create market and/or regulatory forces that incentivize vendors to create products that are verified, secure, interoperable, etc.?
<b>T-41</b>	How do we change the education system to prepare future engineers to work productively in this environment?
<b>T-42</b>	How do you decide what data needs to be collected from the heterogeneous components and suppliers for acceptance into integration?
<b>T-43</b>	How do you build the trust required to ensure that accurate data is being passed in a relevant fashion among nodes in the system?
<b>T-44</b>	How do you collect and update data on system performance to establish service quality of individual components/new requirements?
<b>T-45</b>	What kinds of processes, models, techniques, etc. help you to analyze which new standards actually help, rather than hinder, heterogeneous system evolution?
<b>T-46</b>	How do you analyze data collected on system performance to characterize service quality of individual components and new requirements needed?
<b>T-47</b>	How do we analyze components to determine their suitability for inclusion in a system of interest?
<b>T-48</b>	How do we analyze components related to their security, workflows, user roles, decision support to characterize those aspects across the system?

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<b>T-49</b>	How do we analyze the communication paths and performance among the components to ensure successful—and eventually seamless—integration?
<b>T-50</b>	How do we analyze emergent properties (both good and bad) that are present in the heterogeneous system?
<b>T-51</b>	How do you establish processes that can navigate different legal environments when assuring a heterogeneous system?
<b>T-52</b>	How do you optimize an assurance strategy based on usage of components and scale of integration effort?
<b>T-53</b>	How do you avoid “big bang” integration processes?
<b>T-54</b>	How do you deal with asynchronous upgrades of different elements of your system?
<b>T-55</b>	In an environment of continuously evolving requirements, how do you allocate and or communicate new or changing requirements across all the relevant components?
<b>T-56</b>	How do you manage alignments of user roles, security, workflows, decision support, etc when in the build/integration process when you have all the requirements changing?

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# 8

## Scenarios



*View the full scenarios online—or contribute your own.*

## Scenarios

Processes do not exist outside of some context. The scenarios were developed to analyze the impact of future social, political, technological trends on the software, systems, enterprises, and IT. The scenarios represented extensions of current trends both optimistic and pessimistic. Each scenario was analyzed in terms of the implications for products, people, projects, management, and organization. The implications were then assessed in terms of the requirements they would place on process—especially software process. This led to the definition of detailed process research themes. Each detailed theme was specified in terms of its objective, the problems it was addressing and specific research questions. The detailed themes and research questions across all the scenarios were assessed to identify themes and questions that were common to many different scenarios. Thus we aimed to identify the research themes that were most likely to be of value irrespective of the actual outcome of social, political, and technological trends.

In this section, we present synopses of the plausible scenarios, with an invitation to view the full descriptions at a later time, after this framework has been converted to an online forum. Just as no one can accurately predict the future, a scenario developed during the work of this group might not apply closely enough to your anticipated needs. Readers may prefer to construct their own scenarios that capture the world in which the processes your organization needs must operate efficiently and effectively.

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### **Envisioning a World at War**

*(An environment of continual war reshapes the meaning of survival.)*

The causes are many: conflicts due to regional tensions...the omnipresent threat of a nuclear attack from one or more rouge countries...rising terrorism...a failed Iraq war, with turmoil erupting throughout the Middle East

The effects are staggering: crude oil at \$200 per barrel, triggering gas prices at the pump of \$10/gallon in the United States and 3 to 5 times that elsewhere in the world...every major commercial airline company bankrupt...economic investment drastically reduced...the U.S. and global economies on the brink of collapse.

In this desperate, anxious world, the highest priority assets are sources of supply for food, water, and energy, national and international critical infrastructures, and complex systems of systems including the Internet.

How will people adapt? Technology evolve? Organizations be sustained?

### **Jurassic Park**

*(Reconfigurable packs of capitalists dominate the business landscape.)*

Swiftly moving Corporate Velociraptors thrive in the creative business chaos spawned by rapidly advancing technology that has outstripped the efforts of regulatory forces and confounded big business. Globalization is emerging from the “bottom up,” and traditional value chains have been replaced by dynamic, constantly collapsing and reforming value-creation networks.

These agile businesses move for a fast “kill” in highly mobile and dynamic groups, where the partners of today may be the predators of tomorrow. Mainly virtual enterprises, these organizations define their own mode of working and configure the infrastructure they need for their tasks. This makes them better adapted to a world in which less and less reliability is offered by global infrastructures which once provided stability and growth.

In this age where innovation and opportunism dominate, how can processes be continually refashioned while remaining effective?

### **The Golden Age of the Consumer**

*(End users force changes in how software is developed.)*

Consumers have spoken and systems and software engineering organizations have heeded their concerns. Consumers get precisely what they want (demand) in a global domain where solutions automatically handle geographical, cultural, language, and psychological differences between individuals in the global consumer and end user community.

Around the globe, consumers communicate their needs through the World Technology Organization (WTO), which regulates all publicly accessible technological products having a registered user base exceeding 500 users per country. All WTO member countries (120 and counting) must abide by an extended set of global laws, one of which, the Systems Equality Law, states that “all systems must provide form and function to each user in a manner which neither discriminates on the basis of culture, language, sex, or psychological difference.”

One interesting development is that every user of WTO-compliant systems has a profile implant that broadcasts a psychological profile together with cultural, gender and language details. All WTO systems then present an interface based on this profile—gone are the days of navigating through a Web-based application.

Will organizations follow the WTO model?

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**Cybercrime Pushes Economic Activity to the Brink**

*(Prevalence of cyber threats causes enterprises to reconsider connectedness.)*

The great engine of economic activity, the Internet, spawns the seeds of its own undoing. Cybercrime has become a major problem.

Cyberattacks by worms and viruses cause millions in damage; hackers cripple large financial companies; and “phishing” (sending e-mails that masquerade as requests for details like account numbers and passwords from a genuine commercial organization), “pharming” (attempts to obtain user personal information by use of malicious code) and “poisoning” (attacks on the domain name server that redirect a browser) are increasingly common.

It’s clear, then, that Information Technology (IT) can be used in many ways to further criminal activities. In addition, more complexity in IT systems means more system flaws, which are often exploited to support security attacks.

Will there be a time when people abandon the Internet altogether?

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**Small Teams, Big Needs**

*(Today’s agile methods become tomorrow’s organizing principles.)*

What began years before as a product strategy, planned obsolescence, threatens to over take the business world. We have become a throw-away society.

Groups continually form companies, and then quickly and abruptly dissolve them. Employees work for a company for less than a year, on average. Everyone is self-employed, contracting themselves to teams.

Regulators have given up trying to control the businesses in this world. While this frees companies and allows a sort of “molten lava” approach to flourish, it also means that customers must accept the risk associated with using cheap (or free) software-intensive systems that may or may not always work as promised.

What form of software processes can enable rapidly constructed teams to start-up and working together productively as quickly as possible?

## **Pandemic Triggers Global Instability**

*("Community" is possible only through the Internet.)*

As a global pandemic of avian flu threatens to bring on a second dark age

- One-third of the exposed population recovers quickly.
- One-third recovers after a long period of illness.
- One-third dies.

Also, borders close, all public assembly is banned, hospitals are overwhelmed, and vaccines are not available.

Survivors brace for the impending collapse of civilization. Food, water, and energy supplies are of primary importance. Communications channels such as the Internet become the main means for people to collaborate on improvised survival techniques like self-made isolation suits, water collection and purification, and wind-generated electricity. Commerce, even school and church attendance, are possible only via the Internet.

Given the supreme importance of the Internet to this society, what processes keep it robust enough to play this role?

## **Winning the Cyberwar**

*(Software engineering overcomes cyber attacks.)*

Unknown cyberthreats from unknown sources are dynamic and constantly changing. The highest priority assets are national and international critical infrastructures (complex systems of systems), including the Internet.

Industry, academia, and government finally agree that there is a common threat and that requires collaboration to reduce this threat. Governments make sufficient funds available to support basic research. Industry, academia, and government groups (e.g., US Department of Defense) collaborate to perform necessary fundamental research and exploit that research in commercial and military products and services.

The software engineering workforce is populated with a sufficient supply of software engineers and technicians who hold credentials in information infrastructure assurance and survivability. Courses and other learning materials leading to the knowledge and skills needed for the credentials are widely available from colleges and universities, technical schools, junior and community colleges, and commercial training organizations.

What changes to systems management practices are needed to design, implement, and operate networked systems that can recognize, resist, and recover quickly from attacks?

### **It's a Small World After All**

*(Small, agile companies and collaborative ventures dominate the software industry.)*

A strong interplay between multiple business domains results from a trend towards ever increasing levels of business diversification. Large corporations move into new domain hybrids, looking to capitalize on the blending of their traditional business expertise within other domains. Smaller businesses cooperate to channel their combined forces and expertise into new, innovative means to provide market differentiation and competitive advantage.

How will processes adapt to support the specific blends of skills from different problem domains?

### **Multidisciplinary Convergence**

*(Multidisciplinary convergence isn't seen in products, but in the processes to develop those products.)*

This multidisciplinary convergence is visible in professional journals and meetings.

From *Synergy Week* magazine, January 4, 2015:

Conference Announcements of Note:

➤ The 5<sup>th</sup> International Conference on Bioware has announced its call for proposals. Submitted papers should focus on one or more of the following themes:

- Cellular computing/medical device interfaces
- DNA/neural network integration
- Microsystems dynamics
- Zero-gravity cellular computing environments
- Eco-ware: integration of global bio, hardware, and software applications to effect ecological stability
- Borg-isms: challenges and solutions in integrating self-aware medical devices into human systems

How will processes be defined to accommodate the multiple contexts of the varied disciplines?

## Embedded Software Rules

*(Rapid co-design of product and process overhauls development.)*

It's 2020. Most people don't need a computer anymore, because physical devices they use daily have the intelligence needed to achieve the desired tasks. Embedded software is so prevalent that Embedded Systems and Software (ESS) Inc. is the world's largest employer: It has a work force of about 1 billion people.

ESS has acquired all software and system engineering skills from Infosys, Microsoft, IBM, and SAP, and many more organizations. Still, the demand for embedded system competence far exceeds the supply of competent developers and managers. Consequently, ESS partners with companies that produce end-consumer products (such as cars, clothes, and phones). For each product, there is a peer-team from ESS and the product company called an Embedded Engineer and Domain Expert (EED) that develops the whole product. The EED also designs the development process using process architecture patterns, product architecture and requirements, team competence, and location.

How will the team composition affect the definition of the development process?

## Rain Man Transforms to Answer Man

*(Data mining yields usable results while respecting privacy.)*

It used to be that an Internet user who wished to find information had so much information available, with so little organization, that it is like conversing with the fictional movie character called the "Rain Man": enormous amounts of seemingly related information, presented out of context and with little relevance to the real problem at hand.

Now, instead of a conversation with the idiot savant of "Rain Man," a search on the Internet for information is a conversation with the "answer man." If you ask a reasonably well-framed question, you will get answers to what you intended. If you ask a poorly framed question, the agent will engage you in a short clarification dialogue that will frame the query adequately.

Your searches generate mountains of data that organizations collect with the expectation that it not only will be of value for each task or transaction they perform, but also will become highly valuable in the future. The rules of the road for the privacy and appropriate use of each user's data are managed at a fine-grain level. The "answer man" agent spends its spare time checking up to see if the data it has chosen to release to trusted sources is somehow leaking to other sources. Retribution for those who leak data is exacted by large groups of "answer man" agents abandoning or boycotting data sources and brokers who are not trustworthy.

What would it take to bring the answer man agent about?

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## **Open Source Comes of Age**

*(Open source is a trusted and typical part of the software industry.)*

Industry has adopted open source solutions for incorporation into products in all application areas.

Those software engineers not employed by a large software services corporation have moved either to an independent consultant role or to small- and medium-size enterprises who produce add-ons to open source products. Those employed in the software services corporations are all convinced of the efficacy of the product quality models, process improvement models, and existing technology evolution paths that they use within their organizations to develop their software. These technologies have all been used successfully in recent decades.

However, the corporations also make use of open source software components in their products, although they do not contribute open source software to the market. They do contribute funds and people to the development of open source software by other groups and organizations. This open source software is then incorporated as components within their own products.

The consultant engineering workforce devotes spare time to the development of open source software solutions. Other open source projects employ a single-site development model in which there is no large community of testers but rather a single-site small group of people using informal management techniques with strong configuration management, extensive unit and system testing and planned time boxing of deliverables. In this model, small teams with informal processes rely on close contact using personal and electronic communications.

How can the quality issues of open source be resolved?



# 9

## Sponsor Statements



## BAE Systems

(Provided by Michael D'Ambrosa, the BAE Systems representative to the IPRC)

BAE Systems has a proud heritage that dates back to manned flight and early wireless communications. From the early days when pioneer A.V. Roe built his first airplane that flew little farther than the Wright Brothers at Kitty Hawk to the wireless telegraph operators who saved hundreds by getting the distress signal out from the Titanic to the perilous World War II missions over Europe in Lancaster bombers to the inaugural flight of the world's first vertical takeoff fighter to the total systems integration solutions today's civil and military customers need, BAE Systems' heritage of evolution and mergers has created a global leader that has a proud past and an eye toward the future.

Today BAE Systems is an international company located primarily in the UK and US engaged in the development, delivery, and support of advanced defense and aerospace systems in the air, on land, at sea, and in space. The company designs, manufactures, and supports military aircraft, surface ships, submarines, fighting vehicles, radar, avionics, communications, electronics, and guided weapon systems. It is a pioneer in technology with a heritage stretching back hundreds of years. It is at the forefront of innovation, working to develop the next generation of intelligent defense systems.

We are proud to be a corporate sponsor of the International Process Research Consortium (IPRC). It reflects our continuing interest in process improvement, as reflected on our emphases on internal research and development, our training programs that include partnering with various universities, and our relationship with the SEI and other process-focused organizations. We have developed a Virtual University to ensure a coordinated and integrated approach to education and skills-capability development within BAE Systems and to maximize leverage from our partnerships in education and academia.

We have an Advanced Technology Centre with a focus on systems engineering concerns. It delivers frontline research and technology to BAE Systems, its joint venture organizations, and customers. Its role is to identify and develop technologies, systems, concepts, and processes that will maintain BAE Systems' position as a leading edge organization and enable future growth. Its world-class scientists, technicians and researchers work across a wide range of disciplines including micro and nano technology, deep space telemetry, human-machine interfaces, materials properties, mathematical modeling, and electronic sensors.

We also monitor and evaluate the business potential of technologies under development within academia and other research institutes worldwide.

To further underscore BAE Systems focus on process research and performance improvement is the fact that for more than 10 years BAE Systems has held its own internal SPIRE (Supporting Performance Improvement Realization within Engineering) Conference. Originally focused on software engineering, it has expanded to cover all of engineering and regularly attracts 200–300 attendees. It is modeled after most such conferences with guest lecturers (from the U.K. Ministry of Defence, the U.S. Department of Defense, the SEI, etc.), tutorials, and three to four parallel tracks. We believe that we are the only defense contractor to sponsor an internal conference of this scale.

In summary, BAE Systems' sponsorship of the IPRC is in line with our forward-looking approach. We expect to continue to be involved in follow-on activities and eagerly await the results of some of the targeted research areas, especially those that extend the capabilities of software and systems engineering to effectively manage the ever-increasing needs and complexity of our defense systems.

## Robert Bosch, GmbH

(Provided by Stefan Ferber, the Robert Bosch representative to the IPRC)

Bosch is a leading global supplier of automotive and industrial technology, of consumer goods, and building technology. The investment into the International Process Research Consortium (IPRC) highlights our long-term interest in process engineering research. Bosch funded and participated in this consortium because in our experience, the right processes make a difference in our business.

The International Process Research Consortium was a small research project with the task to envision a technology roadmap for “software processes” in the far future. The scenarios and research themes derived in this highly skilled and international group of researchers and practitioners alike are a base for our own internal research agenda—not only in process engineering but also for software-intensive systems. The intense personal dialog in the IPRC about so called “possible futures” and their implications for software and systems engineering allowed us to evaluate experts’ intuition about what is coming next as a challenge for our company.

The IPRC was also an experiment in multicultural teamwork. The group’s diversity of opinions helped us to think beyond our own limits, and differences in style are still deliberately visible in the final report.

Having one final framework that nicely integrates all the different views is just the starting point. The identified research themes need a continuous update and realignment with reality. Now Bosch expects research institutes, technology-oriented companies, and national as well as international funding agencies to put priority on the derived topics. Bosch’s research project portfolio in 2008 already builds on the IPRC results, and we hope to answer some of the overwhelming number of research questions derived by the IPRC.

## Lockheed Martin Corporation IS&S

(Provided by Lynn Penn, the LMC representative to IPRC)

Lockheed Martin Corporation (LMC), an advanced technology company, was formed in March 1995 with the merger of two of the world's premier technology companies, Lockheed Corporation and Martin Marietta Corporation.

Headquartered in Bethesda, Maryland, Lockheed Martin employs about 140,000 people world-wide and is principally engaged in the research, design, development, manufacture, and integration of advanced technology systems, products and services. As a lead systems integrator and information technology company, nearly 80% of Lockheed Martin's business is with the U.S. Department of Defense and other U.S. federal government agencies. In fact, Lockheed Martin is the largest provider of IT services, systems integration, and training to the U.S. government. The remaining portion of Lockheed Martin's business consists of international government and some commercial sales of our products, services, and platforms.

Integrated Systems & Solutions (IS&S) is one of five principal business areas within Lockheed Martin. IS&S leads the corporation's systems engineering and integration activities for high-value network-centric information and intelligence systems that support missions of the U.S. Department of Defense and other national security customers.

IS&S was proud to represent LMC on the International Process Research Consortium (IPRC). LMC is a leader in many technologies. However, LMC also realizes that technology alone does not make a program successful. It takes a mix of technologies, people, and process. LMC's appreciation for the importance for process is integrated into its business rhythm. LMC was interested in the IPRC's proactive approach to identifying the appropriate process research needed to be prepared for tomorrow's technologies. The process role is important, and LMC is proud to be a member of an international group of experts who did not feel overwhelmed with the goals set forth for them. They embraced the challenge and produced a process research framework for the future.

LMC looks forward to continuing this relationship through periodic reviews of the IPRC frame-work driving research through the next few years. LMC is also actively taking part in the first research project defined by the IPRC, which will study and document improving processes for small settings.

## Software Engineering Institute

(Provided by Bill Peterson, SEI's Software Engineering Process program director)

The SEI's mission is to advance software engineering and related disciplines to ensure the development and operation of systems with predictable and improved cost, schedule, and quality. Our core purpose is to help organizations like yours to improve their software engineering capabilities and to develop or acquire the right software, defect free, within budget and on time, every time. The Software Engineering Process Management Program is one of the key assets within the SEI. Our research works in process maturity and capability, applying best professional practices, and in defining measurement frameworks are very well known worldwide. In our execution of our mission worldwide, we are often approached by individuals and organizations wanting to collaborate with us on work of mutual interest. This often happens on individual projects, but we also work on broader, long-range research topics that don't have an immediate project focus.

The SEI has come a long way since our inception in 1984, and with continued success, we plan to be supporting the software and systems community for another 20 years and more. By then, our world and our technologies should be vastly different from what we see and use today. Preparing for that world requires a dynamic blend of vision, imagination, and action. Partly in response to the interests of researchers and sponsor organizations around the world, and in fulfilling our mission and purpose, the SEI took an action in 2004 to prepare for the next generation of software, systems, and the enterprise processes by establishing the IPRC. As this document describes, we invited researchers to join and bring their special perspectives on current and future issues and topics to the table. We also worked with select sponsors of the research both to be sure the IPRC would respond to their real-world needs, as well as for financial support of the research. These two factions of the project, as well as all of the individuals who participated, melded quickly into a harmonious team pursuing a wide range of research ideas and users' future needs.

The SEI, with its reputation as a “trusted broker” among many independent or even competing organizations, is a unique place where such a team can form and get leverage from the values that all players bring to the table. I am proud to have been part of the formation of the IPRC, to have helped initially sponsor its early explorations, and to also bring additional SEI researchers to bear at the request of the other sponsors. Not only did the SEI’s Process Program provide research representation, the Dynamic Systems and Network Security Programs were asked by the IPRC members to join. The SEI was thus well represented across its research agenda.

I am also excited about the future work of the IPRC beyond the continued development of this framework. Future directed research projects are being identified that provide a lower level of research and development in areas of interest to subsets of the IPRC team. Both sponsors’ interests and researchers’ areas of expertise will be used to identify the directed research projects that they wish to pursue in developing and discovering new and existing solutions to future problems and opportunities.

## Tata Consultancy Service, USA

(Provided by Nidhi Srivastava, the TCS representative to IPRC)

Global operations with bases in 39 countries, a clientele of best in class organizations, and 71000 associates; these characteristics reflect the scale of our operations and the mindshare we enjoy in IT consulting and business services. As businesses have evolved to find new ways to optimize operations, TCS has pioneered in making global outsourcing and managed services a ubiquitous operating model for businesses. Our learning by working closely with global customers and synthesizing best of breed practices has given us a natural evolution in business consulting creating the mindshare we enjoy today.

TCS commenced operations in 1968, when outsourced IT services were relatively obscure. The evolution since then has been significant. We learned in cycles to adapt to and create new service models as we made customers realize benefits of changing paradigms. We gained a grounded understanding of diverse business challenges that confronted global companies. This enabled us to help customers to achieve business objectives and redefine those from new perspectives. Our role in this value chain has been multifaceted. While we attained insights and expertise in diverse industries we innovated in multiple sources of technology to make IT translate to business benefits.

Our “Global Delivery Model” is the strategic service delivery concept that differentiates us by bringing together our unique capabilities. These lie in the diversity of our geographical presence, role in technology ecosystem, and mechanism for tapping heterogeneous sources of knowledge. We thereby made global knowledge sourcing seamless and fluid by bringing in cultural and operational proximity.

TCS is a disciple of multiple management and quality philosophies. As practitioners, these are ingrained in our services and operations, being tested by time and scale. TCS was assessed at CMMI® Level 5 and PCMM® Level 5 in 2004. Our Integrated Quality Management System (iQMS) instills in our operations the quality principles found within these frameworks. The iQMS framework distills best practices by unifying models such as CMMI, PCMM, ISO TL 9000, and AS9100 Rev B. The encapsulation of these best practices and principles into an adaptive framework helps us to make quality in TCS transcend from tactical and compliance objectives to business drivers.



As a sponsor, TCS has introduced the “voice of the customer” to IPRC Workshops and deliberations. The span and width of our experiences has driven us to embark on research to define next-generation software processes based on emerging imperatives and business factors. Our role in the International Process Research Consortium (IPRC) is important in involving the community in this quest. TCS will continue to play an active role in promoting the IPRC framework by fostering exchange and application of ideas between the industry and academia.

## University of Pittsburgh Medical Center

(Provided by Alan Lawson, the UPMC representative to IPRC)

During the past decade, UPMC has reshaped the health care landscape in western Pennsylvania to become the premier health system in the region and one of the most renowned academic medical centers in the United States. As a \$6 billion organization and the region's largest employer, it has transformed the economic landscape as well.

Today, with over 40,000 employees, UPMC is composed of 19 hospitals and a network of other care facilities across western Pennsylvania and throughout the world: doctors' offices, cancer centers, outpatient treatment centers, specialized imaging and surgery facilities, in-home care, rehabilitation sites, behavioral health care, and nursing homes.

Over a period of rapid growth, UPMC has created a genuinely integrated health care delivery system and aggressively recruited superb physicians and researchers to develop internationally renowned centers in transplantation, cancer, neurosurgery, psychiatry, rehabilitation, geriatrics, and women's health, among others. UPMC has also invested significantly in information technology to link and integrate electronic medical records across multiple hospitals and care settings and has invested research monies to seed new fields like regenerative medicine and biosecurity. In partnership with Italy's region of Sicily, UPMC has exported its expertise internationally, developing a hospital in Palermo to provide transplantation and other specialized services.

UPMC also has leveraged its world-renowned clinical services and patient care reputation into one of the country's fastest growing health insurance plans offering an array of commercial, Medicare, and Medicaid products. A pioneer in the management of chronic diseases like congestive heart failure, asthma, and diabetes, UPMC Health Plan has been recognized as one of the best insurance plans in the nation by the National Committee for Quality Assurance, which in 2005 ranked it among the top five in the mid-Atlantic region for effectiveness of care.

UPMC's standing as one of the nation's outstanding medical centers is a source of civic pride. The region benefits from UPMC's many charitable contributions and its broad array of community-based programs that are designed to eliminate health disparities in underserved populations. UPMC also has made a major commitment to arts organizations to ensure that the region has not only an outstanding scientific community but an outstanding cultural one as well.

A passion for innovation lies at the heart of UPMC's success. Through such innovation, UPMC has already launched a portfolio of new businesses in information technology, biosecurity, and bio-medicine—all nurtured from its core service lines. UPMC's unique strategy of combining clinical and research excellence with business-like discipline translates into excellent patient care for western Pennsylvanians and the promise of new jobs, new businesses, and a new biotechnology-based economy for the region.

UPMC has been a leader in the application of process improvement disciplines for health care information technology with a commitment to CMMI, CoBit, and ITIL. UPMC has pursued a fusion of the long standing and highly effective tradition of process and quality improvement driven by world-class clinicians.

UPMC's CMMI experiences have been focused almost exclusively on closing the gap between the state of the art in process improvement and the state of the practice in the health care industry and UPMC. Adherence to existing CMMI approaches has been highly valuable, yet areas remain where the model is not completely aligned with the reality encountered when serving UPMC's clinicians and their patients. UPMC's participation in the International Process Research Consortium (IPRC) is a welcome opportunity to help the process improvement research community to target the key issues that limit progress. In the health care industry, challenges remain with the issues of complex systems of systems from multiple suppliers based on multiple technologies that must serve diverse customer usage models in a widely dispersed geographical area. Clinical and business solutions are needed to interoperate in a semantically consistent, process-efficient manner that permits UPMC's best people to remain focused on patient care. UPMC has great expectations that pursuit of excellence, on behalf of the patients and communities served, will be a common goal shared by process researchers. Advances in the state of the art of process improvement are needed to address specific health care industry needs. It is UPMC's pleasure and privilege to assist the IPRC in challenging the process research community to make these process improvements a reality.



# Appendix



# An Instantiation of Research Nodes and Questions for Security

## Description of the Research Nodes

This description interprets and expands the research nodes and questions contained in Section 4 for the security product quality. All questions in Section 4 remain applicable (substituting security as the product quality of interest) and are not repeated here.

### Research Node S.1: Establishing Security in the Systems or Software Development Life Cycle<sup>19</sup>

The objective of this research node is to determine the extent to which processes can be used to accurately reflect and cause the instantiation of required security product quality attributes for each software development life-cycle (SDLC) phase.

Research questions associated with this node include<sup>20</sup>

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**S-1** How is security expressed in each phase of the SDLC?<sup>1</sup> What are appropriate expressions, from a security perspective, of how the system is to be used (see S1.4 misuse/abuse cases)?

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**S-2** What processes best ensure the instantiation of established security principles?<sup>2</sup>

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**S-3** What are effective processes and methods that ensure that known causes of security vulnerabilities are not present in each phase of the SDLC?<sup>3</sup>

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**S-4** What processes and methods can be used to accelerate adoption of known methods for developing low-defect-rate<sup>4</sup> (and thus more secure<sup>5</sup>) software? (state of art/state of practice gap)

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**S-5** What are the compelling cost/benefit arguments to do so?

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**S-6** Is it possible to build and verify secure software and systems using agile methods [Beznosov 2005]?

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**S-7** What processes can be used to ensure that security requirements are met for systems composed from existing components?<sup>6</sup> For extensible systems?<sup>7</sup>

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19 A series of research papers that address requirements engineering, survivable systems analysis, models and templates including life-cycle models for survivable systems is available at <http://www.cert.org/research/papers.html>. Jarzombek and Goertzel describe a comprehensive treatment of security as a product quality during all SDLC phases [Jarzombek 2006].

20 The questions associated with this example instantiation are identified with a letter S. Elsewhere in this report, research questions for the theme on the relationships between processes and product qualities are identified with a Q, those for the process engineering theme with an E, for managing process processes with a P, and for process deployment, a D. The questions associated with the technology factors in the section on the effects of emerging technology trends are identified with the letter T.

### **Research Node S.2: Establishing the Relationship between Process and Security as a Product Quality**

The objective of this research node is to establish whether there is a direct relationship between security as product quality and the processes used to develop the product.

Research questions associated with this node include

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- S-8** What is the role of process in ensuring that software and systems are engineered such that they continue to function correctly under malicious attack, failure, and accidents?<sup>8</sup>
- 

### **Research Node S.3: Measuring and Monitoring Security Performance**

The objective of this research node is to establish processes to accurately capture meaningful measures that aid in determining if a system is meeting its security requirements (and how well) during all SDLC phases.

Research questions associated with this node include

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- S-9** What are the definitions of meaningful, informative security measures? What processes are needed to reliably collect these?
- 
- S-10** What measures indicate that a system has met its security requirements for each SDLC phase? What are the processes for collecting, analyzing, and reporting these measures?
- 
- S-11** What measures and evaluation processes can be used to determine the effectiveness of different secure software development processes?
-

### **Research Node S.4: Verification and Validation of Security**

The objective of this research node is to enable managers to select appropriate assessment, evaluation, verification, and validation processes to confirm the achievement of security requirements. Process selection is guided by the nature and complexity of the system being constructed and operated. Methods include the use of scenario-based misuse/abuse cases.

Research questions associated with this node include

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**S-12** How is an adequate or acceptable level of security determined, tested, verified, certified?

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**S-13** What processes are most effective for assessing, evaluating, verifying, and certifying the security of software and systems (including those provided by third parties)?

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**S-14** What processes and methods are most likely to reveal security issues, flaws, and vulnerabilities during each SDLC phase?<sup>9</sup> And with third party, open source, and COTS, or other component software?

In the case where such processes already exist and have empirical evidence to justify their use, what can be done to accelerate their adoption? (state of art/state of practice gap)

---

**S-15** What processes and methods allow for building misuse/abuse cases that predictably provide evidence that security product qualities are present?

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### **Research Node S.5: Sustaining Adequate Security**

The objective of this research node is to enable managers to select processes that result in establishing, sustaining, and evolving an adequate level of security throughout the full product life cycle.

Research questions associated with this node include

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**S-16** How do we define and sustain adequate security in the face of increasingly sophisticated attacks (attack evolution), technology evolution, enterprise evolution, supply chain evolution, and the like (all sources of change that require a system to evolve)?<sup>10</sup>

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### **Research Node S.6: Usable Security**

The objective of this research node is to enable users to effectively apply and use required security mechanisms, to the extent these are visible to the user.

Research questions associated with this node include

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**S-17** What user interface processes and methods result in users applying protection and security mechanisms routinely, automatically, and correctly?

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**S-18** What processes result in minimal to no user involvement in security?

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### **Research Node S.7: Using the Marketplace to Drive Adequate Security (may be out of scope)**

The objective of this research node is to establish processes resulting in a consumer/customer marketplace that will not purchase software known to be insecure.

Research questions associated with this node include

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**S-19** What processes, market forces, and other mechanisms can be used to require organizations that produce software with a significant annual volume of reported vulnerabilities to improve their products?<sup>11</sup>

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## Research Questions for All Themes

### Theme Q: The Relationships Between Processes and Product Qualities

- 
- Q-1** How can a consumer with limited expertise be facilitated to express their needs in a sufficiently prescriptive way?
- 
- Q-2** How do we specify product quality requirements in general and such that they reflect business requirements?
- 
- Q-3** What levels of product quality are required for specific types of products? For specific markets? How are levels expressed?
- 
- Q-4** How do we specify product quality requirements in a quantifiable, measurable manner? (How will we know it when we see it?)
- 
- Q-5** Does the level of need for each ‘-ility’ vary by business domain? If so, how?
- 
- Q-6** Is there a direct relationship between desired product qualities and the processes used to develop the product? If so, how is this relationship expressed and how does it differ based on the maturity of the process used?
- 
- Q-7** How do we determine the relationship between process and product qualities?
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- Q-8** What is the evidence that better processes are instrumental to delivering better products?
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- Q-9** Do the issues for product quality and process relationships change for composable components and for products assembled from composable components?
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- Q-10** How do we model and predict product quality—process relationships in the context of different maturity levels?
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- Q-11** How do we model and identify the tradeoffs between business requirements, process, and product qualities (such as degree of quality, cost (affordability), schedule (timeliness), team competence, risk)?
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- Q-12** How do we model and identify tradeoffs among required product qualities?
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- Q-13** How do we make well-informed decisions using the results of trade-off analyses?
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- Q-14** How do we select processes to meet specific product quality requirements?
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- Q-15** What process steps significantly influence the achievement of a specified level of product quality?
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- Q-16** When composing systems of individually certified components, how do you ensure that the non-functional product quality attributes such as security are achieved in the composed system?
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- Q-17** Can quality attributes associated with intermediate work products be used as indicators for quality attributes in the final work product?
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- Q-18** If not in absolute terms, can intermediate work products be used to inform the risks of failing to achieve final product qualities?
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- Q-19** How do we determine and specify product quality acceptance criteria?
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- Q-20** How do we test, verify, validate, assess, and audit that product quality requirements are met in the product?
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- Q-21** Using product quality and process measures, how can we determine that we are on track to achieve the desired level of product quality during each life-cycle phase?
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- Q-22** Do product quality verification and validation approaches scale up and/or change in the context of different product architectures (e.g. complex systems and systems of systems)?
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- Q-23** What is the role of automation in product quality verification and validation?
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- Q-24** How do we sustain product qualities in the face of product operations, product requirements change (both functional and non-functional), and product evolution?
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- Q-25** How do we measure (assess, audit) that product qualities continue to be present at the required level and degree throughout the product life cycle?
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- Q-26** What is the role of automation in product quality sustainment?
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## Theme E: Process Engineering

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- E-1** How can usable best practices be identified?
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- E-2** What kinds of processes are needed for value-creating networks; virtual teams; partnering; outsourcing, multi-site development, end-user development?
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- E-3** How can we align processes with business goals?
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- E-4** How to perform a gap analysis between today's state and a desired future state?
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- E-5** How can we best specify a process?
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- E-6** How can process definitions be packaged together with a quantitative/qualitative model describing their behavior?
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- E-7** What are appropriate process notations?
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- E-8** Can a process be analyzed to determine if it is implementable?
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- E-9** What process evidence is required?
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- E-10** What evidence is required with respect to process risks?
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- E-11** How can this evidence be specified and applied to the selection, tailoring and integration of processes?
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- E-12** How to combine evidence and “context”?
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- E-13** How does the context of a process (e.g., organization size, culture, process distribution) influence process selection criteria?
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- E-14** How can acquired process components be evaluated and certified (so they can be trusted)?
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- E-15** How can knowledge from the related areas of organizational and behavioral studies be incorporated into the definition and specification of processes that can be effectively implemented?
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- E-16** How can we assure that a process will meet product/project requirements and standard compliance?
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- E-17** What does it mean to certify a process component and how could this be achieved? (For example, what criteria could such certification be made against?)
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- E-18** How can we improve process specifications based on feedback from deployment and use?
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- E-19** How can the value of a process be determined and monitored?
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- E-20** How can the quality and cycle time performance implications of process decisions be evaluated?
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- E-21** What effects do different domains have on the selection criteria for processes? The critical issue here is the need for a clearer schema for classifying and categorizing “domains.” There is confusion between business domains, application domains, and industry domains, as well as with factors incorporating cultural issues. Identification of critical domain characteristics is crucial. Once these are known, the process and systems engineering issues can be addressed.
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<b>E-22</b>	How can we define the scope of process lines?
<b>E-23</b>	How can we define the value of process lines?
<b>E-24</b>	How can we organize processes and evidence into one or more process lines (similar to the concept of product lines)? This includes domain-specific issues.
<b>E-25</b>	What is the appropriate degree of commonality of processes/procedures (e.g., across multiple sites, disciplines, and cultures)?
<b>E-26</b>	How to understand the difference between different domains with respect to processes and measurement?
<b>E-27</b>	What effects do different domains have on the selection criteria for processes?
<b>E-28</b>	How can process line engineering be aligned with product line engineering?
<b>E-29</b>	How should a process architecture be constructed for a process asset base?
<b>E-30</b>	How can the right process elements be identified in the asset base for a specific project as a function of product requirements and team competence?
<b>E-31</b>	Can a formal approach, based on a sound theoretical basis, be developed to address the tailoring of processes for specific implementations?
<b>E-32</b>	What are the organizational and environmental factors that affect tailoring choices (e.g., tailoring for small enterprises or for agile development)?
<b>E-33</b>	How can we tailor processes with predictable effects on efficiency?
<b>E-34</b>	How can processes be designed for easy tailoring?
<b>E-35</b>	How to specify processes including variability?
<b>E-36</b>	To what extent is it possible to integrate different processes, in particular when they are based on different paradigms, for example, agile processes versus more waterfall-like approaches?
<b>E-37</b>	How can we harmonize the mental model of sequential development with the reality of continuous iteration?
<b>E-38</b>	How can processes be packaged together with a quantitative/qualitative model describing their behavior?

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- E-39** Are there mechanisms for understanding and improving interoperability between processes (composability analysis: pre/post conditions, inputs/outputs, styles, assumptions)?
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- E-40** How can domain-specific development processes (product dependent) and software/systems development processes be synchronized?
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- E-41** How does the context of a process (e.g., organization size, culture, process distribution) influence process evolution?
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- E-42** How can we evolve process lines based on deployment feedback?
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- E-43** How can processes be made sufficiently adaptive to provide effective support in responding to domain-specific change?
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- E-44** What process infrastructures are appropriate to support the new technologies and concurrent engineering?
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- E-45** How do we create easy to use “experience bases” that allow knowledge to be stored, updated, and accessed by developers at varying levels (to facilitate the continuous evolution of problem domains and technical skills required as businesses move into new hybrid domains, for example)?
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- E-46** How do the team competencies affect the engineered development processes?
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- E-47** How do we educate people for process engineering in general and the use and/or development of process lines in particular?
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- E-48** How do we educate people in the need for and the use of evidence?
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- E-49** Which activities related to evidence creation, process line engineering, and usage can or should be automated?
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- E-50** What automated decision support is useful and how can automation and human (educated) creativity be balanced?
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- E-51** How do we perform process model configuration management?
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- E-52** How could “process patterns” be best used?
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- E-53** What is the role of process simulation in providing trust, scaling, and supporting process prediction, selection, tailoring, and integration?
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- E-54** What visualizations can support process management (including different views for different stakeholders and different business domains)?
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- E-55** What level of statistical analysis is feasible and reasonable to apply to process management?
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- E-56** What is appropriate support for automated metrics collection?
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- E-57** How can an inference engine for effective display and retrieval of processes be constructed?
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- E-58** How can we use process evidence to derive theories about process, product, and resource dependencies?
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- E-59** How do we define intellectual property for a process?
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- E-60** How can we integrate process engineering and workflow management tools?
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## Theme P: Managing Project Processes

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- P-1** How do we select the best possible project process or set of processes to use? The latter is particularly relevant when having different processes. Selection of the project process is a key issue to be able to achieve project goals. Moreover, it must be possible to adapt the process to different types of applications, project size, and so forth.
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- P-2** How do we scale processes to our needs? How does an SME know when it is time to have more formal procedures in place? SMEs cannot be expected to have well-defined processes in place. It is hence important to be able to have as little overhead as possible, but still sufficient to enable the delivery of high-quality software. As a small company grows, it is important to realize that the processes used have to change. The questions are when to change them and how to change them. It is easy for a company to grow out of its process support.
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- P-3** What are the needed competencies for the required tasks on a specific project? How is the relation between competence profile and development process handled? It is a challenge to have the right mix of competencies in a given project, in particular when certain type of competence may be needed in too many projects at the same time. It is also a particular problem for small companies where often the same person must take on multiple roles. This issue becomes an even larger challenge when looking into successive nodes within this theme. Furthermore, how do you “process-bond” teams that are brought together from outside the company for specific projects?
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**P-4** How do individual competencies sum up in the team? The distribution across site means on the one hand that competencies at different sites become available, but on the other hand it may be difficult to get what one wants from a project perspective. This may be because the site manager has many projects and would like to staff them according to an optimization for the site and not for a project.

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**P-5** How do we make optimal use of available competencies? Different companies mean different competencies. How do we effectively combine competencies that are available in different companies?

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**P-6** How do we capture and share experiences across sites? Project work means building experience, which is difficult to share in general, but becomes even more complicated when the team is distributed across sites. A certain understanding or experience may come at a site internal meeting, but how is this experience communicated to others not at the meeting, and in particular if they are at another site?

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**P-7** How do we manage development between different locations? This includes managing, for example, responsibilities and risks between locations (including risks inherent in distributing in the first place). Development across locations is in many cases a necessity for large project and large companies. This means that the actual distribution of the development must be managed. What management procedures are needed to manage a distributed project? How is time reporting done? To what extent do things have to be done in the same way at the different locations?

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**P-8** How do we divide the work effectively and efficiently between locations? The work should not only be divided between the locations, it should be divided in an effective and efficient way. This includes taking the current architecture into account

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**P-9** How do we distribute quality requirements? The distribution of work often means that functionality is distributed, but how do we handle non-functional requirements? The customer or market has expectations on certain quality aspects for the whole system, but when distributing the work it may mean that quality requirements are forgotten or it is very difficult to break them down to parts of the software. A typical example is how to handle performance.

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- P-10** How do we handle different time zones? Time zones are obstacles for communication, but also an opportunity for having development 24 hours a day. This includes challenges related to
- How do we handle time zones and how do we effectively communicate the results from one site to another? How do we make use of differences in time zones? This question is about the opportunities. How can different time zones help us develop software more efficiently? Is it possible to work 24 hours a day with development and pass assignments around? Can technologies such as Instant Messaging and Voice over IP make the world one global workplace?
  - What is the productivity drag, if any due to time zone differences? Is the productivity different in different sites? Why? How can we leverage from the best? Do people in different cultures make different types of mistakes?
  - How do we work toward a joint base (configuration management)? Many configuration management tools exist, but are they able to cope with potential issues such that developers in different sites wanting to work on the same component at the same time?
  - How do we manage different cultures and time zones between different companies? Different companies imply different processes. Distributed development around the globe also implies different cultures. How do we handle the mix of cultures and mix of processes?

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**P-11** How do we handle cultural differences? Cultural differences are a fact. The challenge is first to be aware of them and then to use them to our advantage. Can formal training deal with the above challenge? How do we educate people to work in global software development? What additional knowledge is needed to ensure that developers can work in a global environment? It does not only require knowledge about software development, but also a good understanding of the challenges with global development and with other cultures.

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**P-12** How do we ensure the same process interpretation in different cultures? Can Enterprise Process Frameworks address the issues of multiple process styles? How heavy or light should an enterprise framework be to meet business objectives? Even when having the same process across sites, there is no guarantee that it is interpreted in the same way. The likelihood is higher if being within one country and with people with a similar educational background, but it becomes much more a challenge when having people from different cultures.

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**P-13** How do we make use of experiences in one culture in another place? It is well-known that it is difficult to share experiences effectively. However, it becomes even more complicated to share and use experiences in one culture with another culture. How can this be done? It is probably insufficient to publish experiences; they have to be transferred, but what is the best, most effective way?

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- P-14** How can the end-user perspective be captured in global software development? The end-user comes further away from the development when the development goes global. Thus, it may become even more difficult to include the end-user perspective into the development.
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- P-15** How do we make processes that are compliant with accepted standards? Different companies in different countries may have different standards or they may even be required to follow different standards due to legislation. How can global software development be conducted with different standards?
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- P-16** Are global standards an imperative for this model to succeed? Is it possible to succeed with global development without having common standards? Can global process interface standards be developed?
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- P-17** How do we handle the use of different project processes? Different locations may have different project processes or at least different flavors of the same process. This poses some challenges that are reflected in the remaining questions in this group.
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- P-18** Is the output from one process producing the input needed in another process, or are the differences between processes at different locations a problem?
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- P-19** How do we handle interfaces between processes? The interface between different processes in distributed development must be well specified and the output from one process should be the input to another process.
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- P-20** How are the abilities to deal with multiples process style managed? For example, is it possible to combine a waterfall approach in one location with a much more agile approach in another location? What requirements have to be put on the development to ensure that we obtain one integrated system at the end of the day?
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- P-21** How can we handle companies with different process capability? How do customers, suppliers, and vendors with different process capabilities work effectively? Is the process capability determined by the lowest common denominator?
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- P-22** How do we integrate open source code in company-specific products? Open source is often used as “good example.” How can software from open source be used in commercial context? How can we learn from how open source development is conducted?
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- P-23** How do we manage virtual teams? How are virtual teams formed? How are competencies found and combined? A virtual team is here defined as a team of individuals working together in a specific role, for a specified time and with a specific goal, however without any supporting organizational structures.
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**P-24** How do we identify suitable partners/subcontractors? How are the relationships between different roles managed? The problem here is about identifying the most suitable partners to meet our goals. This includes identifying suitable collaborative partners and subcontractors. What is the role of SMEs in these relationships?

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**P-25** How do we put requirements on subcontractors? What is a minimal set of requirements when subcontracting internationally? This includes both functional and non-functional requirements.

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**P-26** How do we accept components delivered from a subcontractor? Delivered software must be accepted. How do we perform acceptance testing? This may be particularly difficult when only part of a system is delivered. How do we certify a specific quality level for a component or subsystem of the final system? Particularly where the overall product qualities may not be directly traceable to that 'component'?

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**P-27** Do locations need a primary and secondary role based on competencies within a company too? Should one location act as the primary location and other work as subcontractors? The actual roles and responsibilities must be clearly defined. Should sites be structured for growth as "Centers of Excellence"?

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**P-28** How should relationships between partners be formulated? Joint development of a system means having some explicitly agreed-upon relationship. The relationships include other sites, outsourcing, partner development, and networks of partners. The networks may be formed for a specific project or may be more long-term and go beyond the scope of any one project. It is important to decide what the core assets are and what is suitable to let others handle.

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**P-29** How can we handle interfaces among several small companies? To compete with larger companies we may see networks of small companies working together. They are often less mature and they may not have well-documented processes. How do small companies together become mature and able to handle larger projects?

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**P-30** How should a process for collaborative development be formulated? The development at different companies requires some process for the actual collaboration. How should it be handled?

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**P-31** How do we handle change? Requirements change during development. This becomes much more cumbersome when a change may affect not only one company, but several. What routines need to be in place to handle change across companies in distributed development?

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**P-32** How do we create value-based networks of partners to work as peers in projects? How do we establish shared goals? Different companies may have different goals, but to be successful shared goals are needed. Is it possible to agree on common goals?

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## Theme D: Process Deployment

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- D-1** What infrastructures have been tried and what are their relative merits?
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- D-2** What is the best advice, then, on which infrastructure fits which (contingent) context?
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- D-3** Where should the infrastructure sit inside the served organization? What is the best governance model?
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- D-4** How much responsibility for the adoption cycle is it appropriate and effective for it to take as its charter?
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- D-5** What is the profile of the best-suited people to staff the infrastructure roles?
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- D-6** What is the quantitative relationship between investment in infrastructure and the achievement of adoption goals?
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- D-7** How do organizations work (in the ways relevant to adoption)?
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- D-8** How do organizations change and improve?
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- D-9** Assuming there is more than one answer to the first question and to the second, how do we map the ways in which organizations work to the ways in which they change?
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- D-10** How do we estimate the resources and duration needed to make planned change?
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- D-11** Is there a way to assess the degree to which an organization is ready to make a change to an extent we specify, both in depth and rate (how much, how soon)?
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- D-12** What is the best way to characterize the environment of the organization that is relevant to understanding and tailoring the deployment?
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- D-13** Is there a difference in deploying process vs. product?
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- D-14** What is the best way to align and increase the motivation and ability of personnel to adopt new processes? In fact, what motivates change for each type of change target? For example, are business cases relevant?
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- D-15** What is the best way to plan the tailoring of the new processes in light of the answers to all of the questions above? To tailoring the organization?
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- D-16** What organization-based confidence or acceptance criteria ensure that when defined processes are adopted, the desired results will be produced? (These criteria are used to decide when the engineered processes produced by the Process Engineering layer are worth deploying in the organization.)
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- D-17** How do we determine and coherently express understanding of the cause and effect relationship among processes/process changes, deployment, and product outcomes?
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- D-18** What explains the difference in the rate and success of deployment (i.e., small vs. large, government versus commercial, business sector differences, etc.)?
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- D-19** What are the key strategies and tactics to motivate process use in settings where process adoption has failed in the past?
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- D-20** How can we best formulate process needs related to business goals?
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- D-21** How should value-based processes be deployed?
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- D-22** How can we best construct sets of processes that when deployed will deliver desired business outcomes?
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- D-23** How do we express process needs so as to ensure that an organization is able to adopt processes meeting its needs, e.g., by taking into account the relationship between process capability and organizational maturity? (Depending on an organization's process maturity--and many other factors--it may be able to adopt some processes better than others. This needs to be taken into account when selecting and tailoring processes, i.e., these constraints need to be expressed when stating an organization's process needs.)
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- D-24** How do we express process needs so as to ensure that deployed processes will be able to respond effectively to changes in the organization and/or the business environment?
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- D-25** Do current models for process capability and selection reflect the linkage to risk appetite and risk tolerance in the organization or project?
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- D-26** What are enablers and barriers for process adoption?
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- D-27** How does the level of team competency affect the deployment of processes?
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- D-28** How do we ensure that required competencies can be rapidly developed and applied in the deployed processes?
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- D-29** What are the key factors influencing the successful deployment of engineered processes?
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- D-30** How do the processes for expressing deployment requirements affect the need for transition infrastructure? Are some processes cheaper or faster than others? Do some require less infrastructure and, say, more active participation by those who are affected by the changes?
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- D-31** How do we ensure that required competencies can be rapidly developed and applied in the deployed processes (JIT Training)?
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- D-32** How can we support team performance versus individual performance?
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- D-33** What is needed to develop effective teams and team architecture (e.g., leadership and team motivation)?
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- D-34** How do you make the transition mechanisms of processes designed for one context easily and efficiently adaptable for a new context? (i.e., when an organization is acquired into another enterprise)?
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- D-35** How can CEOs and other management personnel be educated and trained for process deployment, and how can we best measure the effectiveness of training?  
In fact, does it matter how effective executive sponsorship is?
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- D-36** How do we define measures of breadth of process adoption in a particular context?
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- D-37** How do we define measures of depth of process adoption in a particular context?
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- D-38** What are the appropriate success criteria upon which to judge deployed processes?
- Can we develop a generally accepted set of measures describing the effectiveness of deployed processes and the impact of improvement actions?
  - Process reality is different for different organizations; how does this affect our understanding of success criteria?
  - What is the difference between documented and practiced processes? Is the development performed according to the documented processes or how does the actual development differ from the documented process within an organization?
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- D-39** What level of automation can be introduced to facilitate the assessment process?
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- D-40** How can we best validate processes, to confirm fitness for purpose and return on investment?
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- D-41** What aspects of process capability are important and relevant for assessment?
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- D-42** How can we be sure that the results of process evaluation really reflect the ability to satisfy business needs?
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- D-43** What lessons can be learned from different forms of process evaluation?
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- D-44** How can we improve the efficiency and effectiveness of process evaluation approaches?
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- D-45** How do we convert process evaluation to a continuous activity that can be effectively automated?
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- D-46** Since all measurement is taken in a context, what is the best way to characterize the adoption context? What is the best way to measure that context?
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- D-47** How can adoption effectiveness be compared across organizations or between any two organizations? That is, how do we know which aspects of deployment to transfer from one organization to another? How do we know what we are supposed to learn from each other?
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- D-48** What is the impact of changes in the organization and the business environment on the process needs and capabilities of the organization?
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- D-49** How do we best monitor on a continuous basis the capabilities and everyday use of deployed processes?
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- D-50** How can we best monitor the ongoing returns on investment on process deployment and improvement? Is ROI an important indicator?
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- D-51** What is the most effective way of identifying and addressing changes in competencies driven by changes in the organization and business context?
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- D-52** How can we identify causes of variations in performance and capability so as to initiate effective process evaluation?
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- D-53** How do we create easy to use “experience bases” that allow knowledge to be stored, updated, and accessed by developers at varying levels?
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- D-54** How can concepts like network-centric knowledge management (could be social and/or infrastructure) be employed to leverage process knowledge across multiple contexts?
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- D-55** What kind of ontology would be useful for classifying process-based knowledge and the context of its acquisition and use?
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- D-56** How can we improve the design and use of process asset repositories to support effective learning from experience?
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- D-57** Can the full validity and usefulness of statistical process control be demonstrated in relation to software and systems engineering and management processes? If yes, how should it be used to aid adoption?
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- D-58** What are the limitations of applicability of statistical process control in this context?
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- D-59** Can the collection and analysis of process metrics be improved to reduce effort and increase acceptance?
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- D-60** How can we best identify gaps in the extent to which an organization's processes address its goals, and what is the optimal mechanism to address these gaps?
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## Process Effects of Emerging Technology Trends

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- T-1** How do you anticipate the pressures for change early in the system life?
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- T-2** How do you anticipate requirements volatility and unknown, unidentified requirements early in the development life cycle?  
How do you adapt processes to allow for this?
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- T-3** What metrics can we develop to characterize the level of known requirements satisfaction and the level of dynamism expected in future?
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- T-4** How do you characterize the level of known requirements satisfaction with initial build and the level of dynamism expected in future?
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- T-5** How do you support a requirements management system/process that accounts for both expected and unexpected change?
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- T-6** How do you instantiate a life cycle that explicitly recognizes incomplete requirements as its basis for initial development?
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- T-7** How do you instantiate development with partial requirements?
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- T-8** How do we instantiate processes for verification and validation in initial build that account for high requirements dynamism?
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- T-9** How do you keep verification and validation tightly coupled to requirements when the requirements are "a moving target"?
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- T-10** How do you gather and filter the relevant data to support "the next evolution" in your requirements?
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- T-11** How do you instrument the system to collect information that will permit appropriate requirements evolution?
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- T-12** How do you model the eco-system the system will be a part of?
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- T-13** How do you measure requirements volatility in a useful way?
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<b>T-14</b>	How do you sustain and evolve an eco-system model for the world the system lives in?
<b>T-15</b>	What is important and essential to include in SoS requirements analysis models?
<b>T-16</b>	What data about user behavior needs to be collected that will help infer the need for requirement changes?
<b>T-17</b>	What information about new technologies needs to be collected to help infer the need for requirements changes and the impact of the new technology on the existing system
<b>T-18</b>	What replaces “quality = conformance to requirements” in a system where continuous requirements evolution is present?
<b>T-19</b>	How do you instantiate an assurance strategy (a process for doing so) given that a subset of the requirements do not have to be met all the time? (i.e., in a SLA context)
<b>T-20</b>	How do you establish a release cycle that balances environment change with user ability to integrate or deploy the new increment?
<b>T-21</b>	How do you anticipate (determine) the pressures for change at a given point in the system life?
<b>T-22</b>	What are the relevant utility functions for establishing release cycles?
<b>T-23</b>	How do you recognize when to re-architect for future anticipated changes?
<b>T-24</b>	What are key elements of the design or architecture that accommodate operating and evolving a system when there is, and will continue to be, incomplete system state knowledge?
<b>T-25</b>	For a given system type and operational context, can we characterize a framework of where and how incomplete knowledge can be tolerated or dealt with?
<b>T-26</b>	What are the processes for determining what is important to know or not know about system state and configuration?
<b>T-27</b>	What are the processes for using knowledge (complete or incomplete) about system state and configuration for system build and integration?
<b>T-28</b>	What are the processes for determining what is knowable and unknowable about the operational state or configuration of a system at different points in its evolution?
<b>T-29</b>	How do we determine what data will help us to move from “unknown unknowns” to “known unknowns” to “knowns”?

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<b>T-30</b>	How do we determine the “shelf life” of data to be collected at various points in system evolution?
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<b>T-31</b>	What are approaches for understanding which elements of your configuration can be ignored at any particular time?
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<b>T-32</b>	How do we provide frameworks for eliciting more complete pictures of system context and data more effectively?
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<b>T-33</b>	How do we effectively collect information about ambiguous data and data types to help reduce that ambiguity?
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<b>T-34</b>	What kinds of modeling and analysis techniques for assurance help us to characterize the level of completeness of our assurance strategy in relation to the knowledge that is available?
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<b>T-35</b>	How do we provide “data cleansing” to deal with data issues when we’re acknowledging incomplete data sets?
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<b>T-36</b>	Given that conclusions from assurance activities are necessarily probabilistic in nature, what’s the decision process to use them for release decisions, etc.?
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<b>T-37</b>	What kinds of processes can be used for relevant quantitative assurance when system state or context of use is unknown?
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<b>T-38</b>	Are there requirements approaches that will reduce integration and assurance challenges for heterogeneous systems?
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<b>T-39</b>	How do we understand the indirect and cascading effects that are inherited from component systems when we try to initially integrate them?
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<b>T-40</b>	How can we create market and/or regulatory forces that incentivize vendors to create products that are verified, secure, interoperable, etc.?
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<b>T-41</b>	How do we change the education system to prepare future engineers to work productively in this environment?
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<b>T-42</b>	How do you decide what data needs to be collected from the heterogeneous components and suppliers for acceptance into integration?
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<b>T-43</b>	How do you build the trust required to ensure that accurate data is being passed in a relevant fashion among nodes in the system?
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<b>T-44</b>	How do you collect and update data on system performance to establish service quality of individual components/new requirements?
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<b>T-45</b>	What kinds of processes, models, techniques, etc. help you to analyze which new standards actually help, rather than hinder, heterogeneous system evolution?
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<b>T-46</b>	How do you analyze data collected on system performance to characterize service quality of individual components and new requirements needed?
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<b>T-47</b>	How do we analyze components to determine their suitability for inclusion in a system of interest?
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<b>T-48</b>	How do we analyze components related to their security, workflows, user roles, decision support to characterize those aspects across the system?
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<b>T-49</b>	How do we analyze the communication paths and performance among the components to ensure successful—and eventually seamless—integration?
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<b>T-50</b>	How do we analyze emergent properties (both good and bad) that are present in the heterogeneous system?
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<b>T-51</b>	How do you establish processes that can navigate different legal environments when assuring a heterogeneous system?
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<b>T-52</b>	How do you optimize an assurance strategy based on usage of components and scale of integration effort?
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<b>T-53</b>	How do you avoid “big bang” integration processes?
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<b>T-54</b>	How do you deal with asynchronous upgrades of different elements of your system?
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<b>T-55</b>	In an environment of continuously evolving requirements, how do you allocate and or communicate new or changing requirements across all the relevant components?
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<b>T-56</b>	How do you manage alignments of user roles, security, workflows, decision support, etc when in the build/integration process when you have all the requirements changing?
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## An Instantiation of Research Nodes and Questions for Security

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<b>S-1</b>	How is security expressed in each phase of the SDLC? What are appropriate expressions, from a security perspective, of how the system is to be used (see S1.4 misuse/abuse cases)?
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<b>S-2</b>	What processes best ensure the instantiation of established security principles?
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<b>S-3</b>	What are effective processes and methods that ensure that known causes of security vulnerabilities are not present in each phase of the SDLC?
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- S-4** What processes and methods can be used to accelerate adoption of known methods for developing low-defect-rate (and thus more secure) software? (state of art/state of practice gap)
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- S-5** What are the compelling cost/benefit arguments to do so?
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- S-6** Is it possible to build and verify secure software and systems using agile methods?
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- S-7** What processes can be used to ensure that security requirements are met for systems composed from existing components? For extensible systems?
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- S-8** What is the role of process in ensuring that software and systems are engineered such that they continue to function correctly under malicious attack, failure, and accidents?
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- S-9** What are the definitions of meaningful, informative security measures? What processes are needed to reliably collect these?
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- S-10** What measures indicate that a system has met its security requirements for each SDLC phase? What are the processes for collecting, analyzing, and reporting these measures?
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- S-11** What measures and evaluation processes can be used to determine the effectiveness of different secure software development processes?
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- S-12** How is an adequate or acceptable level of security determined, tested, verified, certified?
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- S-13** What processes are most effective for assessing, evaluating, verifying, and certifying the security of software and systems (including those provided by third parties)?
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- S-14** What processes and methods are most likely to reveal security issues, flaws, and vulnerabilities during each SDLC phase? And with third party, open source, and COTS, or other component software?  
In the case where such processes already exist and have empirical evidence to justify their use, what can be done to accelerate their adoption? (state of art/state of practice gap)
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- S-15** What processes and methods allow for building misuse/abuse cases that predictably provide evidence that security product qualities are present?
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- S-16** How do we define and sustain adequate security in the face of increasingly sophisticated attacks (attack evolution), technology evolution, enterprise evolution, supply chain evolution, and the like (all sources of change that require a system to evolve)?
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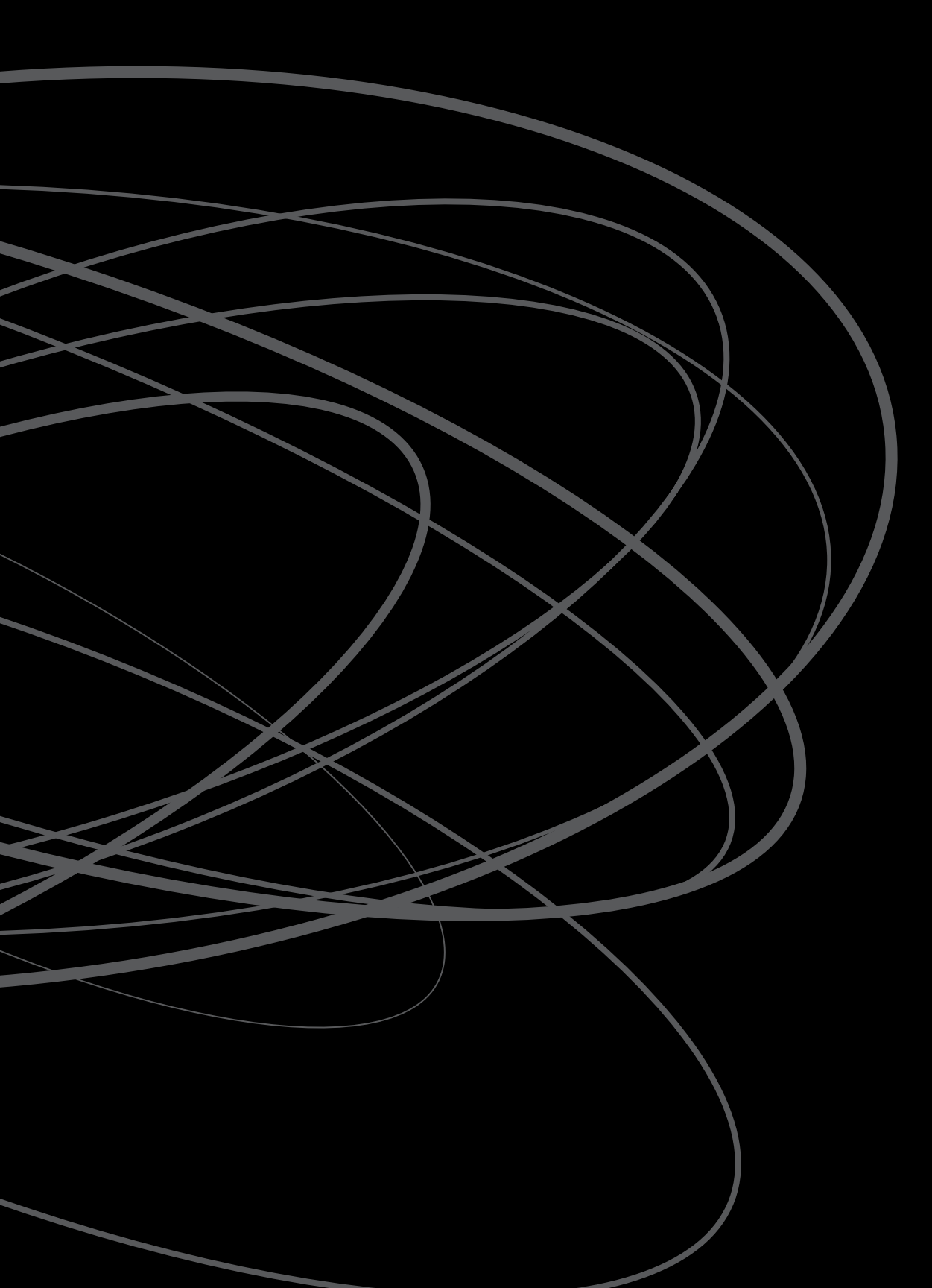
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