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Steven Alter
University of San Francisco, alter@usfca.edu

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System Interaction Theory: Describing Interactions between Work Systems

Steven Alter
University of San Francisco
alter@usfca.edu

Abstract:

Interactions between systems are a necessity, a source of opportunity, and a source of difficulty and complication in building, implementing, and maintaining IT-reliant systems in organizations. This paper presents system interaction theory (SINT), a theory for analysis that covers almost all intentional and unintentional interactions between work systems that may be sociotechnical or totally automated. SINT is a broadly applicable theory that encompasses interactions between the types of systems that are central to the IS discipline. To minimize redundancy, this paper summarizes SINT immediately after introducing the research goal and, thereby, provides a context for the many distinctions and references that follow. A discussion of SINT's domain and scope explains why SINT views interacting entities as work systems rather than as tasks, components, or software modules. The literature review positions SINT in relation to topics under headings that range from general systems theory and computer science to human computer interaction and organization science. Topics in SINT include relevant characteristics of systems and system interactions, purposes and/or causes of system interactions, system interaction patterns, direct effects of system interactions, responses to direct effects, and outcomes related to system interactions. The paper discusses a variety of potential contributions to theory, practice, and research.

Keywords: System Interactions, System Interaction Patterns, Characteristics of Systems, Characteristics of System Interactions, Requirements Engineering, Systems Analysis and Design, General Systems Theory, Organizational Design, Coordination Theory, Work System Theory.

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1 Introduction

System interactions are essential for the operation of any enterprise, organization, or IT-reliant system. The division of labor achieves efficiency, control, and specialization by establishing system interactions. In addition to being essential, however, system interactions also bring significant risks. Regardless of how well an IT-reliant system is constructed, direct and indirect interactions with other systems may degrade that system's performance and may cause inefficiency or even catastrophic failure of that system and other systems. Table 1 identifies examples of system interactions that exhibit different types of issues and management challenges. The proposed theory of system interactions covers this range of situations along with many other situations that Table 1 does not include.

In every example in Table 1, individual and mutual details and characteristics of two interacting systems affected the nature and impacts of interactions between those systems. In turn, in all cases, inadequate or problematic performance resulted that called for system changes, workarounds, or other responses. In all cases, understanding the situation required focusing on more than a technical interface or a task interaction. Many other examples could have been cited, such as Volkswagen's programming its engines to generate misleading data for emissions testing systems (Ewing & Boudette, 2017), Uber's thwarting local regulators by making sure they could not see available cars (della Cava, 2017), and the U.S. Government's disabling a link between its tax system and a widely used college financial aid system (Dynarski, 2017).

The need to go beyond analyzing or evaluating systems in isolation. The examples in Table 1 show why the analysis, design, and evaluation of systems in organizations needs to look beyond internal system operations that convert specific inputs into specific outputs. Systems theorists such as Ackoff (1994) and Checkland (1999) observe that systems typically exist to serve other systems and that understanding or analyzing a system requires understanding whatever systems are being served and how those systems are being served. A thorough analysis needs to go further by considering planned and unplanned interactions with other systems regardless of whether they serve or are served by a focal system of primary interest. The many types of interactions between systems range from repetitive interactions such as supplier-customer transactions to transient interactions related to mishaps or malicious actions. A thorough understanding of system interactions needs to include indirect impacts such as effects of inconsistent goals, inconsistent standards, and inconsistent treatment of personnel. It also needs to consider direct and indirect impacts when other entities perform unexpectedly or inadequately. Thus, analysis, design, and evaluation efforts should include organized attention to system interactions while also continuing to focus on systems in isolation and on the surrounding context in general.

Impact of trends toward digitalization. A deep understanding of system interactions is increasingly important in today's increasingly digitalized business world. That world features strong trends toward outsourcing, interorganizational systems, complex supply networks, business ecosystems, operation through service-level agreements, partial or complete automation of knowledge work, and automated control or monitoring of many work environments. We cannot fully understand these environments by focusing solely on individual tasks or business processes that operate in isolation in departments or enterprises. As work is reconfigured, subdivided, distributed, outsourced, and automated, we need to increasingly essential to consider system interactions through which distributed work is coordinated and executed. Research has described configurations of increasingly distributed design, production, sales, and support systems in many ways, such as value constellations (Normann & Ramirez, 1994), as systems of systems (Boardman & Sauser, 2006) that may interact in productive or counterproductive ways, as coalitions of systems (Greenwood & Sommerville, 2011), as organizational ecosystems (Mars et al., 2012), and as new types of sociotechnical systems that cross organizations (Winter, Berente, Howison, & Butler, 2014). Overall, trends toward digitalization and toward new forms of coordinated activity at many levels call for increased attention to intentional and unintentional interactions between systems.

Addressing gaps in knowledge related to system interactions. A genuinely useful theory of system interactions should address significant gaps in concepts, tools, and methods related to the treatment of system interactions. Current views of interactions focus on particular types of interactions between certain types of entities but, in combination, address system interactions in an incomplete and disjointed manner. One can see aspects of the gap in current knowledge in the literatures of systems analysis and design (SA&D), requirements engineering, human-computer interaction, computer science, and organization studies. Each of those areas provides approaches to interactions that focus on some phenomena and ignore other phenomena that a theory of system interactions should cover. A theory of system interactions should provide a more inclusive and more integrated way to organize and consolidate concepts and results from many existing ways of thinking about interactions.

Table 1. Examples of problematic system interactions

Problematic interaction between two work systems	Example
Work systems' operating at cross purposes	**Corporate management system and corporate safety system**. A corporate management system punishes non-compliance with rules and expectations that undermines a system for reporting safety-related incidents. (Naveh & Katz-Navon, 2014)
Overlapping responsibilities in multiple work systems	**Medical treatment system and data collection system**. Some doctors and patients believe that data entry by doctors during patient visits diminishes the quantity and quality of time doctors can spend interacting directly with patients. (Lovett, 2014)
Coding of information in one system is inconsistent with coding of the same information in the other system	**Decision support system and data system**. A pilot of an AI-based medical decision support system used a major hospital's old electronic medical records (EMR) system and could not operate using data from the hospital's new EMR system. More generally, "there's no standard way to record a heart rate, a blood-glucose value, or temperature measured at the bedside." (Hernandez, 2017)
Mutual interference when two work systems use the same infrastructure technology	**Two independent information systems**. Sixty-nine percent of respondents to a survey about corporate cloud usage were "aware of the 'noisy neighbor problem', which happens when a cloud infrastructure tenant hogs resources and negatively impacts the performance of other users." (Kontzer, 2016)
Differing priorities in two work systems makes the product of one less useful for the other	**Software development system and software maintenance system**. A traditional disconnect between priorities of software development groups and priorities of software maintenance groups exacerbates maintenance challenges. A response is the trend toward DevOps, which asks development groups to maintain what they build.
Problems in one work system degrade efficiency in another	**Shipping system and unloading system**. The bankruptcy of the world's seventh largest shipping line left ships sitting at anchor for days because it could not pay port fees to unload merchandise, which resulted in lost work by dock workers and supply chain disruptions. (Stevens, 2016)
Activities in one work system cause accidents in another	**Driving system and communication system**. "Every day in the United States, over 8 people are killed and 1,161 injured in crashes that are reported to involve a distracted driver", and "Distracted driving activities include things like using a cell phone, texting, and eating" (Centers for Disease Control and Prevention, 2016).
Faulty handoffs between work systems cause errors	**Supplier and customer work systems**. In nine pediatric residency programs, moving to standardized handoffs between medical teams "was associated with a 23% relative reduction in the incidence of preventable adverse events." (Starrer et al., 2014)
Faulty infrastructure maintenance system causes outage in another system	**Flight system and IT infrastructure**. Delta Air Lines flights were grounded for at least six hours" "by a global computer system outage, causing large-scale cancellations and stranding hundreds of thousands of passengers…. The problem was a failure overnight in a piece of equipment known as switchgear that affected only Delta." (Isidore, Mullen, & Sutton, 2016)
Operational system hides rogue behavior from inadequate control system	**Sales system and internal control system**. "For years, Wells Fargo employees secretly issued credit cards without a customer's consent. … They set up sham accounts that customers learned about only after they started accumulating fees…. Federal banking regulators said the practices…reflected serious flaws in the internal culture and oversight at Wells Fargo, one of the nation's largest banks." (Corkery, 2016)
A vendor's data collection constitutes surveillance of the customer's environment	**Lighting system and data collection system**. "While a 'smart' lighting system promises to adapt to an owner's preferences or help the environment by lowering electricity bills, it also provides a company a permanent foothold in a person's home from which he can be monitored". (Silverman, 2016). Also see Zuboff (2015)
One system intentionally attacks another	**Domain server system and attacker**. "Someone took down numerous popular websites in a massive distributed denial-of-service (DDoS) attack against the domain name provider Dyn. DDoS attacks are neither new nor sophisticated. The attacker sends a massive amount of traffic, causing the victim's system to slow to a crawl and eventually crash." (Schneider, 2016)

A broadly applicable theory of system interactions should cover interactions between sociotechnical systems and/or totally automated systems. A sociotechnical work system contains human participants who perform activities in the work system. In contrast, machines perform all activities in a totally automated work system, and some of these machines may perform physical work and may or may not be controlled by computers. A theory of system interactions should be equally relevant to interactions between components of those systems that can be viewed as systems in their own right. In sociotechnical systems, division of labor involves defining tasks, assigning tasks to people and/or machines, and making sure that the various subsystems interact in a way that achieves the larger system's goals. A sociotechnical system depends on the extent to which its various subsystems interact efficiently and effectively. Totally automated systems such as totally automated information systems express division of labor as assignment of tasks to separate modules with particular responsibilities and that operate when triggered by particular conditions or inputs. The operation of the entire system depends on interactions between its subsystems.

Covering both sociotechnical and totally automated systems with one theory requires ideas from a range of disciplines that study different types of tasks, processes, and systems through which current organizations operate. Examples of relevant disciplines include:

- Computer science, which brings concepts related to interface design, service orientation (in a technical sense), modularity, and cohesion and coupling of software modules.
- Organization science, whose content includes task interdependence, organizational routines, coordination theory, and impacts of loose and tight coupling in organizations.
- Systems analysis and design, which concerns analyzing and designing systems but generally treats system interactions as interactions between hardware/software entities.

1.1 Goal

This paper presents a theory of system interactions that addresses circumstances and issues that are relevant for researchers and practitioners interested in identifying, describing, analyzing, and designing many different types of system interactions. System interaction theory (SINT)[1] encompasses many types of interactions between work systems rather than just between objects, people, tasks, or software modules.

SINT's goal is to support describing, analyzing, designing, anticipating, and evaluating interactions between IT-reliant work systems including information systems. SINT is potentially valuable to managers, work system participants, system developers, and researchers. Its potential value comes from the non-trivial and frequently surprising nature of system interactions, which often involve much more than task interactions, interpersonal interactions, or software interactions viewed in isolation. SINT is relevant to the frequent occurrence of both beneficial and necessary system interactions on the one hand and system conflicts and inefficient or disastrous system interactions on the other.

This paper addresses the following research goal:

RG: Specify a theory of system interactions that covers most common types of intentional and unintentional interactions between work systems. The theory should encompass the main interaction-related topics emphasized in the existing literature of disparate disciplines that are relevant to business and computing. More important, it should be useful in supporting the

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[1] This paper refers to "a theory of system interactions" when speaking generally about possible theories of system interactions. It refers to "system interaction theory" (SINT) when discussing the specific theory that it proposes. The acronym SINT was chosen to minimize confusion related to previously existing acronyms. Prior use of the terms "social interaction theory" (SIT) and "symbolic interaction theory" ruled out the use of SIT as an acronym for system interaction theory. (Social interaction theory, also called theory of social interaction, seems to be a general compilation of knowledge about social interactions and their impacts. That term has been cited many times in relation to topics such as learning in educational settings, relationships in medical settings, and relationships in virtual teams. Symbolic interaction theory is used in sociology to focus on subjective meanings that people impose on objects, events, and behaviors.)

A Google Scholar search for "system interaction theory" found no published papers specifically about that topic even though papers mentioned it several times as a future possibility. A search for "theory of system interaction" found one computer science theory about interactions between software systems composed of interfaces and components (Broy, 2006). A broader Google Scholar search for "interaction theory" found situation-specific theories including symbolic interaction theory, vigilant interaction theory, personality systems interaction theory, parent-child interaction theory, cross-cultural interaction theory, and other theories from the natural sciences such as weak interaction theory and strong interaction theory from physics, air-sea interaction theory, configuration-interaction theory, and so on.

analysis and design of work systems and the development of new understandings, concepts, tools, and methods related to interactions between work systems.

I pursued this research goal because I believed that research in that direction could advance the current understanding of system interactions, especially since many of the ideas in the existing literature are basically about interactions between components, tasks, or people rather than interactions between systems. I also believed that pursuing this research goal would likely produce more broadly useful results than I could produce through a narrower research goal about only a small part of the interaction landscape. A personal impetus was to address a conceptual gap in a work system metamodel (Alter, 2016a; Alter & Recker, 2017) that reinterprets every element of the work system framework (Figure 1) in a more detailed way in order to support collaboration between business and IT professionals. One of many relationships in the metamodel says that zero or more “other work systems” (possibly including customer work systems) may interact with a focal work system that is being described or analyzed. In essence, SINT elaborates on the meaning and various guises of that single relationship.

1.2 Organization

This paper explains what SINT is about, how it combines and extends a variety of topics that stem from disparate disciplines, and how one might use it in research and practice. It is organized as follows: Section 2 presents an overview of SINT based largely on a summary diagram (Figure 2) and a more detailed diagram (Figure 3). Section 3 introduces a literature review most of which is deferred to the Appendix because many readers will want to move directly to the detailed explanation of SINT in Section 4. Section 5 discusses the paper’s contributions and other conclusions. The Appendix summarizes relationships between SINT and ideas from various subdisciplines that provide concepts for describing and designing interactions between various types of entities such as tasks or software modules but not necessarily interactions between systems.

SINT was developed iteratively by building on knowledge of IS theory, awareness of a very large number of IS examples, and literature searches to learn more about what seemed to be gaps in knowledge about system interactions. This approach is consistent with general discussions of theory development and production of conceptual papers that have appeared in leading IS journals such as *JAIS* (Hirschheim, 2008; Weber, 2012), *EJIS* (Rowe, 2012) and *MIS Quarterly* (Rivard, 2014) and also in other leading journals such as the *Academy of Management Review* (Weick 1999; Corley & Gioia 2011). Moreover, it is consistent with Grover and Lyytinen’s (2015) comments about why methodological scripts should not be expected in theory-development research.

2 Overview of System Interaction Theory

This section’s overview of SINT identifies the domain that SINT covers, defines system interaction, and identifies the types of system interactions included in SINT. It summarizes the structure of SINT and shows some of the relevant vocabulary without explaining the various characteristics, causes, patterns, effects, responses, and outcomes that will be covered in the complete explanation in Section 4. To minimize redundancy in discussing a large number of topics, it presents SINT before the literature review that Section 3 summarizes and the Appendix discusses in detail.

2.1 Systems at the Core of the IS Discipline

SINT assumes that the IS discipline is fundamentally about IT-reliant work systems (Alter, 2003). Research in the sociotechnical literature has discussed the idea of work systems for decades (e.g., Trist, 1981; Sinha & Van de Ven, 2005). That term appeared in the first edition of *MIS Quarterly* (Bostrom & Heinen, 1977). More recently, Alter (2013) described it as the basis of the work system theory, which covers both sociotechnical and totally automated work systems.

Work system. 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 specific internal and/or external customers (Alter, 2013, 2015). Most significant work systems use IT extensively and can be described as IT reliant. The work system framework (Figure 1) identifies nine elements of even a basic understanding of a work system's form, function, and environment during a period when it is relatively stable even though incremental changes may occur during that period.

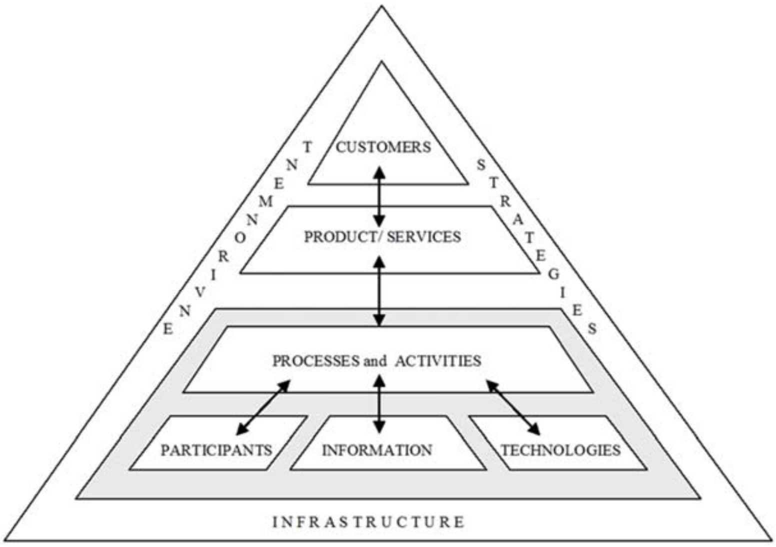


Figure 1. Work System Framework (Alter, 2006, 2013)

Enterprises that grow beyond a largely improvised start-up phase can be viewed as operating based on the internal activities and interactions of multiple work systems. For example, typical business enterprises contain work systems that procure materials from suppliers, produce products, deliver products, find customers, create financial reports, hire employees, coordinate work across departments, and perform many other functions. Notice also that supply chains can be viewed as sets of interacting work systems that extend across different enterprises.

Work system interactions are important for several reasons. First, a comprehensive view of an enterprise involves much more than the operation of its work systems in isolation. Second, the analysis, design, and evaluation of any work system should consider the extent to which its interactions with other work systems contribute to its success and to the success of those work systems.

Sociotechnical work systems *and* totally automated work systems. Ongoing trends in the automation of work and creation of new, highly computerized work practices imply that IS researchers need to recognize that many sociotechnical systems in the purview of the IS discipline may be transformed into partially or totally automated systems that will still be of interest. Covering both types of systems could present a challenge for a theory because people often describe sociotechnical versus totally automated systems quite differently. For example, a book on principles for designing computer systems says, “A system is a set of interconnected components that has an expected behavior observed at the interface with its environment” (Saltzer & Kaashoek, 2009, p. 8). The concepts of expected behavior and behavior observed at the interface are quite useful for understanding computer systems that are designed and engineered to meet specific requirements. Those ideas do not apply as well to sociotechnical work systems whose human participants may or may not behave exactly as a designer anticipated. For example, the widely cited sociotechnical principle of minimum critical specification (Cherns, 1976) says that “no more should be specified than what is absolutely essential” because systems with human participants often are highly adaptive and tend to evolve over time.

Relevance to information systems. An information system can be viewed as a work system all of whose activities focus on processing (capturing, storing, retrieving, transmitting, manipulating, and/or displaying) information (Alter, 2008). Information systems may be sociotechnical (e.g., an accounting system whose human participants use IT to produce month-end financial closings) and may also be totally automated (e.g., search systems, GPS systems, biometric identification systems, etc.). Recognizing that information systems may be sociotechnical or totally automated bypasses discussions about whether information systems and IS research are or are not sociotechnical (e.g., Sarker, Chatterjee, & Xiao, 2013). Notice, however, that the whole idea that the IS discipline is fundamentally about IT-reliant work systems may be controversial because it calls for looking more broadly than Benbasat and Zmud’s (2003, p. 187) nomological net around the IT artifact.

2.2 System Interactions

An interaction is a specific occurrence, impact, or influence whereby one entity affects another (a one-way interaction) or two or more entities affect one another (two-way or multi-directional interaction). By that definition, many interactions that occur are beyond the scope of both SINT and the IS discipline in general, such as a collision between two physical objects or an informal conversation between two people. SINT focuses on interactions between work systems and, therefore, applies to information systems, which are a special case of work system. SINT covers interactions between people, objects, or tasks only in the context of interacting work systems.

The concept of system interaction. The term system interaction denotes a one-way, two-way, or multi-directional interaction that involves two or more work systems, each of which may be sociotechnical or totally automated. Thus, SINT covers three types of situations for system interactions:

1. Interactions between two sociotechnical work systems (e.g., supplier/customer relationships and interactions related to coordinated use of shared resources).
2. Interactions between a sociotechnical work system and a totally automated work system (e.g., a company's purchasing department placing orders through a supplier's ecommerce portal where the purchasing work system is sociotechnical while the portal is totally automated).
3. Interactions between two totally automated work systems (e.g., as in service-oriented computing). Here, the interacting hardware/software systems can be viewed as automated work systems because each system performs definable activities using automated means.

System interactions in the context of work systems. Focusing strictly on interactions between work systems does not imply that interactions between people or objects or tasks are irrelevant. For example, consider an interaction between a sales agent (participating in a sales work system) and a purchasing agent (participating in a purchasing work system). While SINT needs to recognize aspects of interpersonal communication, its system perspective encompasses a much broader view based on work system concepts such as the following:

- Information: what information in the two systems is relevant to the interaction?
- Technologies: what technologies in the two work systems support or affect the interaction?
- Participants: how do the skills, knowledge, motives, and cultural background of the participants of each work system affect the system interaction?
- Processes and activities: what is the expectation in each work system concerning the process of performing the interaction and/or the methods for assuring that inappropriate interactions are avoided or minimized?
- Product/services: what are the possible outcomes of the interaction in relation to the internal efficiency and product/services produced by the interacting systems?

Range of system interaction situations. SINT covers a broad range of system interaction situations that the system interactions in Table 1 exemplify. Within the domain of SINT:

- System interactions may be intentional or unintentional.
- System interactions may be instantaneous or may occur over a lengthy timespan.
- System interactions may be direct or indirect.
- System interactions may occur through physical contact, material transfers, formal or informal communication, induced effects, or through other means.
- System interactions may be one-way, bilateral, or multi-directional.
- System interactions may result from planned or unplanned activities and/or from expected, unexpected, or accidental situations or occurrences.

This broad range of system interactions implies that SINT covers more situations than most discussions of interactions that occur in the literature of specific disciplines, as the literature review in the Appendix notes.

2.3 System Interaction Theory

Figure 2 summarizes SINT, which represents the interacting systems in the triangular form of the work system framework (Figure 1) to accentuate the system nature of the interacting entities. The arrows in the diagram summarize the general sequence through which system interactions occur and have effects and impacts in the world.

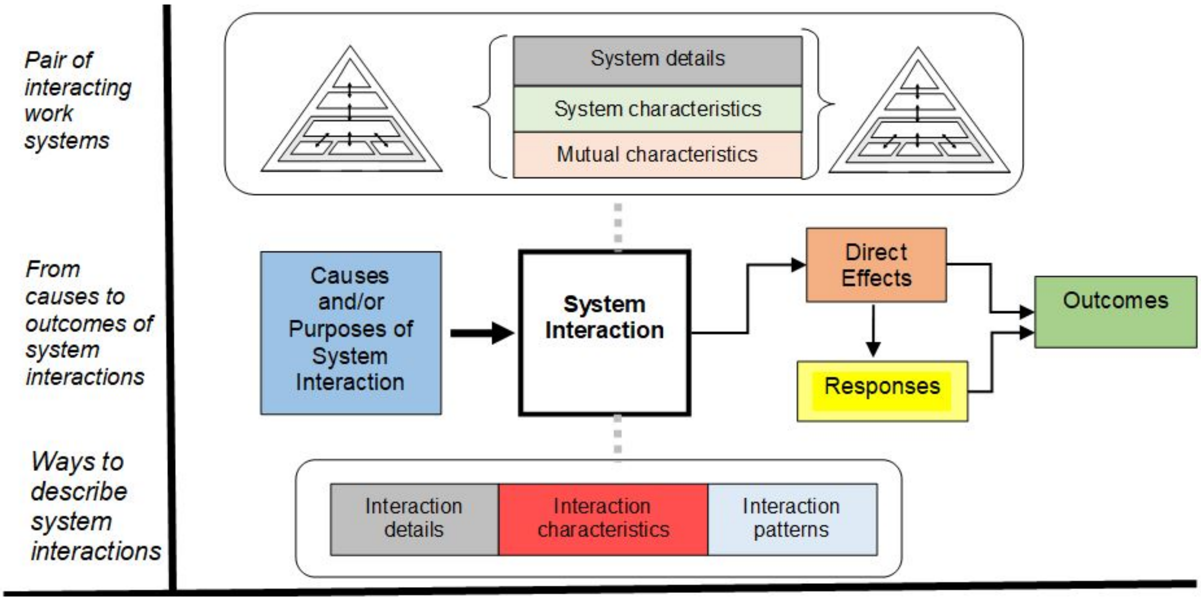
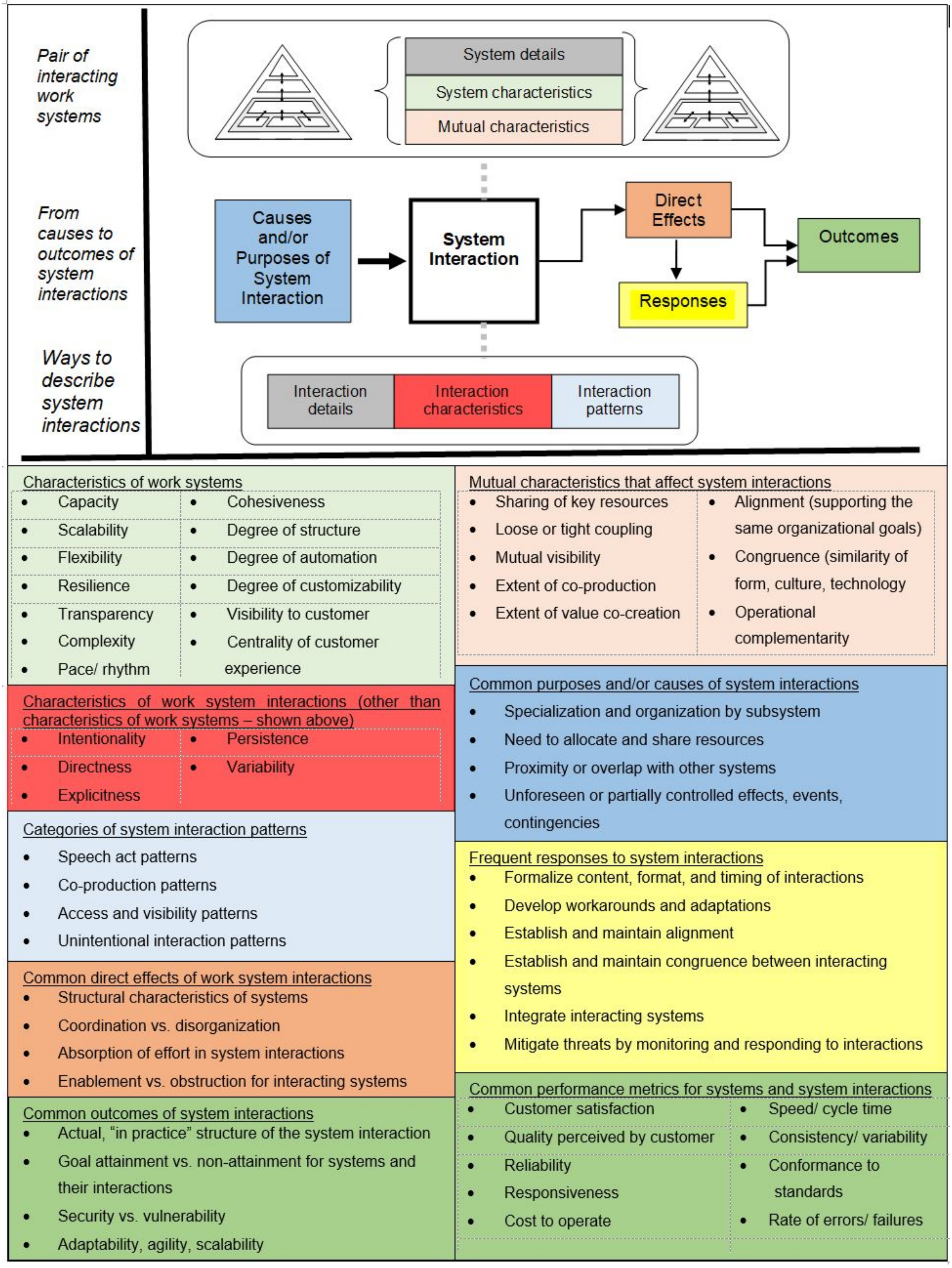


Figure 2. System Interaction Theory without Supporting Concepts Shown in Figure 3

Figure 2 says the following:

- SINT's unit of analysis is an interaction between two work systems. The individual characteristics, mutual characteristics, and operational details of the work systems may affect various aspects of the system interaction and its direct and indirect effects.
- System interactions have a variety of purposes and/or causes.
- System interactions may have a variety of important characteristics and details.
- Many system interactions can be described using one or more of a series of system interaction patterns.
- The direct effects of system interactions often lead to responses that affect the outcomes of the system interactions.
- System interactions have different types of outcomes. The outcomes often can be evaluated in terms of performance metrics for the interacting systems and for the interaction itself.
- Overall, the outcomes of system interactions result from the interplay of details and individual and mutual characteristics of the interacting systems, causes and/or purposes of the system interaction, details and characteristics of the system interaction itself, direct effects of the interaction, and responses to the interaction.

Figure 3 is an extended version of Figure 2. It is designed to help practitioners, researchers, and possibly tool makers recognize and apply a large number of ideas that are important for describing and understanding many system interactions. The top part of Figure 3 repeats Figure 2. The bottom part of Figure 3 identifies concepts that one can use when thinking about different parts of the diagram. The lists are color coded to indicate their relationship to one or more of the components of the diagram at the top of the figure. Section 4 discusses each of the ideas in the diagram and all of the related terms listed in Figure 3.



Characteristics of work systems

- Capacity
- Scalability
- Flexibility
- Resilience
- Transparency
- Complexity
- Pace/ rhythm
- Cohesiveness
- Degree of structure
- Degree of automation
- Degree of customizability
- Visibility to customer
- Centrality of customer experience

Characteristics of work system interactions (other than characteristics of work systems – shown above)

- Intentionality
- Directness
- Explicitness
- Persistence
- Variability

Categories of system interaction patterns

- Speech act patterns
- Co-production patterns
- Access and visibility patterns
- Unintentional interaction patterns

Common direct effects of work system interactions

- Structural characteristics of systems
- Coordination vs. disorganization
- Absorption of effort in system interactions
- Enablement vs. obstruction for interacting systems

Common outcomes of system interactions

- Actual, "in practice" structure of the system interaction
- Goal attainment vs. non-attainment for systems and their interactions
- Security vs. vulnerability
- Adaptability, agility, scalability

Mutual characteristics that affect system interactions

- Sharing of key resources
- Loose or tight coupling
- Mutual visibility
- Extent of co-production
- Extent of value co-creation
- Alignment (supporting the same organizational goals)
- Congruence (similarity of form, culture, technology
- Operational complementarity

Common purposes and/or causes of system interactions

- Specialization and organization by subsystem
- Need to allocate and share resources
- Proximity or overlap with other systems
- Unforeseen or partially controlled effects, events, contingencies

Frequent responses to system interactions

- Formalize content, format, and timing of interactions
- Develop workarounds and adaptations
- Establish and maintain alignment
- Establish and maintain congruence between interacting systems
- Integrate interacting systems
- Mitigate threats by monitoring and responding to interactions

Common performance metrics for systems and system interactions

- Customer satisfaction
- Quality perceived by customer
- Reliability
- Responsiveness
- Cost to operate
- Speed/ cycle time
- Consistency/ variability
- Conformance to standards
- Rate of errors/ failures

Figure 3. System Interaction Theory, Including Supporting Concepts (Note Color Coding)

The diagram and concepts in Figure 3 can be translated into checklists and other tools for visualizing system interactions and for analyzing and designing systems that might be involved in system interactions. For example, the lists could help in considering the purpose or cause of the system interaction, the individual and mutual system characteristics that might affect the system interaction, and the possible direct effects, responses, and ultimate outcomes. The underlying assumption is that much of SINT's practical value is in organizing the concepts listed in Figure 3. While certainly open to improvement, those concepts provide an initial vocabulary for in-depth discussion of specific system interactions and could be used extensively in methods and tools for understanding, analyzing, designing, and evaluating system interactions.

SINT as a theory. SINT is a theory for analysis[2] (Gregor, 2006) that focuses on identifying system and interaction characteristics, purposes and/or causes, direct effects, responses, and outcomes that are relevant in many situations. That type of map addresses several voids. First, it provides a basis for new SA&D tools and methods. In addition, it potentially supports further theorizing related to system interactions in general and to interaction-related topics such as dependencies, coordination, alignment, interoperability, goal attainment, system vulnerability, adaptability, agility, and scalability.

Inspiration for the representation in Figures 2 and 3. The general format of providing a diagram plus lists of relevant concepts was inspired by Orton and Weick's (1990, Figure 1, p. 217) reconceptualization of loosely coupled systems.[3]. Instead of trying to articulate a unidimensional view of systems interactions (e.g., seeing system interactions as fundamentally about supplier-customer transactions or about treatment of dependencies or about coincidences), Figure 2 takes a broad view of system interactions that covers all of those possibilities and tries to serve the same dialectical purpose as the five voices approach in Orton and Weick (1990)[4]. The lists at the bottom of Figure 3 identify frequently relevant concepts in each of those areas and, thereby, provide potential guidance for analyzing, designing, or evaluating most interactions between work systems. Other ideas that contributed to SINT include preliminary ideas about system interactions in Alter (2010) and a series of work system characteristics and design spaces described in Alter (2006).

3 Introduction to Literature Review

This section serves as a brief introduction to a full literature review in the Appendix. The literature review appears in the Appendix because many readers are primarily interested in what SINT says rather than how it is somewhat related to diverse topics from many different disciplines and subdisciplines

3.1 Background

The concept of interaction is important in disciplines that range from computer science and systems analysis and design (SA&D) to organization science and communication studies. Given the widespread importance of interactions and the many ways in which different disciplines claim *system* as a

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[2] Gregor (2006) identifies five different types of theory, theories for analysis (I), for explanation (II), for prediction (III), for explanation and prediction (IV), and for design and action (V). That paper is a widely cited contribution to unresolved controversies about the nature of theories and theorizing in the IS discipline and its reference disciplines (e.g., Markus & Robey, 1988; Sutton & Staw, 1995; Weick, 1995; Gregor, 2006; Weber, 2012; Straub, 2012; Avison & Malaurent, 2014; Niederman & March, 2014; Grover & Lyytinen, 2015). The notion of theory underlying SINT combines aspects of the second of two approaches to theory mentioned in Colquitt and Zapata-Phelan (2007, p. 1281). That approach defines theory in terms of "narratives and accounts". Schatzki (2001, pp. 12-13) expresses a similar view in a book on practice theory in saying that: "theory means, simply, general and abstract account. A theory of X is a general and abstract account of X. [Theories include] typologies of social phenomena; models of social affairs; accounts of what social things (e.g., practices, institutions) are; conceptual frameworks developed expressly for depicting sociality; and descriptions of social life—so long as they are couched in general, abstract terms.".

[3] That paper (in *The Academy of Management Review*) starts by noting that "diverse applications of the concept of loose coupling are embodied in five recurring voices that focus separately on causation, typology, effects, compensations, and outcomes. Each has a tendency to drift away from a dialectical interpretation of loose coupling toward a unidimensional interpretation of loose coupling". (p. 203). The dialectical approach represented in Figure 1 in Orton and Weick (1990) basically says that various causes of loose coupling lead to various types of loose coupling, which, in turn, are related to various direct effects of loose coupling and various compensations for issues that result from loose coupling. Various causes, types, and effects include topics such as causal indeterminacy, fragmented internal or external environment, hierarchical levels, modularity, and requisite variety. The organizational outcomes of loose coupling include persistence, buffering, adaptability, satisfaction, and effectiveness.

[4] Most of Orton and Weick's (1990) five voices appear in the diagram in Figure 2 in a slightly different form: causation becomes causes and/or purposes, typology becomes characteristics and details, effects becomes direct effects, and compensations becomes responses, but outcomes remains as outcomes.

fundamental concept, surprisingly little has been published about interactions that are specifically interactions between systems. Instead, the existing literature related to interactions focuses on more limited topics such as interactions between people, tasks, or software modules.

Searches performed while preparing this paper found many papers related to interactions between tasks, people, or software modules but little specifically that involved interactions between systems that could be sociotechnical. A Google Scholar search on “system interaction” returned 50,300 hits, many of which concerned user-system interaction, human-system interaction, or situation-specific topics such as energy system interaction and nervous system interaction. More limited Google Scholar searches on “work system interaction”, “activity system interaction”, and “sociotechnical system interaction” returned only 18, 17, and eight hits, respectively. Many of those hits were not relevant at all (e.g., one that reported the phrase “how they work system interaction functions).

4 Concepts in System Interaction Theory

This section looks at each part of SINT in turn while focusing on the concepts in the lists in Figure 3. As mentioned above, those lists are essential for achieving SINT’s goal of organizing concepts in a way that can help practitioners and researchers understand interactions between work systems.

4.1 Individual and Mutual Characteristics of Interacting Systems

SINT’s unit of analysis is an interaction between two work systems. Figures 2 and 3 represent the interacting systems in the triangular form of the work system framework to accentuate their system nature. Each interacting work system has its own system details and system characteristics that are relevant to the details and outcomes of an interaction between those two work systems. The interacting work systems also have mutual characteristics that are often relevant. Mutual characteristics are characteristics that are meaningful in relation to a pair of things rather than individual things (as explained by the Bunge-Weber-Wand ontology summarized in Green & Rosemann, 2000).

Table 2 identifies commonly significant characteristics of work systems and provides a brief example that illustrates why those characteristics could have a significant impact on direct or indirect interactions between work systems. Table 3 does the same for commonly significant mutual characteristics of pairs of work systems. Tables 3 and 4 refer to the interacting work systems as X and Y in order to minimize verbiage. A more extensive discussion of system details, characteristics of individual systems, and mutual characteristics of interacting systems affect system interactions could fill an entire paper.

The form of the examples in both Table 2 and Table 3 affords relatively easy conversion into research questions related to impacts of specific characteristics on system interactions. For example, a work system’s interactions with other work systems sometimes restrict its flexibility. The nature of those restrictions could be an interesting research topic, especially with ongoing trends toward increasing outsourcing and automation.

Table 2. Situations that Illustrate the Impacts of Characteristics of Individual Work Systems on Direct or Indirect System Interactions

Characteristic	**Situation in which the characteristic matters for a system interaction** (Interacting work systems are named X and Y to minimize verbiage in the table)
Capacity	A mismatch in capacity between X and Y may have a negative effect on the performance of either or both systems. If X’s capacity is much larger than Y’s capacity, then X may be idle or partially idle while Y uses previously unused outputs of X that are still available. Conversely, insufficient capacity in X will cause idleness in Y.
Scalability	If X and Y are subsystems of a sequential production system, increasing the scale of either system affects the larger production system efficiently only if the changes are balanced.
Flexibility	Flexibility in X or Y may be limited by restrictions or standards in the other system.
Resilience	The ability of Y to recover quickly from a mishap in X may depend on the resilience of X.
Transparency	Greater transparency in both systems may be useful if something goes wrong in their interaction.
Complexity	Greater complexity in either system may hinder one system from interacting efficiently with the other and may make it more difficult to respond to mishaps in their interactions.

Table 2. Situations that Illustrate the Impacts of Characteristics of Individual Work Systems on Direct or Indirect System Interactions

Pace	A mismatch in the pace of X and Y might result in buildup of a queue or other excess of resources in front of Y or could deprive Y of needed inputs from X, thereby preventing it from operating well or even operating at all.
Rhythm	Synchronized rhythms in X and Y may make their interactions more predictable and efficient. Poorly synchronized rhythms (e.g., X ordering once a week on Tuesday and Y starting production runs on Monday morning) may reduce responsiveness and may generate unnecessary delays.
Cohesiveness	If X and Y have greater cohesiveness, then it may be easier to diagnose faulty interactions related to internal details of either system.
Degree of structure	The extent to which processes and activities in X are structured may have positive or negative impacts on its ability to respond to unexpected conditions or requirements in Y and vice versa.
Degree of automation	The extent to which X is automated may have positive or negative impacts on its ability to adjust to changing demands from Y and vice versa.
Degree of customizability	Increasing the customizability of X's product/services may increase the amount of interaction that is necessary between X and Y and vice versa.
Visibility to customer	Increasing Y's visibility of X's process of producing product/services for Y may have positive or negative effects on the cost of operating X and/or Y.
Centrality of customer experience	Greater emphasis in X on the centrality of the customer experience in Y may have important impacts on the operation of X (in the extent to which it uses resources to pay attention to Y) and on customer satisfaction in Y (in the extent to which its needs are addressed).

Table 3. Situations that Involve Mutual Characteristics of Interacting Work Systems

Mutual characteristic	**Situation in which a mutual characteristic matters for a system interaction**
Sharing of key resources	Reliance on shared resources may minimize unnecessary investment in those resources. To the contrary, however, it may interfere with efficient operation of either system as when individuals who perform activities in both systems cannot perform those activities simultaneously or when both systems cannot use the same material resources simultaneously.
Loose or tight coupling	Tight coupling between work systems X and Y may increase the likelihood that errors in X will cascade into additional errors or inefficiencies in Y. Loose coupling between X and Y may minimize communication between X and Y and may delay the process by which important changes, errors, or inefficiencies in X affect Y's operation. (e.g., see Weick, 1976; Perrow, 1984; Orton & Weick, 1990)
Mutual visibility	Greater mutual visibility may increase mutual empathy, thereby facilitating coordination. Lower mutual visibility may increase efficiency by focusing each work system's attention on its own specialized responsibilities.
Extent of co-production	Co-production is a customer's direct involvement in activities in a supplier's production process. Some definitions of service (e.g., Fitzsimmons & Fitzsimmons, 2006; Sampson & Froehle, 2006) say that services necessarily involve interactions and, therefore, are co-produced at least to some extent. More extensive co-production between a supplier and customer may reduce the efficiency of production but may increase the likelihood of addressing customer needs.
Extent of value co-creation	Value co-creation is a provider's direct involvement in a customer's value creating work systems. The marketing literature often says that customers create value for themselves (Vargo & Lusch, 2008, 2016) but also contains debates about the extent to which value co-creation is optional (Grönroos, 2008, 2011). More extensive value co-creation tends to increase costs for providers by absorbing time and attention during their production processes. Less extensive value co-creation tends to provide less support for a customer's value-creating work systems.
Alignment	Alignment between work systems X and Y describes the extent to which they serve the same goals (usually goals of a system served by both X and Y). It is possible for X and Y to serve goals of a larger system in completely different ways. For example, X may contribute largely to maximizing internal productivity in the larger system, whereas Y may focus on customer satisfaction and/or conformance to regulatory requirements.

Table 3. Situations that Involve Mutual Characteristics of Interacting Work Systems

Congruence	Congruence of work systems X and Y refers to the similarity of their corresponding components such as technologies and information in terms of form, logic, and details Congruence between two work systems tends to facilitate their interactions but is not necessary if they serve highly independent roles in the larger system. For example, congruence between a sales system and an accounting system is not important and sometimes unlikely even though it is important that they be aligned with corporate goals.
Operational complementarity	Operational complementarity of work systems X and Y is the extent to which X provides what Y needs in terms of content, format, timing, and other issues that are important to Y. The general idea of operational complementarity goes beyond interoperability of technology. It touches on details of both work systems, including information, participants, processes and activities, product/services produced, and even customers. X and Y can be both congruent and aligned without being operationally complementary as when X and Y sometimes serve the same customers but in different, possibly contradictory ways.

4.2 Purpose and/or Cause of System Interactions

System interactions have a variety of purposes and/or causes. Purposeful system interactions stem from specialization and organization by function and from the related need to allocate and share resources. Malevolent forms of purposeful interactions involve interference, sabotage, or theft. Causes of system interactions that may or may not be purposeful include proximity or overlap with other systems and unforeseen circumstances, effects, events, and contingencies.

The wide range of different purposes and/or causes presents a challenge for SINT but also illustrates why a broadly applicable theory of system interactions is needed. Purposeful system interactions deriving from specialization and division of labor are obviously essential for efficient design and operation of any significant work system. It is also important to consider non-purposeful causes, however, because they often have direct and indirect impacts on the operation of work systems and enterprises.

Specialization and organization by subsystem. Organization studies and economics discuss this topic in relation to the division of labor, while computer science discusses it in relation to organization through subsystems or modules. In both cases, organizing around specialization and focus ideally leads to more efficient and effective task performance. Such specialization brings the cost of additional communication and the cost of other interactions that maintain the integrity and coherence of the work system, enterprise, or computer system in which the tasks occur.

The division of responsibility and accountability that goes along with division of labor makes work systems more manageable, especially in situations in which different activities involve different knowledge and information. Similar issues are relevant in totally automated work systems whose understandability, testability, and maintainability are enhanced through organization as subsystems that can be understood and tested separately. SA&D textbooks discuss the division of functions between modules in terms of coupling (i.e., how closely modules are linked) and cohesion (i.e., the degree of focus or unity of purpose in a module).

Need to allocate and share resources. Specialization and organization by subsystem requires allocation of resources and often requires that subsystems share resources. In many situations, the same human, physical, and informational resource might be potentially useful to two different work systems simultaneously. Coordination theory addresses this type of situation.

Proximity or overlap of systems. Proximity between work systems X and Y may take many forms including overlaps in context, purpose, domain, time, space, and resources used. Greater proximity between X and Y usually enhances the likelihood of interactions whether or not those interactions are part of a conscious design, Thus, interactions between systems that are nearby in time, space, domain, or content tend to be much more likely than interactions from great physical, temporal, or content-related distances.

Unforeseen or only partially controlled circumstances, effects, events, and contingencies. The design of X and Y usually focuses on the individual systems and on their intentional interactions with other systems. System interactions can also come from unintentional causes, including design flaws, unanticipated overlaps, unanticipated one-way and mutual impacts, accidental malfunctions, and unanticipated conditions. While it is impossible to design for all unintentional interactions, the effort during

SA&D to consider interactions related to unforeseen circumstances may help in avoiding undesirable outcomes.

Purposeful interference or sabotage. A final cause of system interactions is purposeful interference or sabotage in which X purposefully attempts to disrupt, sabotage, and/or steal from Y. The many examples of "computer crime" by employees, hackers, and industrial spies reinforce the importance of paying attention to purposeful interference or sabotage as a type of system interaction.

4.3 Detailed Modeling of System Interactions

A detailed model of a system interaction would identify exactly how it should occur or how a particular system interaction occurred in the past. Detailed models can take many different forms, several of which are mentioned here.

Using BPMN and/or UML. If the focus is on producing software or verifying that existing software might be acceptable, typical software development tools such as BPMN and/or UML can be used to model details of processes in the interacting systems and details of the interactions themselves (similarly for using entity relationship diagrams to model the data details in the systems or their interactions). For example, consider a sales transaction in which the supplier offers products for sale, a customer decides what to buy, the customer enters the order using the supplier's order entry portal, the supplier verifies that the products are available in the desired quantity, and the customer pays using some form of credit or money transfer. That situation could be viewed as a single extended interaction between two systems (a selling system and a purchasing system) or as a set of smaller interactions between those systems or complementary subsystems. In either case, the two interacting work systems would appear in separate BPMN lanes. An additional lane for the interaction might be required if computing or other activities are part of the interaction and are not viewed as part of the supplier or customer activities represented in the other lanes. In a UML model of the interaction, a sequence diagram would show the sequential logic in terms of passing messages between the supplier and customer during the interaction. Notice how neither BPMN nor UML representations would fully capture considerations related to characteristics in Tables 3 and 4.

Work system model of the interaction. Some complex interactions between two work systems can be viewed as separate work systems on their own right. A work system view of the supplier-customer interaction would identify the participants (actor roles in the supplier and customer work systems), the information and technologies used in the interaction, the processes and activities in the interaction, and the product/services that the interaction produces for specific customer roles. That view of an interaction can be represented using a work system snapshot, a central tool in the work system method (Alter, 2013, p. 86).

4.4 Characteristics of System Interactions

Another way to describe an interaction between two work systems is in terms of characteristics of the interaction itself. Wherever a system interaction can be viewed as a work system on its own right (Section 4.3), the characteristics mentioned in Table 2 also apply to that interaction. Additional characteristics mentioned in Table 4 apply to system interactions but not necessarily to work systems in isolation.

4.5 System Interaction Patterns

Figure 3 identifies four categories of system interaction patterns. Table 5 expands the four categories to include 19 system interaction patterns that Alter (2016b) describes in detail. The idea of system interaction pattern was inspired by an analogy to software design patterns (see Appendix, Section A2) and by the beginnings of a typology of system interactions in Alter (2010). I could not find research that identified or codified system interaction patterns that are relevant to work systems in general.

The general goal of SINT's system interaction patterns is to provide a vocabulary and common frame of reference that makes it easier to initiate and focus management-level discussions of interactions between sociotechnical systems and/or totally automated systems. That type of starting point also could facilitate discussions of software-related patterns that are more rigorous and more tightly linked with known "solutions" to recurring software development problems. SINT's system interaction patterns do not need the rigor or specificity of programming-oriented patterns because they serve more as a map for identifying different types of interaction situations and some of the issues that need to be addressed in those situations.

Table 4. Characteristics of System Interactions (Excluding Characteristics of Systems from Table 2)

Characteristic	Possible impact on system interactions
Intentionality	Intentionality describes the extent to which interactions between two work systems are intentional. System interactions in SINT's scope may be anywhere from completely accidental to completely intentional.
Directness	Directness describes the extent to which interactions between two work systems occur through well-defined boundary objects or sharing of resources without being affected by obstacles or intermediate activities involving other work systems. System interactions in SINT's scope may be anywhere from completely indirect to completely direct. Indirect interactions sometimes are mediated through factors that are not associated with either of the interacting systems, as when other systems mediate the interactions in a business ecosystem (e.g., treatment of ecosystems in Mars, Bronstein, & Lusch, 2012; Vargo & Lusch, 2016).
Explicitness	Explicitness describes the extent to which interactions between two work systems are described with clarity and specified using unambiguous terms. System interactions in SINT's scope may be anywhere from induced to explicit. Induced interactions occur when the characteristics or events related to one system affect another system without transferring messages, information, or physical things.
Persistence	Persistence describes the extent to which interactions between two work systems extend over time. System interactions in SINT's scope may be anywhere from transient and short-lived to persistent over a long period. Even transient interactions that occur rarely or occasionally may have major consequences (e.g., failures of electric systems or cloud computing infrastructures that shut down entire businesses).
Variability	A realistic operational perspective on interactions should consider random and non-random variability in how specific system interactions might occur. It should consider the possibility of non-compliance to expectations related to activities and responsibilities in either interacting work system. Those factors result in uncertainty about the form and magnitude of work system interactions and related impacts.

Table 5. Nineteen System Interaction Patterns in Four Categories

Speech act patterns (unidirectional)	Co-production patterns (bilateral)
• Inform • Command • Request • Commit • Refuse	• Converse • Negotiate • Mediate • Share resource • Supply resource
Access and visibility patterns (unidirectional)	**Unintentional impact patterns**
• Monitor • Hide • Protect • Attack	• Overlap interaction • Market-based interaction • Spillover interaction • Indirect interaction • Accidental interaction

Template for system interaction patterns. The general template for system interaction patterns (explained in Alter, 2016b) identifies both likely elements of most system interaction patterns and occasionally relevant elements that apply to some patterns but not others. The choice of elements to include under each heading was based partly on the typical elements in a software design pattern (e.g., Shalloway & Trott, 2004).

The likely elements include actor roles, actor type, actor rights for each actor role, actor responsibilities for each actor role, cause or trigger, desired outcome, generic processes or activities, state space (different possible states of the interaction), and alternative enactments (e.g., some patterns may be performed person-to-person or machine-to-machine). Occasionally relevant elements of a system interaction pattern should not be overlooked even though they may not seem to be essential for developing models of interactions. Occasionally relevant elements include constraints, risks and risk factors, byproducts, especially relevant concepts (i.e., concepts relevant to a particular pattern but not to other patterns), verification of interaction (important for some types but not for others), and evaluation of interaction (important for some types but not for others).

The four categories of system interactions in Table 5 can be summarized as follows.

Speech act patterns. This category contains unidirectional interactions that have been studied in relation to the language action perspective (LAP). The five patterns in this include inform, command, request, commit, and refuse, all of which appeared in a study of email (Cohen, Carvalho, & Mitchell, 2004). All five also make sense as types of interactions between systems. For example, system X may inform system Y about a price change regarding services that X provides for Y. System Y may command system X to stop producing those services because the price is too high. And so on for the other patterns in this group.

Co-production patterns. These bilateral patterns involve jointly produced interactions whose instantiations can be observed as sequences of unidirectional interactions, some of which may be described by speech act patterns. Co-production patterns include converse, negotiate, mediate, share resource, and supply resource. The first three concern bilateral speech situations; the other two concern coordination (drawing on ideas from coordination theory). For example, system X and system Y may negotiate about an issue or X and Y may share a resource.

Access and visibility patterns. These unidirectional system interaction patterns involve obtaining or preventing access or visibility. Patterns in this category include monitor, hide, protect, and attack. The first of these involves a typical management activity. The next two involve defensive maneuvers. The last pattern represents a threat. Patterns in this group may be only partially specified because it is difficult or impossible to know what an attacking system will do.

Unintentional patterns. While it is not possible to predict all or even most unintentional impacts, ignoring the possibility that they will occur is not a beneficial practice in design or engineering. Unintentional patterns are included even though they are not articulated as well as the patterns in the other categories. For example, patterns in the other categories are named using verbs, whereas unintentional patterns are just types of impacts. A key reason for the less articulated nature of these patterns (in the current version shown in Table 5) is the huge range of possible sources and effects of unintentional interactions. Patterns in this category can be illustrated based on unintentional interactions related to an outsourcing relationship between hypothetical firms MegaCorp and ServCorp:

- **Overlap interaction.** Key managers who play central roles in MegaCorp's coproduction system with ServCorp also manage other operational systems in MegaCorp. Thus, they serve roles in separate systems that sometimes require their participation at the same time. The result is inefficiency in both systems.
- **Market-based interaction**. MegaCorp is considering using a task bidding website that supports competitive bidding on jobs. Trends in that direction might change aspects of the sourcing process with ServCorp.
- **Spillover interaction**. A new product introduction at MegaCorp was far more successful than anticipated. The result was much higher demand for design work by ServCorp, which had great difficulty staffing up to complete the additional work on short notice.
- **Indirect interaction**. ServCorp's strict practices related to employee vacations are a source of dissatisfaction for its employees, especially those who interact occasionally with MegaCorp's employees, who enjoy practices that are more favorable to employees.
- **Accidental interaction**. One of MegaCorp's competitors is a ServCorp client. Last week, ServCorp accidentally mixed some of MegaCorp's designs with designs sent to its competitor.

The four categories and 19 examples of system interaction patterns were developed iteratively based on literature cited in Alter (2016b). It is certainly possible that deeper literature searches would find other system interaction patterns or would describe the existing patterns in a more complete way. The detailed explanation of the patterns in Alter (2016b) uses the example of a variety of outsourcing arrangements that involve MegaCorp and ServCorp. That explanation shows how the template applies to two patterns in each of the first three categories and how it might support an organized inquiry about the fourth category. A full demonstration of the utility of those ideas would require future applications in a series of software development projects or organizational research projects.

4.6 Direct Effects of System Interactions

Figure 3 says that direct effects of system interactions include structural characteristics of systems, coordination versus disorganization, absorption of effort in system interactions, and enablement versus obstruction for interacting systems.

Structural characteristics of systems. The effort of designing work systems should include designing planned system interactions and trying to anticipate unplanned interactions. Regardless of how processes in the interacting work systems may have been designed, the structure-in-practice of the interacting work systems depends on how interactions occur in reality, which may involve various types of workarounds or non-compliance. Such workarounds and non-compliance may have direct effects on the larger system's structural characteristics, such as its degree of integration, complexity, and automation; its rhythm; and the variety of activities for work system participants.

Coordination versus disorganization. System interactions of various types are essential for coordinating subsystems to maintain cohesive focus on goals and minimize confusion and disorder. On the other hand, ineffective or misguided system interactions may increase confusion and degrade performance as when conflicts between goals and strategies of systems X and Y are never resolved. Even when it is possible to coordinate through methods such as decision rules, contingencies may arise that require direct interaction that may override the decision rules.

Absorption of effort in interactions. An additional direct effect of system interactions is that those interactions absorb effort, as has been studied in depth in relation to transaction cost economics (Williamson, 1985). TCE was initially developed to explain the scale and scope of firms, but has been used to study topics include vertical and lateral integration, transfer pricing, corporate finance, marketing, the organization of work, long-term commercial contracting, franchising, regulation, and many other contractual relationships (Shelanski & Klein, 1995). In all of those situations, the time and effort that system interactions absorb may have significant impacts on the efficiency and effectiveness of interacting systems.

Enablement versus obstruction. Just as interactions may enable efficient and effective activities in systems or subsystems, interactions may also create obstacles, difficulties, and uncertainties. In this paper’s introduction, Table 1 identifies many such obstacles and difficulties that have appeared in published papers in recent years. Table 6 covers most of those examples and others by summarizing common types of problematic interactions between hypothetical systems X and Y. The obstacles identified in Table 6 can be incorporated into systems analysis and design using checklists or other tools to minimize the likelihood of ignoring or downplaying system interactions that could affect work system performance.

Table 6 is organized around the elements of the work system framework to show that faulty interactions can be traced to different work system elements (i.e., not only to the work system as a whole). That point accentuates the value of describing interactions through the lens of work system interactions rather than one dimensional lenses such as task interaction, human communication, or messages sent between software modules.

4.7 Responses to Direct Effects

The various types of direct effects may have positive and/or negative impacts on the operation or performance results of either interacting work system. Either or both work systems may need to respond in situations where the interactions might persist and might have continuing effects over time. Responses to some of the issues raised by system interactions include formalizing the content, format, and timing of interactions; establishing and maintaining alignment; establishing and maintaining congruence; integrating subsystems; and mitigating threats by monitoring and responding to interactions.

Formalize content, format, and timing of interactions. Formalization is one way to make system interactions and their direct effects more controllable and predictable. Formalization of content and format is not a question for interactions between software modules because the content and format of messages and other outputs and inputs must be defined explicitly. Formalization of interactions between sociotechnical systems is accomplished through approaches such as structuring business processes, defining business rules, and establishing accountability and responsibility for specific actions and decisions. Those approaches can be applied to the interacting work systems and to the interaction itself, especially if the interaction is viewed as a separate work system on its own right.

Table 6. How Specific Elements of the Work System Framework May Be the Source of Problematic Direct Effects through System Interactions

Work system element	Typical examples of obstacles related to direct or indirect and persistent or transient interactions between systems X and Y
Customers	• Goal divergence: If X is a supplier and Y is a customer, conflicts between primary goals of X and Y may interfere with their interactions and may affect the performance of supersystem Z. • Errors, exceptions, or other events in X cause inefficiency or delays in Y or diversion of resources from Y to X. • Transient problems in X cause Y to shut down.
Product/services	• Delays, fit issues, or other problems in X decrease the satisfaction of Y's customers independently of Y's efforts to meet customer expectations. • Inconsistencies between customer requirements for X's product/services and Y's complementary product/services reduces customer satisfaction (e.g., work system X's primary customers are concerned with cutting costs, while Y's customers are concerned with maintaining an image of top quality). • X's product/services do not fit well with customer Y's needs. • The quality and/or timeliness of Y's product/services is affected by faulty interactions with supplier X. • Unanticipated inconsistencies between X's product/services and Y's product/services cause inefficiency for their mutual customer Z.
Processes and Activities	• Operating at cross-purposes: Y undoes some of what X does. • Operational interference: X's operation interferes with Y's operation. • Built-in delays: the structure of the interaction between X and Y generates delays. • Inadequate synchronization or ineffective resource sharing between X and Y causes delays, inefficiencies, or overload in X or Y. • Errors, exceptions, or other unanticipated circumstances involving X's work practices cause inefficiency or delays in Y. • X's participants and management devote excess time to dealing with Y, which diverts time and energy from achieving X's goals. • Inconsistencies in work practices of X and Y cause morale problems. (e.g., why are workers in X allowed to go home earlier while those in Y need to stay later?)
Participants	• Personal or organizational disputes and rivalries between participants in X and participants in Y are counterproductive or disruptive. • People who participate in both X and Y sometimes become inefficient or overworked due to multiple demands and may not be able to perform all of their roles and responsibilities with appropriate care. • Participants in Y cannot perform activities efficiently due to occurrences or activities in X.
Information	• Inconsistency between information used in X and information used in Y causes problems. For example, X wastes time and effort due to inconsistency between information used in Y and information used by X to manage Y. • Errors, exceptions, or design flaws in the information flow between X and Y cause inefficiency, confusion, or delays (e.g., Y is not aware of what X will provide and when that will happen). • Y's operational performance suffers due to lack of access to information about the status of X or the status of whatever Y will receive from X.
Technology	• X's technology is not interoperable with Y's technology. • Technical inconsistencies between X and Y cause extra work. (e.g., one uses Wintel PCs; the other uses Macs.) • Technical failure in X causes extra work or delays in Y.
Environment	• Cultural inconsistencies between X and Y make communication and other interactions more difficult. • Inconsistencies between X and Y regarding regulations and standards cause operational problems for Y.
Infrastructure	• Inadequate methods for sharing of human, technical, or informational infrastructure negatively affect the performance of X and Y or interactions between X and Y.
Strategies	• Strategy inconsistencies between X and Y or between X, Y, and the surrounding organization cause counterproductive interactions, inefficiency, or other problems.

Develop workarounds and adaptations. In relation to work systems rather than just technologies, a workaround is a “goal-driven adaptation, improvisation, or other change to one or more aspects of an existing work system in order to overcome, bypass, or minimize the impact of obstacles, exceptions, anomalies, mishaps, established practices, management expectations, or structural constraints that are perceived as preventing that work system or its participants from achieving a desired level of efficiency, effectiveness, or other organizational or personal goals” (Alter, 2014). Workarounds and adaptations related to system interactions occur for the same reasons.

Establish and maintain alignment. Table 3 identifies alignment of systems or subsystems as a mutual characteristic. Approaches for establishing and maintaining alignment between systems X and Y include creating plans, following instructions from a system that both X and Y serve, negotiating about mutually relevant issues, revising work system structure to increase alignment, and applying business rules or guidelines that maintain alignment.

Establish and maintain congruence. Table 3 identifies congruence of systems or subsystems as a mutual characteristic. Structural approaches for maintaining congruence include establishing shared standards and similar structure for processes, information, and technologies. Participant-related approaches involve nurturing shared values and mutual understanding.

Integrate interacting systems. If the current structure of the two interacting systems reflects too little coupling between them, one possible improvement approach is to integrate those systems to create a larger system that eliminates deficiencies in coupling. That approach may reduce the cost of interfaces but also may result in losing some specialization and agility.

Mitigate threats by monitoring and responding to system interactions. A final way to compensate for interaction difficulties is to mitigate threats using approaches such as:

- Using participant training to raise general awareness of possible forms and consequences of system interactions
- Using monitoring and alerts to notify work system participants that unintended system interactions are occurring or that system interactions are occurring in an unintended manner
- Using business rules to adjust automatically wherever possible, and
- Implementing specialized subsystems that identify and repel threats.

4.8 Types of Outcomes

The combination of the causes, types of interaction, direct effects, and responses that characterize situations affect outcomes related to system interactions in those situations. The types of outcomes that are relevant include the actual “in-practice” structure of the interaction, goal attainment versus non-attainment for the interacting systems and for their interactions, security versus vulnerability, and possible impacts on change-related characteristics such as adaptability, agility, and scalability.

Actual, “in-practice” structure of the system interaction. All of the previous sections’ types of responses to direct effects of system interactions may result in changes in the actual, “in-practice” structure or rationale of the system interaction. Those changes are consistent with the observation that work systems (and hence recurrent work system interactions) change over time through a combination of planned change and unplanned change, as described in the work system life cycle model (Alter, 2013).

Goal attainment or non-attainment. System interactions have a range of direct and indirect impacts on attainment or non-attainment of work system goals. The negative impacts often concern goal conflicts, delays, lack of fit, inefficiency, and confusion. Some of those interactions may be persistent while others may be transient conditions that arise occasionally due to misalignments and/or errors, exceptions, and other unexpected events.

Security versus vulnerability. The quality of system interactions has many implications for system security versus vulnerability. The nature and details of system interactions are part of widespread attention to security-related methods such as physical security, encryption, passwords, biometric identification, and role-related control of access to database and networks.

Adaptability, agility, and scalability. System interactions have significant impacts on change-related characteristics such as adaptability, agility, and scalability. For example, part of the rationale for service-oriented architectures is based on the advantages of loose coupling and high cohesion in software modules. Work systems whose subsystems are more tightly coupled may tend to be more difficult to change due to complex interactions and/or overlaps between subsystems. The nature of system interactions also affects scalability since simpler interactions and greater focus in subsystems could make it easier to add human and technical resources.

4.9 Evaluation of System Interactions

A complete evaluation of any specific system interaction needs to consider not only the performance of the interaction itself but also impacts on each of the interacting work systems. For example, a sales interaction that occurs quickly and efficiently when viewed in isolation may have required previous non-standard processing by the supplier to suit the particular customer's needs and, subsequently, may require non-standard activities by the customer as well. That example illustrates that thoughtful performance measurement for system interactions sometimes requires considering both the system interaction itself and previous and subsequent events in the interacting systems.

The final list at the bottom of Figure 3 identifies typical performance metrics that one can apply to both individual work systems and interactions between work systems. It is likely that other performance metrics would be relevant for many specific types of interactions. Some of the metrics relate to customer perceptions of whatever is produced and others relate to internal, operational performance within the work system. Every part of the sequence in Figures 2 and 3 may influence results for any of those internal or external performance metrics. For example, the sales interaction mentioned above may have been inefficient for the interacting work systems due to some of their individual characteristics and some of their mutual characteristics. Various combinations of purpose, direct effects, and responses may have a variety of consequences that ultimately influence measures of performance.

5 Discussion and Conclusions

This paper's explanation of SINT expands its general logic (Figure 2) to include many ideas related to relevant characteristics, phenomena, and metrics (Figure 3). Discussions related to Tables 2 through 6 provide a deeper look at many concepts that are associated with the various parts of SINT.

The nature of many of the situations that SINT covers implies that there is no simple formula for estimating performance results based on characteristics of the interacting work systems or generic descriptions of aspects of interactions. SINT's potential value lies in supporting the description and analysis of the entire gamut of system interactions, including planned, improvised, and accidental interactions. Treating the interacting entities as work systems rather than tasks, people, or software modules provides a richer way to achieve SINT's intended value.

Beyond siloed approach to interactions. A reader might ask whether such a detailed approach is necessary for a theory of system interactions. For example, criteria such as rigor and parsimony imply that a better theory of system interactions might be stated concisely and might be explained in just a few paragraphs or a few pages. That might be possible for a mid-range theory that contains just a few concepts (e.g., see Grover and Lyytinen's (2015) critique of the "mid-range script" that is common in IS publications). SINT simply is not that type of theory.

SINT's goal as a theory for analysis (see footnote 2) is to be as useful as possible for researchers and practitioners trying to understand, analyze, and possibly design system interactions. The diversity of interaction-related situations calls for a theory that is useful across a broad landscape currently addressed by disjointed, almost siloed approaches from separate technically and socially oriented disciplines. In combination, the straightforward flow at the top of Figures 2 and 3 and the additional concepts in the lists in Figure 3 could support application across a wide range of interaction situations.

This concluding section addresses three topics: whether the research goal was achieved, contributions from this effort, and next steps.

5.1 Was the Research Goal Attained?

This paper pursued an ambitious research goal that covered three types of issues: scope, coverage across disciplines, and usefulness.

- SINT was to be a theory for analysis covering most common types of intentional and unintentional interactions between work systems.

- SINT was to encompass the main interaction-related topics emphasized by existing literature of disparate, but relevant disciplines.
- SINT was to be useful in supporting the development of new understandings, concepts, tools, and methods related to interactions between work systems.

Scope. As Figures 2 and 3 portray, SINT covers the full range of system interactions mentioned in Section 2.2. It applies to both sociotechnical work systems and totally automated work systems that may have a variety of characteristics:

- **Intentional or unintentional**. Intentionality is one of the system interaction characteristics in Figure 3. The purposes and/or causes mentioned in Figure 3 range from specialization and organization by subsystem (intentional) to unforeseen or only partially controlled circumstances, effects, events, and contingencies. That full range leads to system interactions that may have any of the characteristics included in Figure 3 and may operate according to any of the system interaction patterns.
- **Instantaneous or persisting over a lengthy timespan.** Persistence is one of the system interaction characteristics in Figure 3. System interactions with varying degrees of persistence may be intentional or unintentional.
- **Direct or indirect:** directness is another of the system interaction characteristics. System interactions with varying degrees of directness may be intentional or unintentional.
- **Occurrence through various media or means**. System interactions described by Figures 2 and 3 may occur through any of the following: physical contact, material transfers, formal or informal communication, induced effects, or other means.
- **One-way, bilateral, or multi-directional**. The system interaction patterns in Section 4.5 include speech act patterns (one way), coproduction patterns (bilateral or multi-directional), access or visibility patterns (one-way), and unintentional impact patterns (one-way, bilateral, or multi-directional),
- **Planned or unplanned, expected or unexpected, or intentional or accidental**. Figures 2 and 3 cover all of those.

Covering such a broad scope in a useful way requires including many of the topics in Figure 3. It is certainly possible to look at a smaller range of system interactions, such as only intentional interactions or only interactions between totally automated systems. Unfortunately, that would not touch many of the issues and topics that SINT addresses and would be less useful in a world in which automated systems increasingly support sociotechnical systems.

Coverage across disciplines. The research goal called for providing a theory of system interactions that covers the main interaction-related topics emphasized by existing literature across disparate disciplines that touch on relevant interactions in various ways. Interaction-related concepts discussed in the Appendix include message-based interaction, coupling, and modularity through task interdependence, coordination, and loose versus tight coupling in organizations, among others.

The key to attaining the coverage goal is to define SINT in relation to interactions between two work systems, each of which could be either sociotechnical or totally automated. The work system approach to system interactions says that each system can be described in terms of processes and activities, participants, information, technologies, and other elements of the work system framework. That approach covers interactions that involve tasks (processes and activities), people (participants), and software modules in operation (work systems on their own right because they exhibit the properties of systems). The many topics in Tables 2, 3, 4, 5, and 6 show that the work system approach provides a perspective for looking at system interactions in depth.

Usefulness. This paper suggests various in which SINT can be useful. In relation to the conceptual development of the IS discipline, the literature review in the Appendix shows that existing coverage of interactions in disparate disciplines is unnecessarily limited and somewhat siloed. In relation to systems analysis and design, the ideas in Figure 3 might be incorporated into checklists or tools. On the other hand, in this paper, this paper does not demonstrate SINT's usefulness because tools based on SINT have not been produced yet and because there is no empirical or experimental demonstration that SINT provides insights that might not otherwise occur. Those projects remain for future research.

5.2 Contributions

This paper's contributions include:

Articulating the challenge of producing SINT. The idea of developing a broadly applicable theory of system interactions that covers both sociotechnical and totally automated systems contributes to the literature in itself because that idea is barely visible in the existing literature. At minimum, SINT provides an integrated approach that researchers can critique and improve on.

Work system perspective on interactions: SINT differs from most theoretical approaches to interactions because it treats the unit of analysis as interacting work systems rather than isolated elements of a work system such as tasks, people, or technologies (i.e., software modules). As Figure 3 and Tables 2, 3, 4, 5, and 6 illustrate, a work system perspective on system interactions provides a multi-faceted unit of analysis that leads to potentially richer and more nuanced views of system interactions than are implied by treating tasks, people, or software modules as the unit of analysis.

Integrated view of sociotechnical and technical system interactions. Traditional views of sociotechnical systems and technical systems are based on quite different assumptions and metaphors. Views of interactions between tasks or between people are based on organization theory and on the assumption of interactions involving communication between people and/or transfer of boundary objects. (Bowker & Star, 1999). Views of interactions between technical entities are based on service computing assumptions that frame interactions as exchange of coded electronic messages. (e.g., Brown, Delbaere, Eeles, Johnston, & Weaver, 2005; Cherbakov, Galambos, Harishankar, Kalyana, & Rackham, 2005, Oberle, Barros, Kylau, & Heinzl, 2013). SA&D activities related to business systems need to consider both types of system interactions because business requirements reflect business activities and issues, while technical requirements focus on hardware/software functionality.

Possible contributions to SA&D. SINT may lead directly to straightforward analysis guidelines, checklists, and tools for SA&D. The guidelines would encourage serious consideration of system interactions that could improve or degrade new or upgraded systems. Checkoff lists based on ideas in Figure 3, Tables 2, 3, 4, and 6, and more elaborated descriptions of system interaction patterns in Table 5 could make it more likely that important system interactions will not be overlooked.

Possible contributions to organizational research related to interactions. The same types of contributions also apply to organizational research by providing a conceptual basis for tracing and evaluating system interactions in organizational settings.

Possible contributions to business innovation research. Much business innovation occurs through business ecosystems that cross enterprises. The activities in those ecosystems can be examined from a work system perspective by focusing on different work systems that perform the relevant activities in the ecosystem. SINT can be used to visualize the interactions between the work systems in the ecosystem.

System interaction patterns. Development of the idea of system interaction patterns was an integral part of this research. That idea is explained in more detail elsewhere (Alter, 2016b), and future research could develop it further.

Step toward better visualization of service-orientation. SINT's unified approach for thinking about system interactions might prove useful in visualizing both advantages and challenges of harnessing service-oriented computing architectures (i.e., SOA) in order to make organizations more service-oriented in a business sense. The transition from SOA as part of IT infrastructure to genuinely service-oriented enterprises (SOE) requires dealing with system interactions on many different levels (see Nayak et al., 2007; Welke, Hirschheim, & Schwarz, 2011).

Step toward understanding systems of systems. Section 1 notes the importance of digitalization trends that support outsourcing, business ecosystems, and automation—all of which operate through system interactions in systems of systems. SINT may support deeper understanding of the opportunities and challenges of creating and maintaining mutually beneficial interactions in systems of systems.

Extension of work system theory. Section A9 in the Appendix notes that SINT can be viewed as an addition to a series of extensions of WST beyond its conceptual core. Alter (2015) proposed that a "taxonomy of work system interactions" in Alter (2010) might be developed much further as SINT does. Similarly, a work system metamodel that extends WST includes an interaction relationship between a focal work system and "other work systems". SINT fleshes out the meaning and complexity of that relationship in the metamodel.

5.3 Next Steps

SINT was developed iteratively and somewhat informally through a typical theory development process as noted at the end of Section 1. This conceptual paper's ideas have not been tested empirically or experimentally and have not been used in practice. Next steps include:

Developing alternative theories. It is certainly possible that others will find a better way to cover the same general territory. In relation to theorizing per se, it is possible that a different approach to SINT might be more parsimonious even though Orton and Weick (1990) suggests a similarly complex approach to the more limited topic of loose coupling (see footnotes 3 and 4). The system interaction patterns (see Section 4.5) related to unintentional interactions are less developed than the other interaction patterns. That area calls for more development.

Testing SINT against existing case studies. Interactions play important roles in many case studies and examples that have appeared in research publications. Future research could analyze a large sample of these cases or examples based on SINT to test the extent to which SINT describes all the interactions found in the cases and to try to identify omissions or confusions in SINT.

Extending the existing theory. Even though this paper is quite long, future research could develop its ideas more completely in a monograph or book. For example, it would be possible to go into more depth in explaining many of the concepts in Figure 3 and in discussing important ways in which its concepts and interaction patterns are sometimes related to specific concepts in subsequent steps in SINT.

Specifying propositions for empirical testing. Although SINT is a theory for analysis, it is possible to tease out areas where SINT potentially leads to other types of theories such as theories for explanation or prediction (see footnote 2). For example, parts of the content of Table 2, such as statements about the impact of a higher or lower degree of structure, automation, or visibility to customers could be restated as propositions that could be tested empirically.

Developing SA&D checklists and tools. SINT could provide a basis for checklists used at several points in analysis and design processes. It might form the basis of a computerized questionnaire or other type of tool for identifying important or problematic interactions in a system that is being built or improved. For example, the issues listed in Tables 2, 3, 4, and 6 could be incorporated into SA&D checklists or other tools to minimize the likelihood of ignoring or downplaying important system interactions that could affect the efficiency, effectiveness, and reliability of work systems through which organizations operate.

Using SINT in SA&D experiments. The potential value of SINT might be tested experimentally in SA&D courses. A simple version of the experiment could involve a system-design exercise performed by two groups in a university course. The control group would receive a standard or traditional version of SA&D learning materials. The treatment group would also receive a checklist or some other guidance based on SINT. The instructor would compare the results to determine whether the SINT-based guidance makes a difference. The instructor would explain the difference in the results to students in both groups as part of the learning experience. Bolloju, Alter, Gupta, Gupta, and Jain (2017) used a similar design to test whether basic ideas related to work systems could help third-year undergraduates generate better "user stories" related to a case study designed for teaching about the agile method called scrum.

The possible next steps above illustrate that the development of SINT to date might be an initial step toward making system interactions more visible in IS practice and research. System interactions are sometimes overlooked despite their impact on the performance of information systems and other work systems that use IT in significant ways. Further development and application of ideas related to system interactions could be a fruitful area for future research.

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Appendix A: Literature Review

As mentioned earlier, this literature review is presented as an Appendix because many readers are likely more interested in what SINT says than in how it somewhat relates to a large number of disciplines and subdisciplines. Overall, this literature review reflects the broad importance of different types of interactions and the general lack of theory specifically about system interactions despite the ubiquity and frequent impacts of system interactions. It identifies and summarizes perspectives on interaction that are often associated with different disciplines or subdisciplines. In each case, it uses one or several bullet items to summarize how ideas from specific perspectives influence SINT and how SINT can add a distinctive perspective related to system interactions. After mentioning general system theory, it moves from perspectives with a more technical orientation, such as SA&D and requirements engineering through perspectives more related to organizations.

Readers familiar with the subject matter in each section in this literature review will notice that only several representative examples are mentioned in each area. A complete literature review of past research in each area related to interactions in one way or another could be a complete paper on its own right, which would go far beyond the current purpose of indicating how SINT relates to key ideas in specific disciplines or subdisciplines.

A1. General Systems Theory

General discussions of systems and system concepts typically start with a definition such as the following: “A system is a set of interrelated elements. …Each of a system’s elements is connected to every other element, directly or indirectly.” (Ackoff, 1971, p. 662). General systems theory (GST) contains concepts, processes, and patterns related to many system-oriented theories from different disciplines (e.g., see Skyttner, 2001). Common GST concepts such as input, transformation, output, boundary, and environment are so general and taken for granted that they provide little specific guidance for understanding the kinds of systems that the IS discipline studies. On the other hand, systems theorists such as Checkland (1999) and Ackoff (1994) have observed that understanding or analyzing a system requires one to understand whatever systems are being served and how those systems are being served.

The distinction between a system and its components is often only a matter of perspective and level of detail. This observation is consistent with Skyttner (2005, pp. 56-57), who notes that a system is not something presented to an observer; rather, it is something to be recognized by an observer. Many systems (including almost all information systems) contain components that can be viewed as systems in their own right. A system of systems operates through the operation and interactions of its component systems. Accordingly, SINT must cover interactions between system components that are systems.

- SINT makes largely implicit use of ideas from GST by including descriptions of systems, system interactions, and causes and/or purposes of interactions. Those ideas include wholeness, identification of a system, boundary and environment, inputs and outputs, transformations, goals, controls, feedback, hierarchy, and subsystems.
- Understanding how one system serves another requires clarity about how the systems interact in ways that may be direct or indirect, intentional or unintentional, and persistent or transient.

A2. Service Concepts and Design Patterns from Computer Science

Computer science brings many relevant concepts related to service orientation (in a technical sense, discussed below), modularity, cohesion, and coupling of software modules. The latter topics appear in the discussion of SA&D in Section A3. Here, I focus on two topics: the computer science idea of service and the idea of design patterns.

Distinct from a hospitality or marketing view of service, the computer science view of service describes a totally structured relationship between a client and a server. A service “is generally implemented as a course-grained, discoverable software entity that exists as a single instance and interacts with applications and other services through a loosely coupled (often asynchronous), message-based communication model” (Brown et al., 2005, p. 728). Further, as Cherbakov et al. (2005, p. 654) state: “The component that consumes business services offered by another business component is oblivious to how the provider created the business service”. An overview of the Unified Service Definition Language (USDL) says: “services constitute encapsulated and exposed functionality drawing from core artifacts, e.g., those related to business processes, applications, objects, and resources., whereas business process activities are said to be orchestrated across collaborating resources, service capabilities are delivered to consumers by providers. …They provide functionality aimed at delivering value to consumers in terms of expected outcomes, subject to delivery constraints." (Oberle et al., 2013, p. 158).

The representation of SINT in Figures 2 and 3 includes "system interaction patterns" as one way to describe system interactions. As Alter (2016b) discusses, that idea was inspired by the idea of software design patterns that represent recurring solutions to recurring software problems, which itself was inspired by design patterns for architecture (Alexander, 1977). Features of design patterns for software include: name, intent, problem, solution, participants and collaborators (entities involved in the pattern), consequences, and implementation (a concrete manifestation of the pattern) (Shalloway & Trott, 2004).

- The service computing underpinnings of many totally automated systems necessarily involve interactions between systems or between subsystems. SINT needs to cover that type of service interaction if it is to cover all sociotechnical and totally automated systems.
- Section 4.5 explains that SINT describes system interaction patterns in terms of a set of "likely elements" and also that they may include one or more of a set of "occasionally relevant elements". The likely elements of a system interaction include actor roles, actor type, actor rights for each actor role, actor responsibilities, cause or trigger, and so on. The occasionally relevant elements include factors such as constraints, risks and risk factors, and byproducts.

A3. Systems Analysis and Design

Most SA&D textbooks treat systems as configurations of hardware and software that users use rather than as work systems. For example, Dennis, Wixom, and Tegarden (2009, pp. 4-5) say: "The analysis phase answers the questions of who will use the system, what the system will do, and where and when it will be used". They go on to note: "The design phase decides how the system will operate, in terms of hardware, software, and network infrastructure; the user interface, forms and reports; and the specific programs, databases, and files that will be needed". Similar views of "the system" appear in the first chapters of Hoffer, George, and Valacich (2008), Kendall and Kendall (2011), and Valacich, George, and Hoffer (2012). Similarly, formal methods such as the unified process (Rational Software, 2011) emphasize defining a totally automated computer system rather than defining interactions between sociotechnical systems. The diagrams in UML clarify processes, information requirements, and some details of processing logic but ignore indirect and unintentional interactions and also ignore interaction issues related to skills, incentives, and organizational culture.

Most SA&D textbooks go into great depth about many topics but treat system interactions rather sparsely as is apparent from looking in their indexes and glossaries for terms such as interaction, modularity, and coupling. The term interaction appears in the classification of UML diagrams. Interaction diagrams include sequence diagrams and collaboration diagrams, both of which document the flow of messages between objects based on UML classes to which objects belong. Table A1 presents typical statements about interaction, modularity, and coupling from SA&D textbooks. The statements related to those terms reflect a conscious, computer-centric perspective in which interactions basically concern the flow of computerized messages between objects. While that approach and related tools and methods are obviously very important, treating interactions as messages is not sufficient for interactions between most sociotechnical work systems. Such systems may have human participants rather than just human users of technology and may have interactions that involve the transfer or use of physical objects.

SINT covers system interactions that may be sociotechnical or totally automated. Those interactions may occur through explicit and unambiguous messages as extracts from SA&D textbooks in Table A1 illustrate, but SINT also needs to cover many other types of system interactions.

Table A1. Typical Statements about Interaction, Modularity, and Coupling from Systems Analysis and Design Textbooks

Topic	Related statements
Interaction	“Typically an interaction is a transaction that takes place in a business domain.” (Dennis et al., 2009, pp. 223-224) “In the following sections, and in industry practice, we often use the terms interaction and message interchangeably.” (Satzinger, Jackson, & Burd, 2009, p. 253) “Dynamic modeling is also about interaction. Unlike the real world in which objects interact in many different ways, residents of a virtual world can only interact through messages: requests and instructions that are passed between the system and the outside world, or among the system's components.” (Ashrafi & Ashrafi, 2009, p. 294)
Modularity	“Modularity is the result of decomposition. It refers to dividing a system into smaller chunks or modules.” (George, Batra, Valacich, & Hoffer, 2007, p. 8) “Modularity implies that a component contains everything it needs to fulfill its responsibilities.” (Ambler, 2004, p. 63) “Module: a self-contained component of a system that is defined by its function.” (Hoffer et al. 2008, p. 463)
Coupling	“Coupling: the degree to which one class is connected to or relies on other classes.” (Whitten & Bentley, 2007, p. 666) “Coupling is a qualitative measure of how closely the classes in a design class diagram are linked.” (Satzinger et al., 2009, p. 420)

A4. Requirements Engineering

The subdiscipline of requirements engineering (RE) started around the mid-1970s as an attempt to “mitigate and manage complexity associated with software…by capturing, sharing, representing, analyzing, negotiating, and prioritizing requirements as a basis for effective design decisions and interventions” (Jarke & Lyytinen, 2015). While RE generally focuses on software development, sociotechnical and totally automated work systems share many of the issues that it address. For example, requirements for one work system may affect requirements for other work systems as when the goal of interacting efficiently causes one work system to adopt standards that are not beneficial for it but were adopted previously by the other work system.

Three facets of an RE process include discovery, specification, and validation and verification, as noted by Jarke, Loucopoulos, Lyytinen, Mylopoulos, and Robinson (2011). Discovery is the determination of the needs that are to be addressed by whatever is to be designed. Specification is the representation of the requirements so that they can be discussed and validated. Verification and validation analyzes whether the RE process has been conducted effectively and whether it is likely that the specification will lead to a successful development effort. That paper suggests four new principles that underlie contemporary requirements processes: 1) intertwining of requirements with implementation and organizational contexts, 2) dynamic evolution of requirements, 3) emergence of architectures as a critical stabilizing force, and 4) need to recognize unprecedented levels of design complexity.

- SINT may contribute to RE in various ways because much of the complexity in requirements concerns interactions between systems. In relation to discovery and specification in an RE process, SINT may help by providing new ideas and frameworks (such as the system interaction patterns in Section 4.5) for describing, designing, and evaluating system interactions. The same aspects of SINT may support verification and validation.
- SINT may also prove helpful in relation to the new principles mentioned above. SINT addresses the intertwining of requirements with implementation and organizational contexts by covering both sociotechnical and totally automated systems. SINT’s organized approach to describing system interactions may help in describing architectures and in tracing how they evolve. The fact that SINT supports systems of systems may help in dealing with higher levels of design complexity.

A5. Sociotechnical System Theory

Many summaries of the ideas and history of sociotechnical systems movement are available (e.g., Trist, 1981; Mumford, 2006; Baxter & Sommerville, 2011; Bjørn-Anderson & Raymond, 2014; Eason, 2014). An impression from those accounts is that sociotechnical systems theory has been successful in providing tools and insights for systems design but that it has also spread to so many different domains that it has become diluted to “a banner under which many different concepts and design principles can flourish that have little relation to one another” (Eason, 2014, p. 234). Sarker et al.’s (2013) exploration of whether the academic IS discipline has been faithful to its espoused sociotechnical paradigm reflects an aspect of that dilution. Many sociotechnical practitioners and researchers would say that the SA&D approaches mentioned above are not sociotechnical approaches because they focus on technologies and pay little attention to needs, interests, and values of work system participants.

If taken literally, the view of sociotechnical systems in Mumford (2006, pp. 321-322) supports the need to understand system interactions in depth: “The objective of socio-technical design has always been ‘the joint optimization of the social and technical systems’” and “Relationships between the two systems, and between them and the outside environment, must also be carefully analysed”. On the other hand, the social system, technical system, and joint optimization often are not defined clearly. For example, the Bostrom and Heinen (1977) model of interacting technical and social systems can be questioned based on the extent to which task, structure, information, and technology belong in one system or the other or alternatively whether the two systems overlap in those areas. The representation of SINT as an interaction between two work systems (see Figures 2 and 3) bypasses the issue of a separate social and technical system by assuming that a work system is a single system rather than a combination of two systems.

- If one assumes that a sociotechnical system comprises a social system and a technical system, then SINT or some other theory of system interactions might support the type of sociotechnical analysis of a focal work system that Mumford (2006) describes (i.e., joint optimization of the technical subsystem and social subsystem).
- If one assumes that the separation between the social system and technical system is more metaphorical than analytical, then the work system framework or some other single-system view of a sociotechnical system would be more useful than a theory of system interactions for understanding or improving a sociotechnical system in isolation. In that case, SINT or some other theory of system interactions would be more useful in relation to interactions between a sociotechnical system and other sociotechnical and/or automated systems.

A6. Human-computer Interaction

The idea of human computer interaction (HCI) has expanded in scope over the years. Initially, it focused on direct interactions between people and computers and on creating guidelines for interface design such as the eight “golden rules” in Shneiderman (2017). In contrast, in June, 2016, the website of the *AIS Transactions on Human-Computer Interaction* described the journal’s editorial objective in a way that sounds more like a study of IT-reliant work systems in which people use computers: “to enhance and communicate knowledge about the interplay among humans, information, technologies, and tasks in order to guide the development and use of human-centered information and communication technologies (ICT) and services for individuals, groups, organizations, and communities”. A search of the *THCI* repository in the AIS elibrary on the term “system interaction” found only four papers that included that term. None of those papers fundamentally dealt with the interaction between two work systems.

- SINT focuses on interactions between work systems, rather than on direct interactions between people and computers. Interactions between people and computerized devices are relevant to SINT because there are many instances in which a participant in one work system interacts with a website or other technical resources that another work system provides. An example is a purchasing agent (a participant in a purchasing work system) interacting with an order entry portal that is part of an e-commerce vendor’s order entry work system. In that context, the purchasing interaction occurs between two systems rather than just between a person and a computer system.

A7. Risk Analysis

The risk of system failure has been a prominent theme during the entire evolution of the IS discipline, which has led to many papers about the probability of success or failure, correlates of success or failure, early signs of project failure, and critical success factors for projects. Many approaches for minimizing the likelihood and impacts of failure have been proposed, ranging from better communication and better business/IT alignment to controlling projects more tightly, reducing project size, using agile methods, and de-escalating runaway projects. Somewhat peripheral to the IS discipline, Six Sigma and related areas of business analysis contribute failure mode and effect analysis (FMEA) and other forms of risk analysis.

- SINT potentially contributes to risk analysis by providing a broadly applicable approach for visualizing and discussing interactions between systems and especially for finding facets of those interactions that are risky or prone to failure. The fact that SINT covers both intentional and unintentional system interactions may encourage attempts to identify types of interactions that might otherwise be overlooked.

A8. Organization Science

Many concepts and theories in the organization literature relate to interactions, but it is difficult to find broadly applicable examples specifically related to system interactions. Topics related to interactions include division of labor and task interdependence, designing work between organizations, coordination theory, and loose coupling theory.

Division of labor and task interdependence. Organization science covers many topics and theories related to the division of labor and organizational operation, maintenance, and evolution. For example, Thompson (1967) identifies three types of task interdependence: pooled, sequential, and reciprocal. Methods for coordinating between two units can be designed around the type of interdependence that applies. For example, coordination by plan is often effective for sequential interdependence, whereas mutual adjustment is more appropriate for reciprocal interdependence.

- SINT recognizes the division of labor as one of the fundamental causes of system interactions. Going beyond task interdependence, SINT covers interactions between any of the elements of interacting work systems, not just between tasks in the work systems. Also, it covers a broader range of situations including unintentional interactions and indirect interactions.

Designing work between organizations. A paper about designing work in and between organizations (Sinha & Van de Ven, 2005, p. 389) says that “three issues require attention to advance the knowledge of work design: 1) defining the boundaries of work systems, 2) examining how the system is nested in a hierarchy within and between organizations, and 3) determining interactions between the elements of a work system”. It proposes a method of frontier analysis for finding equally effective work designs for different combinations of inputs. It associates a vertical dimension with division of work in an organization and a horizontal dimension with division of work between organizations. Those two dimensions highlight three interrelated problems of work design: modularity (division of labor between organizational units), hierarchy (coordinating work in specifying the nature of responsibilities across hierarchical levels), and a network problem produced by interactions of the various organizational units. The paper identifies general types of input, design, and output variables for work systems and their subsystems.

- The paper focuses on work system design (including division of work systems into subsystems) rather than on understanding and improving interactions between several work systems. It argues for the relevance of many topics that that appear (mostly in the form of synonyms) in the lists in Figure 3. It identifies characteristics that are important for work system design just as SINT identifies characteristics that are important for system interactions. It identifies work design mechanisms such as differentiation, centralization, routinization, and discretion. Related ideas appear in the parts of SINT concerning causes, direct effects, responses, and outcomes. It identifies outputs such as effectiveness and productivity just as SINT includes outcomes of several types.

Coordination theory focuses on the management of dependencies involving activities and resources; it identifies different types of dependencies and basic mechanisms for managing each type of dependency. (Malone et al., 1999; Crowston 2003; Crowston, Howison, & Rubleske, 2006). The three basic types of dependencies include fit, flow, and shared resources (Malone et al. 1999). Coordination theory identifies coordination mechanisms for managing different types of dependencies. For example, prerequisite constraints in producer/consumer relationships can be managed through notification, sequencing, and tracking. Beyond the original idea of coordination theory, more recent research (e.g., Howiston, Østerlund, Crowston, & Bolici, 2012) looks at “implicit coordination” that uses outcomes of shared work as coordination devices similar to the biological process of stigmergy, first described in relation to how the reconstruction of termite nests is coordinated based on the evolving state of the nest. (e.g., Theraulaz & Bonabeau, 1999)

- The central focus of coordination theory concerns managing dependencies among activities and resources. In contrast, SINT includes coordination and other types intentional and unintentional interactions and, thereby, covers system interactions that are may or may not be related to coordination.

Loose coupling theory appeared in the organization science literature in the 1970s (Glassman, 1973; March & Olsen, 1975). Weick's (1976) widely cited paper on educational organizations as loosely coupled systems identifies many characteristics of loosely coupled systems and notes important advantages of loose coupling related to issues such as the ability to absorb changes, improved sense making, the ability to allow localized adaptations, mutations, and novel solutions, and the ability for a larger system to endure breakdowns in particular subsystems. Coming at loose versus tight coupling from a different direction, a book called *Normal Accidents* (Perrow, 1984) uses many examples to illustrate the dangers of technically complex high-risk systems that are tightly coupled. It argues that "no matter how effective conventional safety systems are" (p. 4), the possibility of cascading failures within tightly coupled systems makes accidents inevitable and, hence, "normal".

- SINT focuses on interactions *between* systems rather than on loose or tight coupling within systems. SINT is still relevant to loose and tight coupling in work systems because components can be systems on their own right. Conversely, some of the ideas about loose and tight coupling are related to ideas about system interactions.
- The graphical form of loose coupling theory in Orton and Weick (1990) was a direct source of SINT's structure as mentioned in Section 2.3

A9. Work System Theory

SINT is based on work system theory (WST), which comprises three components, the first two of which play a prominent role by defining the category of systems whose interactions SINT describes. The components are:

1. The definition of work system (see Section 2.1).
2. The work system framework (Figure 1), a static view of a work system as it exists during a particular time interval when it retains its identity and integrity even though it may change slightly through small adaptations, workarounds, personnel changes, and even unintentional drift.
3. The work system lifecycle model, a dynamic view of how work systems change over time through a combination of planned and unplanned change.

Viewing system interactions as interactions between work systems (rather than interactions between tasks, people, or software modules) provides a richer view that calls for considering all nine elements of the work system framework for both interacting work systems and for the system interaction itself. Those elements include customers, product/services produced, processes and activities, participants, information, technologies, environment, infrastructure, and strategies. Alter (2013, 2015) provides a complete explanation of WST. Among the extensions of WST are successive versions of a work system metamodel (Alter, 2016a, Alter and Recker, 2017) that were developed to support more detailed analysis of a work system than the work system framework (Figure 1) supports. One of the relationships in the latest versions of the metamodel says that a focal work system may interact with customer work systems and/or other work systems. Understanding those relationships as something more than several arrows in a diagram called for the development of SINT.

- All discussions of WST that I know about focus primarily on individual work systems and say little or nothing about system interactions in general. That omission is an important limitation when trying to use WST in situations that involve important interactions between work systems.
- One can view SINT as an addition to a series of "extensions" of WST (Alter 2013, 2015) that go beyond the three-part core of WST summarized above. Whereas WST looks at an individual work system more or less in isolation, SINT looks at interactions between two or more work systems.

About the Authors

Steven Alter is Professor Emeritus at the University of San Francisco. He earned a PhD from MIT and extended his thesis into one of the first books on decision support systems. He served for eight years as Vice President of Consilium, a manufacturing software firm that went public and later was acquired by Applied Materials. Since returning to academia, his research has focused on developing systems analysis concepts and methods that can be used by typical business professionals and can support communication with IT professionals. His 2006 book, *The Work System Method: Connecting People, Processes, and IT for Business Results*, is a distillation and extension of ideas in a series of IS textbooks (1992, 1996, 1999, 2002) that raised awareness of the essential role of IT in work systems in organizations. Subsequent research continues to extend those ideas in many directions. His papers have been published in many leading journals and conference proceedings.