Challenges in Digital Information Streams from Architecting to the Full Lifecycle

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***Abstract*—In most systems of systems ecosystems, there is a significant number of challenges in the digital information streams between organizations and within organizations. This paper gives a retrospective analysis on the current situation to identify the major bottlenecks. It limits itself to diagnosing the current situation with the purpose that future research can address a roadmap to address the current problems.**

Keywords—life cycle, information flow, digital engineering, MBSE

I. Introduction

The main author of this paper interacts with a wide variety of organizations by teaching to systems engineers and architects in these organizations in Norway, Germany, and the Netherlands. These countries share similar cultures, the so-called Rhineland model [1], which states "The Rhineland business model and the leadership practices associated with it can be defined as a management approach based on concepts of cooperation, consensus, social justice, and serving the interests of multiple stakeholders. Chief concern is the long-term sustainability of an enterprise.".

A recurring themein the authors' interactions, e.g. the symptoms, is that these systems engineers and architects perceive the information flows in their organizations and between organizations as poor. Most organizations have defined processes and related artifacts. Organizations within an ecosystem follow mutually agreed working protocols with their related artifacts. Nevertheless, there is pain in handovers where information may get lost, taking manual effort, and creating potential problems with integrity, e.g. agreeing on the status of information.

The systems engineering world advocates MBSE and digital engineering as solutions for the observed problems. [2] state that literature is inconclusive about the value of MBSE at this moment. [3] document a long running case claiming a positive impact of MBSE. Organizations like ESA are busy introducing MBSE [4]. Similarly digital engineering is at a larger scope a topic of much research. For example, [5] proposes metrics to measure digital engineering effectiveness.

This paper takes a step back to "diagnose" the current information flow situation, such that we know what we want to solve with a wide variety of methodologies that researchers are advocating. The paper uses the following research questions:

- What are the main information streams between early phase program definition and the full life cycle?
- Where are boundary transitions in these information streams?
- What are causes of the pain points in the information flow?
- What are options to improve the information flows?

II. Research Method

The main author is teaching and facilitating workshops in multiple domains in various layers of the ecosystem. During this teaching and workshops, similar information flow problems keep re-appearing. The researcher used conversation with experts in various domains to build a set of workflows and information flow models to understand the current situation. The authors facilitate multiple knowledge exchange interest groups, such as the Systems Architecting Study Group in the Netherlands,, the Systems Engineering Study Group in Norway[7], and the international Systems Architecting Forum [8]. The digital information flow is a regularly recurring theme in these sessions. The domains that the experts come from cover energy, defense, transportation, healthcare, high-tech equipment, and maritime and offshore. The author provided trainings and facilitated workshops in the same domains as these experts, and covered the operation, the infrastructure providers, contractors and consultancies, suppliers, and sub suppliers

The workshops and courses follow a standard pattern in analyzing situations. Core to the approach is analyzing the as-is situation, e.g. a stakeholder and workflow analysis. When doing this, participants often already jump to improvements, triggered by the problems that become visible in the as-is situation, Key in the analysis is to analyze sufficiently broad, from original service request to final delivery. Examples of such cross-organizational workflows are [9], [10]

III. Modeling the Information Flows

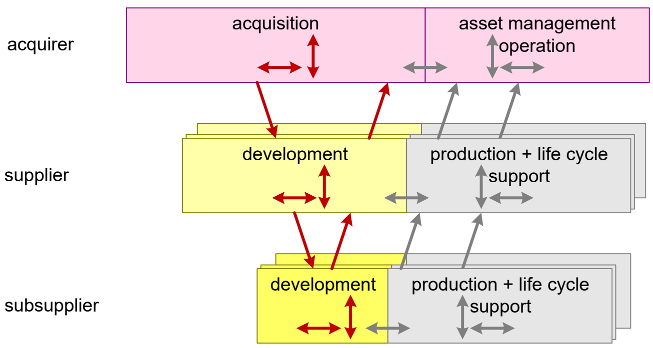

Fig. 1. High-level overview of information flows between ecosystem layers

Fig. 1 simplifies the ecosystem into a few layers e.g. an acquisition organization working with multiple suppliers who recursively use multiple sub suppliers. Each of these organizations typically organize themselves as development and life cycle support. There are information flows for development information (needs, requirements, plans, etc.) and for the life cycle (product documentation, logistics, production, service, etc. information). These flows happen between various disciplines and enterprise functions, and they happen between hierarchical layers within disciplines and business functions. Fig. 2 Shows what information a development project needs from the life cycle to define, design, and engineer a solution.

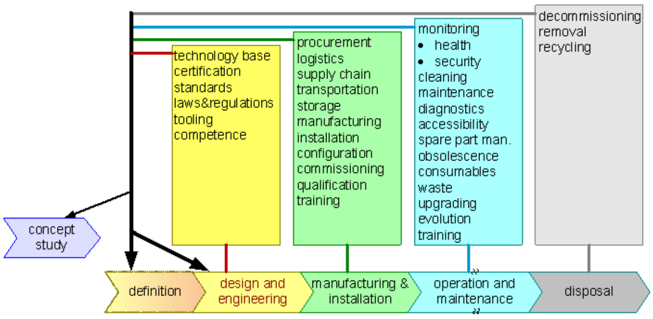

Fig. 2. Life cycle information that development needs to define and design a solution.

Fig. 3 shows as a simplified linear flow how information transforms from mission needs to the detailed information needed for the life cycle support. In reality, this flow is more complex with many feedback loops. The information at the top is application domain specific with a wide variety of stakeholders with political, economic, environmental, social, and legal considerations and interests. Using systems engineering methodologies, marketing managers, and architects analyze needs and application concepts. Architects together with (systems) engineers translate these needs into requirements and a system design. In the engineering flow there is a transition from a multi-disciplinary perspective into mono-disciplinary building blocks. A main responsibility of engineering is to produce all information that stakeholders in the life cycle need. The resulting technical documentation is standardized and extensive. A sustaining organization with industrial engineers maintains this documentation over the life cycle.

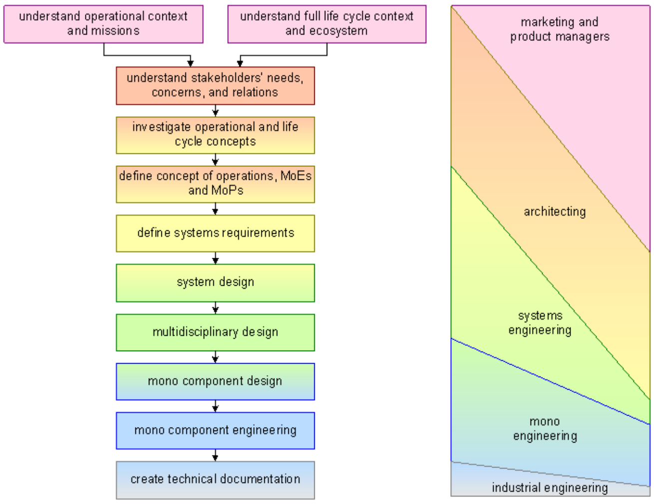

Fig. 3. The logical information flow from mission to industrially usable documentation.

We can map the logical flow of Fig. 3 onto the V-model, as Fig. 4 shows for a specific type of Design-to-Order procurement. Various suppliers apply the V-model recursively. Fig. 4 shows the information flow in the acquisition organization as horizontal bar, left and right of the V-model. The box at the right-hand side shows the critical boundary transitions in these recursive flows. These critical transitions often occur at organizational boundaries.

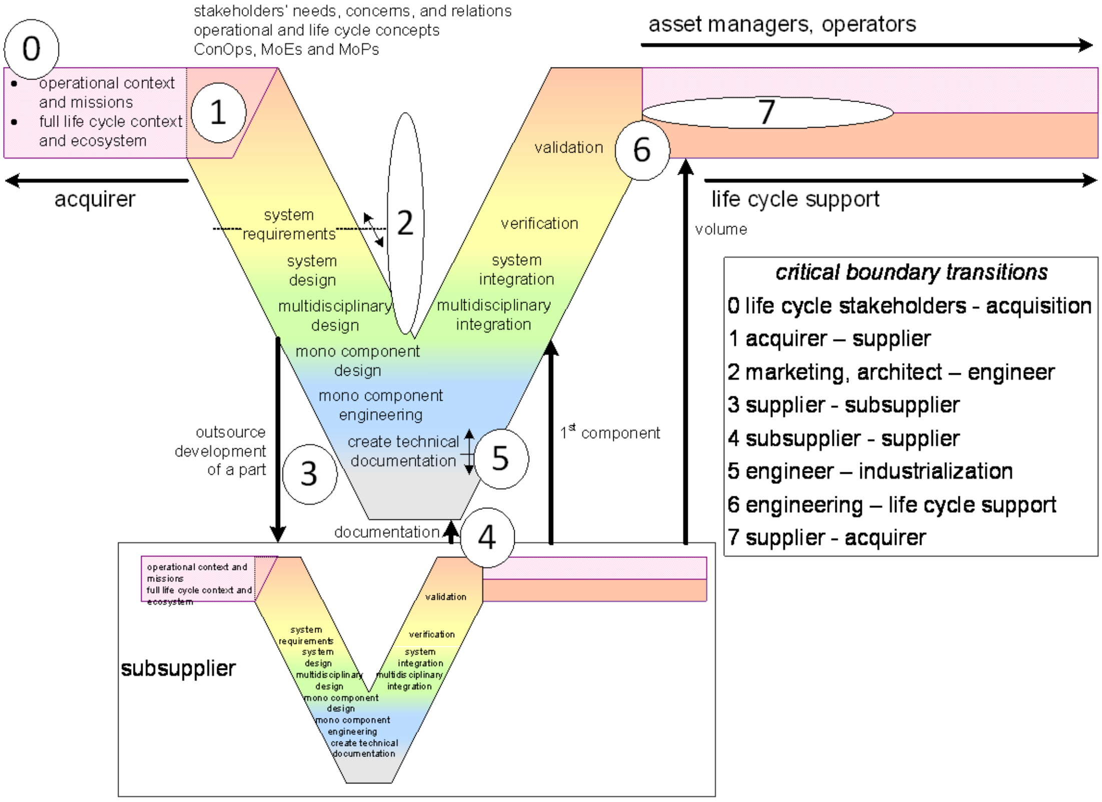

Fig. 4. Mapping the information flow on a recursive V-model.

Fig. 5 shows how the acquisition organization and supplier interact in case of a Design-to-Order procurement. The interaction between supplier and sub supplier for Design-to-Order is similar. An acquisition organization runs programs with many suppliers with even more sub suppliers. All these organizations need to manage their relations. [11] describe how the oil and gas industry uses interface management to do this.

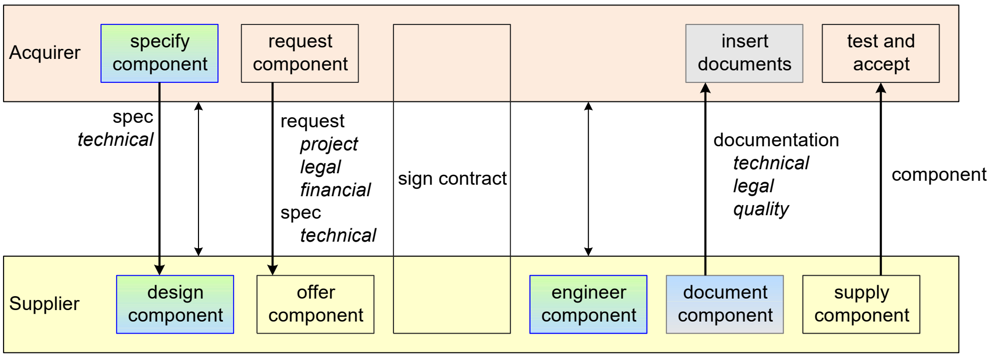

Fig. 5. Interaction between an acquisition organization and a supplier for Design-To-Order.

Within suppliers, dominant information hierarchies are the development and the information in the life cycle support documentation (called Technical Product Documentation (TPD)) in the figures, after the origin of the term in Philips Electronics. The development documentation defines what (performance specification), how (design specification), how to test, and the test result, all for the use throughout the development phase. The TPD defines what and how to produce, how to build, adjust, transport, install, how to commission, maintain, update, decommission, et cetera. The core of the TPD is the product structure with several parts-oriented structures: a commercial structure, a catalogue of parts that sales uses towards customers, a build structure, that procurement uses for purchasing and ordering, and manufacturing uses for production, and a service structure that service uses for spare parts logistics and maintenance. The product structure in most organizations is at the heart of the information management for the life cycle. The Enterprise Resource Planning (ERP) system and the Product Lifecyle Management (PLM) systems use this structure to store and navigate parts information.

Each Mono-discipline typically has its own digital infrastructure with repositories and computer aided design tooling, e.g. CAD-M for mechanical engineering and CAD-E for electrical engineering. Fig. 6 shows IT-tools suppliers are using to do their work; in many organizations this is a landscape with tens if not hundreds of applications. The figure shows at the left-hand side, the development IT with system and mono-disciplinary tools and repositories, and at the right-hand side the life cycle support systems.

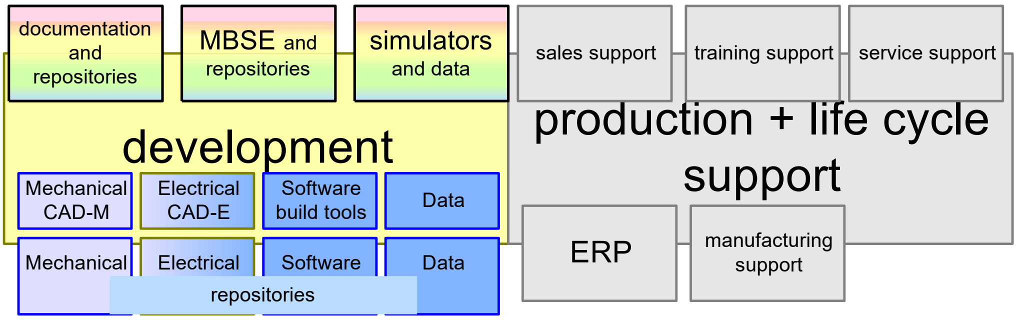

Fig. 6. The IT landscape of a supplier

Each organization in the ecosystem has its own set of IT-tools covering this development and life cycle support functionality, see Fig. 7. The information flowing between the organization is flowing through these IT systems. Typically, at each organizational boundary, the organization will consciously decide what information to export in what format.

IV. Identified Pain Points

From the teaching, workshop discussions, and the conversations with experts, it becomes clear that there are numerous information flows supported by a rather diverse IT landscape with much legacy. The diversity manifests itself in the format of information, ranging from natural language in for instance, Word documents, informal visualization in PowerPoint or Visio, plenty of spreadsheets for a wide variety of purposes and system work arounds, requirements engineering tools, a few more formally specified systems (using well defined syntax and information models), plenty of discipline specific formats, e.g. for software tools, mechanical and electrical CAD.

Frequently mentioned pain points are:

- The product structure in ERP systems has become rigid and is expensive to maintain and change. An example is [12], where the amount of configurations became unmanageable.
- Mono-disciplines find it problematic to communicate with other mono-disciplines. Even communication between different specialization within a mono-discipline is difficult

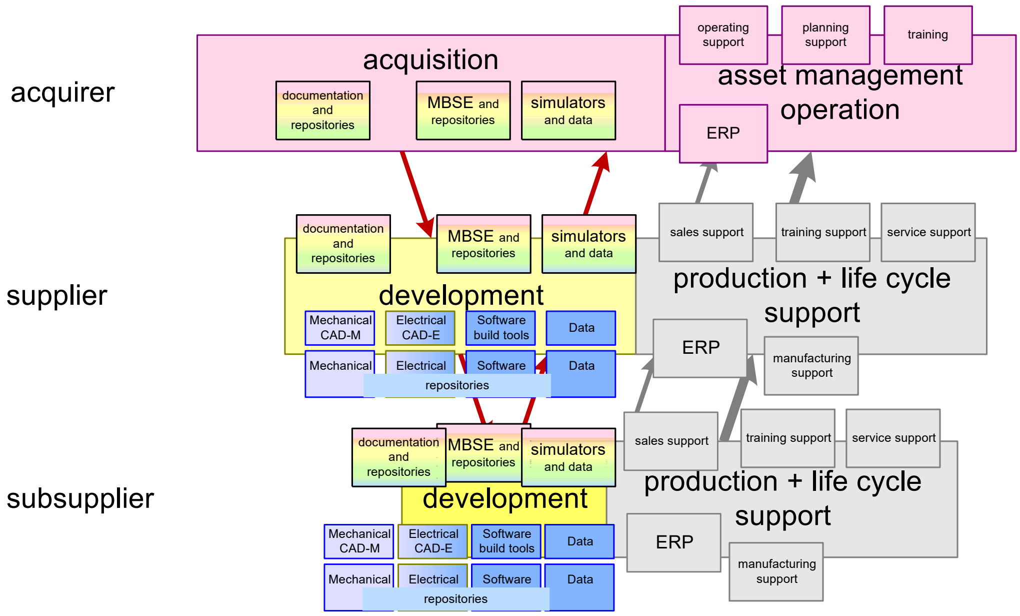

Fig. 7. The IT landscape across the ecosystem layers

- Exchange between organization boundaries is often export-import based, where receivers need manual work to recover necessary information. An example is [9] showing that the supplier send 3D CAD information as 2D pdf file to its suppliers. Who then need to add tolerance information manually.
- There is little interoperability between systems within and across organizations. One of the defense companies did not have a digital transfer from MBSE to ERP
- Many organizations see MBSE as using SysML. There seem to be few users of SysML outside of the defense domain, although nearly all large organizations talk about MBSE [13]
- People with questions about MBSE and advocates of MBSE tend to have no clear answer what the purpose is of using MBSE. A list of potential purposes that participants mention are:
    - to support reuse or a platform-based product strategy to configure, generate, compose, validate
    - to automate or generate tests, simulations
    - to trace needs, requirements, or quality attributes throughout the design and engineering, especially regulated qualities like safety
    - to function as knowledge base for development and engineering
    - to access component-data based on the field configuration (digital shadow)
    - to populate and update PLM systems, e.g. ERP (digital thread)
- The flow of information such as needs from life cycle support to development is rather difficult. Cultural differences between the operationally oriented life cycle support and the conceptually oriented development may be one of the causes.
- The flow of data from the later life cycle to development is functioning poorly in many organizations. Many organizations ask for data-driven development and maintenance, e.g. condition-based maintenance, however, they lack the operational capability. An example is [14], showing much potential value from closing the feedback loop from the life cycle to development.

V. Discussion

A. What are the main information streams between architecting and the full life cycle?

There are many information flows. A prime flow is the downflow from idea, context understanding, and stakeholder needs to an engineered solution to instantiations and a long life cycle. This flow starts with understanding the context with a tremendous amount of information and variation. We simplify this with among others missions, scenarios, ConOps, and stakeholder analysis to achieve a program definition in the form of a Request for Proposal, which is much less detailed. Then in the elaboration, going down in the flow in Fig. 3, the amount of details quickly multiplies again with orders of magnitude [15]. A major challenge is to help a wide variety of stakeholders to access the right information for their role, in a form that fits their worldview, to help them to see this information in a broader context, to help in navigating them through the relevant information, to keep overview, to be able to share and discuss with other stakeholders, and to support decision making [16].

Other major flows where people mention many pain points are the flow between engineering teams and the flow from the life cycle support towards development. In this flow there is much opportunity to improve[14].

B. Where are boundary transitions in these information streams?

Fig. 4 indicates the critical boundary transitions, where the handovers cause much pain:

- life cycle stakeholders - acquisition
- acquirer – supplier
- marketing, architect – engineer
- supplier - sub supplier
- sub supplier - supplier
- engineer – industrialization
- engineering – life cycle support
- supplier – acquirer

Many of the boundary transitions have multiple types of information related to multiple expertise areas, e.g. legal, financial, and technical. Information items tend to be long-living. Over time the information items may have different users with different purposes. Early in the life cycle, they come into existence in a defined project context, while later they serve the life cycle purpose for a long-time.

Even the transition between mono-disciplinary teams, and between engineers at a higher aggregation level and at a deeper aggregation level is causing pain, where the different worldviews of the mono-disciplines and the different ways of working and supporting tools hinder the information exchange.

C. What are causes of the pain points in the information flow?

[17] proposes that to achieve cross organizational capabilities, e.g. information flows, role models, organizational capabilities and individual competencies, processes and organizations, and infrastructure and tools need all to be sufficiently in place, see Fig. 8. Reversely any of these elements that are insufficient cause pain. Core message of [17] is that new capabilities that society and large operational organizations need increasingly depend on an extensive ecosystem. This is the systems-of-systems challenge at a large scale, as [18] describes.

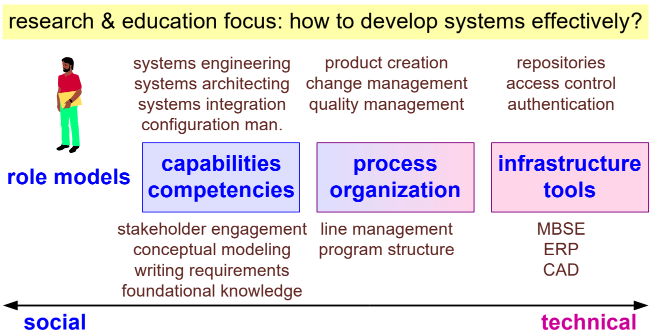

Fig. 8. To achieve cross organizational capabilities, e.g. information flows, role models, organizational capabilities and individual competencies, processes and organizations, and infrastructure and tools need all to be sufficiently in place.

Specific problems start in the infrastructure and tools area. Individual organizations suffer from a complicated IT landscape, where legacy plays a significant role. Interoperability between tool suites and infrastructure elements is limited, partially due to commercial interests. SysML V2 strives to support better interoperability for a small part of the entire IT landscape.

In terms of process and organization, parties in an ecosystem have different roles, interests, and worldviews, resulting in different organizational cultures. Players in the ecosystem have to cooperate to agree on process and organization elements that go beyond the organizational boundaries to address the critical transitions in Fig. 4. A pain is that these organizational differences form a barrier for effective cooperation. Particularly challenging questions are how to cope with needs and limitations to information. For instance, in defense, there are many constraints to information flow complicating the information flows. Proper organizations (where to allocate what task) and processes (how to communicate, how to cope with regulatory boundaries) may help. Another painful barrier are the European outsourcing regulations that severely limit proper information flow, in name of a level playing field. Defense is gradually testing out outsourcing with more cross-organization communication.

D. What are options to improve the information flows?

This question is much too big to answer fully in this paper. However, Fig. 8 indicates that an improvement requires working on social and technical elements concurrently. Each element needs sufficiency of the other elements to be effective.

[17] Proposes orchestration as a competence that enables cross organizational development of solutions, processes, and organizations, see Fig. 9. Most organizations will need one or a few orchestrators to ensure that the ecosystem as a whole may function effectively, despite all differences [17].

When making an organizational transition, which in this case may be a set of transitions of multiple organizations in the ecosystem, a problem is that there are no examples of how to work in a desirable way. In education, role models help people to learn desired behavior by imitating it.[19]

- **Orchestrating** is the competence to **proactively nudge** involved **parties** towards a **fitting solution**.
- Orchestrating requires the abilities:
  - to relate with a wide **variety of stakeholders**, to understand their **interests** and **concerns**, to **connect** with them such that they can **influence** them
  - to **understand** the **problem and solution space** sufficiently
  - coping with **ecosystem complexity**, **uncertainties** and **unknowns**, and helping stakeholders to navigate them
- Orchestrating requires the attitudes:
  - to see the **big picture**, while still have an eye for the devilish details
  - to **own**
  - to be **pro-active**
  - to be **genuinely interested** in stakeholders

Fig. 9. Orchestrating Content and Stakeholders Across Organizations

An observed challenge is that improvement efforts often limit themselves to only one or a few elements of Fig. 8, e.g. introducing a new tool suite with IT infrastructure and tools. However, the embedding of such tool suite in processes and organization is necessary to achieve results. At the same time, the people in the organization need to have the right competencies individually and together as team deliver the organizational capability. A similar pattern is that the management invests heavily in the “soft skills” without scaffolding support in harder skills, processes, and infrastructure.

VI. CONCLUSIONS

Increasing integration of solutions and the organizations developing and operating them requires sufficiently functioning information flows across the ecosystem. Most organizations experience unsatisfactory information flows. The amount of information flowing from idea to end of life is huge and scattered over many organizational entities and managed in a diversity of (legacy) IT systems.

This paper advocates to transition to a more streamlined ecosystem operations, where the players in the ecosystem concurrently address cross-organizational capabilities, e.g. information flows, role models, organizational capabilities and individual competencies, processes and organizations, and infrastructure and tools, throughout the ecosystem. Orchestrators play a major role to make such transition happening.

VII. FUTURE RESEARCH

This paper is diagnosing the current situation based on a wide anecdotal sampling. Future studies can substantiate the diagnosis with more systematic research. A more challenging step is transforming the diagnosis into a roadmap forwards. Especially challenging is that such a roadmap is heavily cross-organizational. The semiconductor roadmap [20] may serve as an example.

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