Produce a Useful and Teachable Theoretical Foundation for IS Engineering

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Abstract

IS engineering (ISE) uses tools such as UML and BPMN, but it lacks a theoretical foundation that is useful and teachable, as has been noted many times. Efforts over the course of 30 years by the author and various collaborators have produced substantial progress toward articulating a useful and teachable theoretical foundation for IS engineering (a TFISE). A clear, intuitively plausible, and practical TFISE could help in assessing strengths and weaknesses of current ISE practice, developing better concepts, tools, and methods, and producing better results.

Research to date unfolded around a core of work system theory, which emerged from a series of IS textbooks, was first formalized in 2013, and is more plausible as an overarching metaphor for a TFISE than known alternatives. Ongoing research aims to produce additional tangible products that could contribute to a TFISE and TFISE specifications. Results from distinct, separable steps such as several mentioned here could be published in conference and journal papers. Explaining a TFISE in detail would require one or several book-length documents.

Current projects focus primarily on consolidating and extending earlier steps toward a TFISE by using knowledge graphs, possibly in conjunction with carefully structured prompting of large language models. Much of the development to date was inspired by university site visits, work with co-authors, and especially international interactions with researchers. The pace of near-term progress will depend on enlisting collaborators.

In addition to work system theory, the long course of this project has produced theories related to workarounds, system interactions, IS usage, and IS user satisfaction; frameworks related to a system value chain, facets of work, smartness of systems, compliance and noncompliance, and roles and responsibilities of digital agents; a taxonomy of knowledge objects; applications of work system ideas to risk, security, collaborative workarounds, software engineering instruction, AI, and digital transformation; a toolkit of templates for description, analysis, and design; and a map of a broader work system perspective that continues to expand.

Keywords

theoretical foundation of IS engineering, work system theory, taxonomy of knowledge objects

1. The Challenge of Developing a Theoretical Foundation for ISE

"Rethink the theoretical foundations of the IS discipline" was tied for first of 21 challenges as a grand challenge for IS research in a Delphi study reported in BISE by Becker et al. in 2015 [1]. It was ranked third of 21 as having an impact on the discipline if it were solved. A

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theoretical foundation for the IS discipline would be similar to a theoretical foundation for IS engineering (a TFISE). It would address an unsolved problem that has been discussed ever since Keen's keynote [2] at the first ICIS meeting in 1980 in debates about whether the IS field is in a crisis and about whether it is stuck in unproductive pursuits (e.g., [3]).

ISE can be viewed as the application of systematic knowledge (beyond routine skills and toolkits) for IS design, development, and evaluation. Quality criteria for a TFISE include coherence, usefulness for practitioners, appropriate level of abstraction, sufficient complexity and depth, and relevance to systems with human and/or nonhuman actors. A clear, intuitively plausible, and practical TFISE could help in assessing strengths and weaknesses of current ISE practice, in developing better concepts, tools, and methods, and in producing better results. There is no reason to assume that the current research will produce the only possible TFISE. Genuine progress requires serious examination of progress toward one or more attempted solutions to the grand challenge, not just commentary and speculation about the source, nature, or importance of the problem.

2. Background

This project started with a series of IS textbooks in the 1990s whose goal was producing books that would have helped the customers and staff of a successful startup software firm where the author worked for eight years before returning to academia. The first academic paper from that effort appeared at the 1995 IFIP conference on IS concepts in Marburg, Germany. It was called "How should business professionals analyze information systems for themselves?" [4]. Textbooks and journal and conference papers addressed different aspects of that question within the context of a broader work system perspective that covers both sociotechnical and totally automated systems. The practicality of the overall approach was demonstrated by (mostly) MBA and EMBA students or student teams using templates based on those ideas to produce700+ management briefings related to improving IT-enabled systems, mostly in their own organizations. (e.g., [5]).

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Type of research. This is fundamental research about ideas that can be used to understand practical situations. Some papers produced during these efforts made extensive use of research ideas to explain real world situations. Examples include use of fundamental ideas about work systems and workarounds as the basis of applied papers about workarounds in Netherlands and Hong Kong and IS security practices in England and Korea.

Research team. To date, this research was pursued largely through personal efforts of the author, who never had PhD or MS students at the University of San Francisco and therefore frequently enlisted co-authors on specific projects. Co-authors of published papers related to WST are from universities in Austria, Brazil, England, Germany, Hong Kong, India, Korea, Netherlands, Romania, South Africa, and the United States. Research with other collaborators from universities in Australia, Germany, Netherlands, and the United States has not yet reached fruition.

3. Milestones Leading to Current Research

This section summarizes milestones leading to the project's current state. Most milestones will be illustrated with a diagram and discussed in only a few sentences. Complete discussions would absorb many pages. The milestones demonstrate that current research extends a highly productive research stream that whose output has appeared in journals and conference proceedings related to the subject matter of CAISE. Aspects of that research were presented twice in tutorials at CAISE (2015, 2023) and have appeared in in proceedings of CAISE (2023), CAISE Forum (2019), CBI (2014, 2016, 2020), EMMSAD (2015, 2020, 2022, 2024), ER Forum (2022), ISEC (2017), PoEM (2018), PRoSE (2019), and WI (2019). Many other papers have appeared in IS-related conferences such as ACIS, AMCIS, ECIS, HICSS, ICIS, and IFIP 8.6 and IS-related journals including ACM DATABASE, CSIMQ, CAIS, DSS, EJIS, EMISAJ, IJITSA, IRMJ, ISF, ISJ, IT&P, JAIS, JDM, JITTA, and THCI.

3.1. Work System Theory

This entire project pursued the long-term vision of creating a systems analysis method for business professionals, which was articulated initially as the work system method (WSM – [6]). The ideas underlying WSM were formalized as work system theory (WST – [7]), where work is the application of human, informational, physical, and other resources to produce product/services for a work system's customers. Work occurs in situations (businesses, governments, homes, etc.) where resources are used to produce outcomes. A work system is a system in which human participants *and/or* machines perform work (processes and activities) using information, technology, and other resources to produce specific product/services for internal and/or external customers and/or for themselves. The three components of WST are the definition of work system and the two frameworks in Figure 1. WST applies equally to work systems in general and to special cases of work systems such as information systems, projects, IS development projects, and requirements analysis. Inheritance of properties of work systems in general by the special cases greatly simplifies the consolidation of knowledge about the special cases.

The work system framework identifies nine elements of a basic understanding of a work system as it exists or could exist at a specific time. The work system life cycle model outlines four phases of a work system's evolution through iterations that often combine planned and unplanned change. More detailed views of both parts have been presented many times.

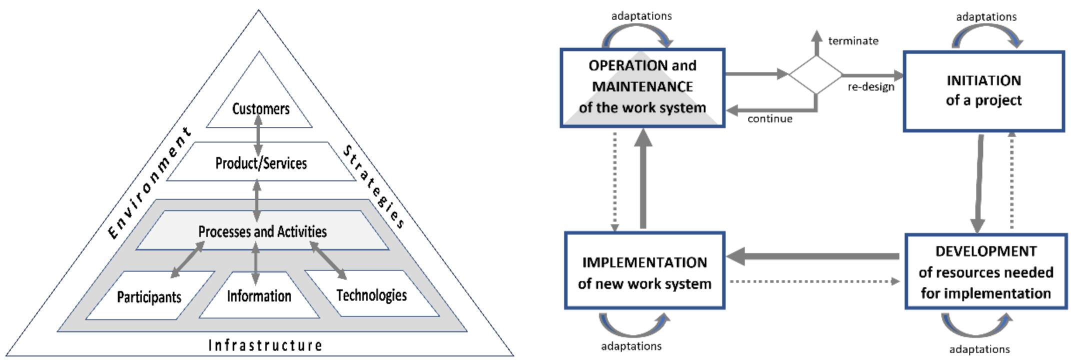

Figure 1: Work system framework and work system life cycle model

Various parts of Figure 1 point to many ISE-related limitations and challenges. Requirements analysis needs to be based on a realistic view of the current and/or future operation of whatever work systems are being created or improved, where "realistic" considers human participants, information, technologies, the surrounding environment, and so on. ISE should recognize that human work system participants may not comply with inconvenient or overstructured processes, either due to mistakes or due to specification flaws that force noncompliance if they want to achieve their work goals. That was a reason for developing a theory of workarounds that has proved quite useful. Additional variability may occur in situations where a work system's customers may perform or co-produce activities within a work system, as occurs in service systems such as education, medical care, and consulting. ISE should recognize that processes and activities in specific situations may be unstructured (e.g., artistic work), semi-structured (e.g., medical exams), workflows (e.g., processing payments), or highly structured (e.g., semiconductor manufacturing). ISE should recognize important information beyond transaction data described by ER diagrams, e.g., goals, commitments, recipes, business rules, audio, video, unstructured data, and so on. The term product/service reflects that fact that outputs and conditions produced by work systems often have some characteristics associated with products (e.g., standardization of process and output) and other characteristics often associated with services (e.g., customization, relationships with customers, involvement of customers). ISE needs to account for forces and factors in the organizational, competitive, and social environment that might impact a work system's operation. Also, alignment between work system elements implied by the bidirectional arrows inside the work system framework may be elusive. An overarching goal for ISE is to contribute to the beneficial evolution of a system rather than just producing software that addresses short term issues.

3.2. Work system perspective

WST is the core of an evolving work system perspective illustrated in Figure 2. Treating WST as a core provides coherent and internally consistent ideas that can be a basis for covering many types of situations that often matter, such as system interactions, workarounds, system overlaps, facets of work systems, and so on. That provides a manageable path for developing these ideas further.

WST is not the only possible core for a theoretical foundation for ISE. Largely technical approaches such as UML, BPMN, SysML, and Archimate would have to be expanded to include much more about customers, system participants, noncompliance, and the surrounding environment. Approaches that consider or hint at those topics in various ways include general systems theory, sociotechnical theory, the viable system model, actor network theory, the theory of organizational routines, activity theory, BPM, CSCW, and HCI. The long-term effort of trying to produce a coherent and internally consistent core for the work system perspective is a reminder of the gap between naming possible alternatives and pursuing and articulating those alternatives clearly and in depth.

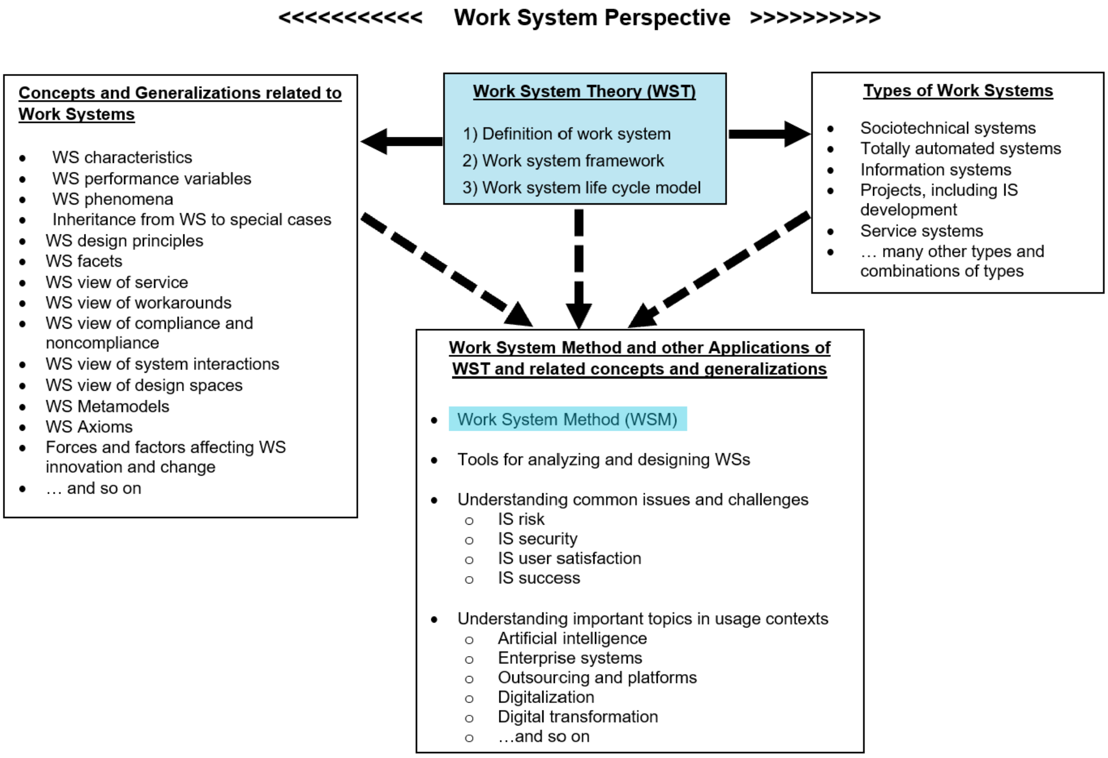

Figure 2: Work system perspective

3.3. A Design Space Accommodating Different Stakeholder Purposes

A key milestone in developing the work system perspective was the visualization of a design space for modeling methods and modeling techniques [8] that accommodates a range of stakeholder purposes, shown as P1 through P7 in Figure 3.

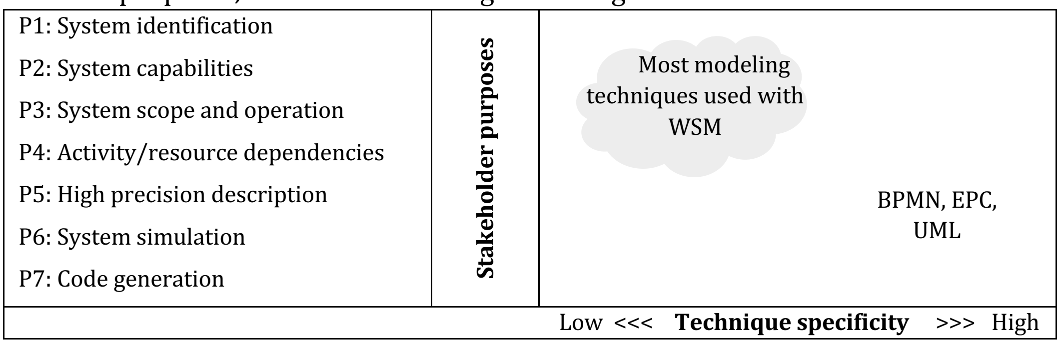

Figure 3: Design space for modeling methods and modeling techniques [8]

Technique specificity is the extent to which a technique defines what to include, what to ignore, and how to proceed. Techniques with low specificity tend to be flexible but may provide too little conceptual or procedural guidance. The reverse applies as well. The design space in Figure 3 resulted from questioning the assumption that a modeling method should have only one modeling technique, modeling language, and modeling procedure. That assumption is too limited for ISE if one assumes that collaboration between business and IT professionals requires different models that address different stakeholder purposes related to the same situation. The related challenge is to produce a systems analysis approach that is coherent, flexible, and respectful of stakeholder interests and training. That goal motivates important aspects of this project's attempt to develop a TFISE.

3.4. Taxonomy of Knowledge Objects

Figure 4 is the third version of a taxonomy of knowledge objects (KOs) that could play a role in a TFISE in conjunction with the idea of a design space for multiple purposes (Figure 3). The taxonomy was developed based on the assumption that science is the creation, evaluation, accumulation, dissemination, synthesis, and prioritization of KOs, including the re-evaluation, improvement, or replacement of existing KOs by other KOs that are more effective within the relevant domain [9]. Data and information can be viewed as KOs, i.e., that non-tacit knowledge is not restricted to abstractions. Generalizations include theories, frameworks, and models, ideas that the taxonomy does not differentiate strictly because related debates absorb attention without contributing significantly to a TFISE

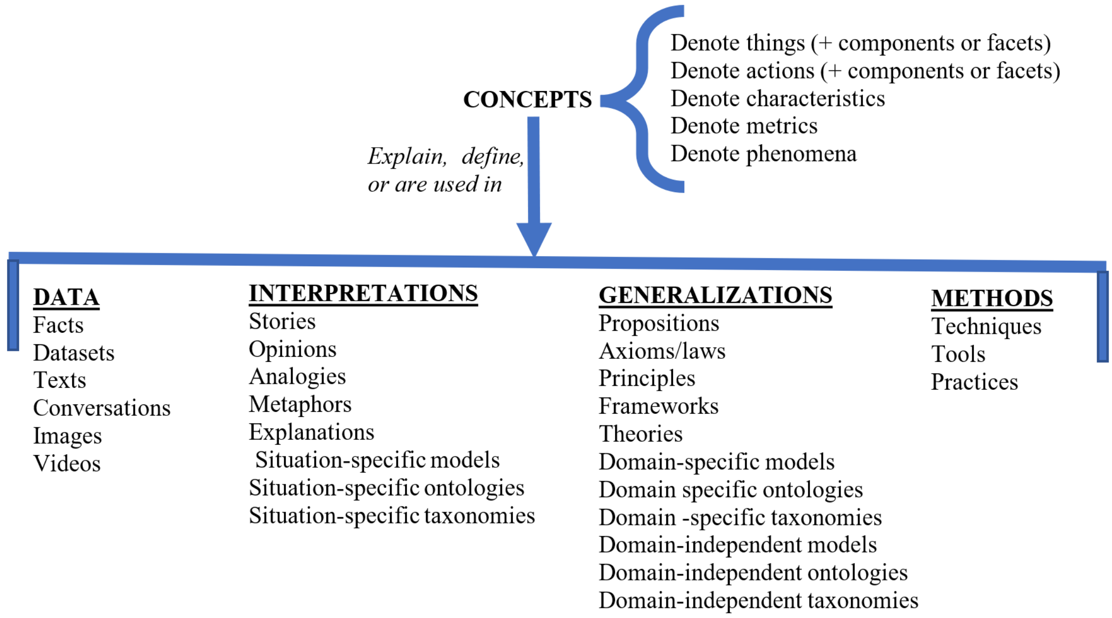

Figure 4: Taxonomy of knowledge objects [9]

3.5. Agent Responsibility Framework

The agent-responsibility (AR) framework (not illustrated) provides a path for describing important aspects of activities in depth. The AR framework is a grid based on assuming that IS usage involves performing one or more of six roles (the horizontal dimension in an illustrated version) related to one or more of 18 facets of work [9] that might be present in an activity (the vertical dimension). The horizontal dimension covers a spectrum from less to more direct involvement in activities: monitoring, providing information, providing capabilities, controlling activities, co-producing activities, or executing activities. The 18 facets include making decisions, communicating, processing information, thinking, performing physical work, interacting socially, and so on. Each facet is associated with many ideas that are relevant to ISE. The facets themselves are not totally independent (e.g., making decisions often involves communication) Combining the AR framework's two dimensions pinpoints design issues, e.g., the extent to which an IS should support or perform specific roles for facets of specific activities. Applications of this framework would focus only on facet-related roles and responsibilities that matter for specific activities.

3.6. A Scaffolding for the Content of a TFISE

Figure 5 represents a possible three-level scaffolding for the content of an TFISE: Level 1 is work systems and special cases such as information systems and projects that inherit work system properties and have other properties. Level 2 is the nine elements of the work system framework. Level 3 is facets of those elements.

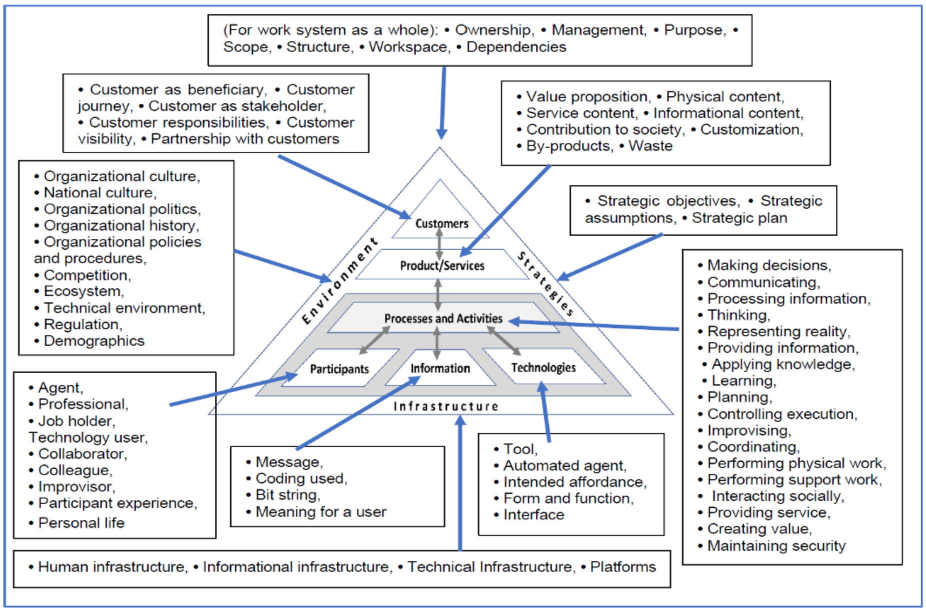

Figure 5: Facets of work systems and of elements of work systems

A proposed or interim TFISE could be organized using a knowledge graph whose nodes start at those three levels and link to other nodes that represent KOs of types in Figure 4. Concepts related to a work system as a whole (scalability, flexibility, resilience, capacity, etc.) are system characteristics that depend on quality and fit of the system's elements. Concepts related to information (precision, age, bias, traceability, etc.) describe informational entities rather than systems as a whole. The rationale for treating some concepts as nodes in a knowledge graph vs. properties of nodes is not yet apparent. An initial rationale for that decision will be part of the creation of a first cut at the TFISE.

4. Next Steps

Producing an initial version of a TFISE calls for proceeding somewhat in the spirit of design science research by aiming to create a first cut TFISE that satisfies criteria mentioned earlier: coherence, usefulness for practitioners, appropriate level of abstraction, sufficient complexity and depth, and relevance to systems with human and/or nonhuman actors. Steps in the project would include compiling a nontrivial set of KOs, organizing those KOs in a knowledge graph, performing iterations of trial usage and evaluation that reveal shortcomings of the overall approach and of its components, and embedding subsets of the TFISE in an organized systems analysis support system that makes KO-based tools and templates available for describing, analyzing, and developing information systems. Interim results from each of the following steps could generate significant value because ISE might produce better results if it had at least the beginnings of a clear theoretical foundation.

Compile a nontrivial set of KOs. This step would use the work system perspective (Figures 1 and 2) and the taxonomy of KOs (Figure 4) to compile a first cut at ideas for inclusion in the TFISE. Those ideas would include concepts (things, activities, characteristics, performance variables, phenomena) related to work systems and important special cases such as information systems and projects; generalizations (including principles, frameworks, models, theories, and so on), and methods (including templates for specific types of queries that are often relevant to systems analysis efforts of both business and IT professionals).

Initial attempts to identify relevant concepts without computerized support seemed tedious but possible to pursue further. A recent exploration of using ChatGPT-4 to generate lists of concepts (e.g., "identify 25 characteristics of information") showed that it could support that effort, but that researchers would have to check that every term makes sense and is categorized appropriately. Experience to date shows that that approach is far less tedious than trying to imagine and compile concept lists for each work system element and for the facets of those elements. Using an LLM to compile generalizations (rather than concepts) would require more supervision due to the inability of LLMs to understand contexts. Despite that, an exploratory effort succeeded in producing a reasonable list of 10 principles that apply to most important information systems. In that exploratory effort, a series of initial prompts asked ChatGPT-4 to produce 25 sentences in each of 20 categories, e.g., "Produce a list of 25 sentences that identify factors that increase the likelihood of major problems or failure in the operation of an information system." Summarization prompts reduced the resulting 500 sentences to 100 sentences, then to 40, and finally to 10 that make sense as principles even though they would seem relatively obvious to an experienced practitioner. Those initial results for both concepts and generalizations show that use of an LLM might facilitate creation of at least parts of an initial version of an TFISE.

Organize relevant KOs in an appropriately structured knowledge graph. This step would organize the KOs as nodes in a knowledge graph based on a hierarchy of concepts related to work systems. Stages in the hierarchy include 1) work systems as a whole, 2) nine elements of the work system framework, 3) facets or components of those elements, 4) concepts, generalizations, and methods that are relevant to entities in each of the first three levels. (An additional layer for sub-facets or subcomponents might be needed in some cases.) Inheritance relationships (from the work system node to nodes for special cases such as information system, project, or IS development project) would be superimposed on top of an initial version that focused on sociotechnical work systems. Advantages and disadvantages of handling inheritance through relationships versus node properties depend on which knowledge graph capabilities are available and convenient to use.

Perform iterations of trial usage and evaluation. This step would extend an initial first cut by looking at how its content might be represented at six different levels of enterprise modeling: enterprise capabilities, work system interactions, work systems, processes within work systems, activities within processes, and automated services requested by activities. Doing that probably would reveal issues that are not obvious in initial thinking about using a knowledge graph as a container for a TFISE.

Embed subsets of the TFISE in support systems for systems analysis. A central goal of producing a TFISE is to facilitate and improve the creation, implementation, operation, and maintenance of information systems and work systems that they support. Achieving that goal conveniently requires linking at least part of the TFISE to support systems for systems analysis. For example, someone trying to analyze a consulting system involving co-production by customers might want to see sample templates for analyzing co-production situations. Someone else might want to see important performance measures related to specific facets of work that are important in a different situation. Someone else might want to look at common facets of the environment to see whether they provide reminders of issues that have not been considered thus far in an analysis. A TFISE would provide greater benefits in those situations if it were integrated with a computerized support system that made it easy to find KOs (concepts, generalizations, and methods) that could be useful or that might otherwise be overlooked or ignored. Competency questions for this type of support system for systems analysis might include "identify important phenomena related to information," "identify quality variables related to communicating (a facet of processes and activities)," or "provide three templates that are relevant to understanding resources used by processes and activities in information systems."

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