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WAx: An integrated conceptual framework for the analysis of cyber-socio-technical systems

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ABSTRACT

Modern work domains are constituted by an intertwined set of social and technical actors with different, often conflicting, functional purposes. These agents act jointly to ensure system's functioning under both expected and unexpected working conditions. Considering the increasing digitalization and automation of work processes, socio-technical systems are progressively including interconnected cyber technical artefacts, thus becoming cyber-socio-technical systems (CSTSs). Adopting a natural science perspective, this paper aims to explore knowledge creation and knowledge conversion within CSTSs, as rooted in an in-depth analysis of work practices and work contexts. The paper proposes a conceptual framework which unveils the relationships between different work representations, i.e. relying on Work-As-Imagined, Work-As-Done, Work-As-Disclosed, Work-As-Observed, intended as knowledge entities generated by different agents, i.e. sharp-end operators, blunt-end operators, and analysts. The recursive and fractal nature of the proposed WAx (Work-As-x) framework ensures its adaptability for different granularity levels of analysis, fostering the understanding, modeling, and analysis of work practices, while abandoning reductionist and over-simplistic approaches.

1. Introduction

Modern work domains call for a large reconsideration of the notions referring to risk and safety management. Such reconsiderations arise from the evolving nature of technology and the competitive fast-moving modern working conditions. In such hardly predictable work environments, the interactions between social and technical aspects of work become symbiotic, as early acknowledged in a 1950s seminal human-related research (Trist and Bamforth, 1951). The notion of socio-technical systems was there used to represent the purposeful structure of interrelated and interdependent social and technical elements, influencing one another, directly or indirectly, to maintain their activity, and the existence of the system itself to purse its goal (Walker, 2015).

Especially considering the recent developments in computer science and information technologies, nowadays it becomes relevant to extend the concept of socio-technical systems in a way that explicitly includes computational entities. As current - and future - systems are even more complex systems, we adopt the notion of cyber-socio-technical systems (CSTSs). These latter represent the class of socio-technical systems extensively constituted of peculiar computational artefacts that provide and use data-accessing and data-processing services for and from other connected entities (Monostori et al., 2016a). Nevertheless, the degree of automation resulting from this cyber dominance does not result in a reduced human interaction or workerless production; it rather demands for a different type of human contribution and respective skills.

Fig. 1 sketchily depicts the scope of a CSTS by means of Venn diagrams. These latter show the evolution of the notion of technical system towards modern CSTSs. Traditional technical systems include physical devices (P in Fig. 1), infrastructures, and machines (e.g. lathes, milling machines), which are used to support human activities. Socio-technical systems deal mainly with the above-mentioned symbiotic interactions (PH) between physical systems (P) and human agents (H), possibly prioritizing the scope of the analysis to the role of human agents under certain assumptions.

Modern technical systems are defined by both a cyber (C) and a physical (P) part. The former encompasses software systems, which nowadays are characterized by increasing autonomy and intelligence, while the latter includes traditional technical systems, hardware

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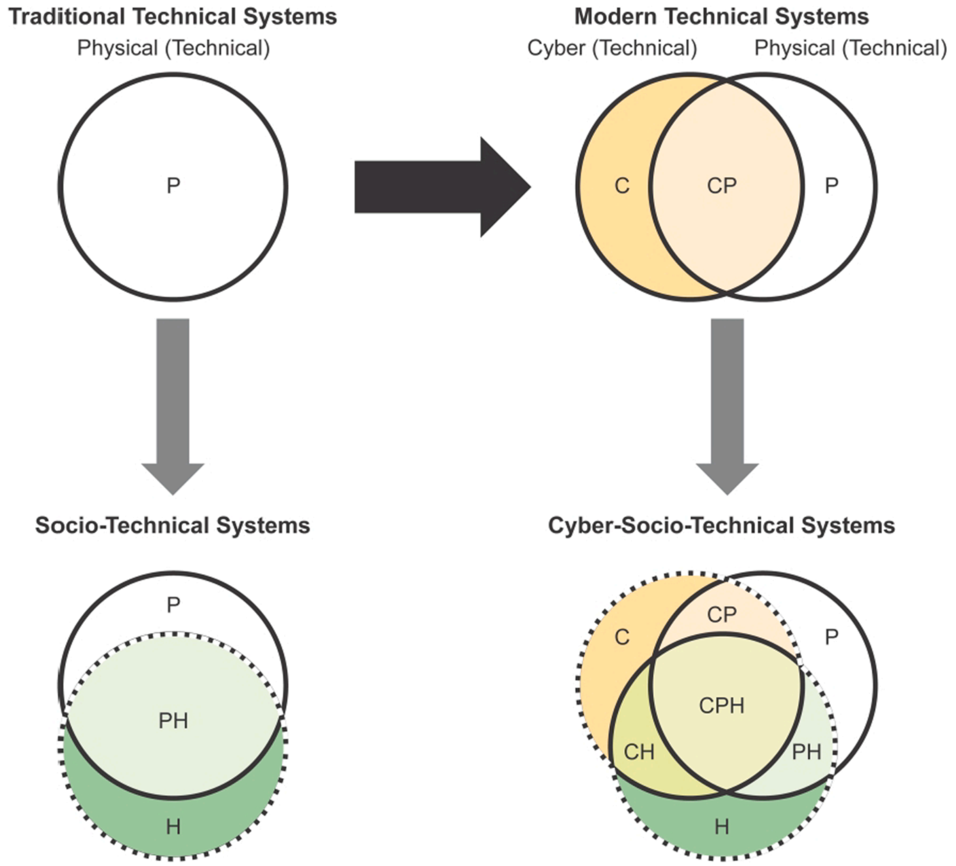

Fig. 1. Evolution of the notion of technical system towards cyber-socio-technical systems (CSTSs).

infrastructures, and other modern physical devices, such as sensors and actuators, that are conceived to interoperate with their cyber counterpart. Examples of cyber-physical systems (CP) are robots where both the cyber and physical aspects work jointly to achieve a functional goal. We consciously use the notion of CSTS to emphasize that our unit of analysis includes those systems that deal with cyber artefacts, physical devices, and human agents (CPH) (Bereket Abera et al., 2020; Sowe et al., 2016). Furthermore, the notion of CSTS allows us to go even further. Differently from the traditional notion of socio-technical systems, in light of the cyber artefacts' increased autonomy and intelligence, the analysis of CSTS extends towards the "social" relationships between humans and cyber artefacts (CH), as well as multiple cyber artefacts that act jointly (C). Hence, the dashed lines of the bottom right Venn diagram (i.e., C, CH, CP, CPH, H, PH) summarize the scope of CSTS, as interpreted in this article.

Such relationships deal with how they cooperate to achieve functional goals and encompass open research issues such as the AI explainability, AI interpretability, and cyber trust (Linkov et al., 2020). In terms of safety, ignoring the relationships between humans and next generation AI devices could have dramatic consequences (Tegmark, 2017), (e.g.) increased social manipulation, new types of warfare or shifts in power dynamics (Everitt et al., 2018).

As early proved by the study of socio-technical systems (Woods and Hollnagel, 2006a, Woods and Hollnagel, 2006b), an individual and disjoint analysis of the tightly interacting components of a CSTS can lead to a biased and ineffective understanding of the respective work environment (Righi et al., 2015). Modern safety science invites analysts to adopt holistic approaches having the potential to ensure robust and representative analyses. The field of Resilience Engineering explicitly builds on the understanding, modelling and engineering of adaptive capacities, subsequently to the exploration and understanding of the nitty–gritty of a work domain (Patriarca et al., 2018). Considering the dominant role of information technology and knowledge-based interactions among a variety of agents (e.g. human individuals, groups of individuals, organizations, computational artefacts), it becomes necessary to complement Resilience Engineering with the principles of knowledge representation (Simon, 1996). From this integrated point of view, it is required an epistemological investigation on the process of making available and amplifying knowledge created by individual entities towards other entities (social or technological) (Nonaka and von Krogh, 2009). The proposed varieties of human work are even less explored in available literature, if Resilience Engineering perspective is adopted for CSTSs.

The aim of this paper is thus to develop a conceptual framework for the representation and the analysis of a complex system's information flows. The proposed framework, named *WAx (Work-As-x) framework*, acknowledges the role played by multiple varieties of work domain representations as well as the centrality of knowledge management, especially when information is distributed among diverse agents. The analysis addresses these dimensions from a natural science perspective in order to develop a set of concepts, a language, with which to characterize phenomena. These artefacts, summarized in the WAx framework aim at developing an information-driven model to better understand the phenomenological creation and conversion of knowledge in CSTS systems (March and Smith, 1995). The notion of conceptual framework is used to represent a product of the qualitative processes of theorization. It is intended as a metaphoric plane of interlinked concepts that together provide a comprehensive understanding of a system's functioning (Jabareen, 2009).

The importance of this contribution is not only referred to the definition and integration of work varieties from a knowledge management perspective. It rather aims at integrating different theories in a unique abstract framework that provides modern safety scientists and safety analysts a deeper understanding of complex CSTSs functioning and information flows. This aim is aligned with a set of commitments gathered in the recently published manifesto for reality-based safety science, specifically focused on providing and emphasizing the need for in-depth work investigation and descriptions of real practices and operating contexts (Rae et al., 2020).

The remainder of the paper is organized as follows. Section 2 deals with the foundations of the proposed conceptual framework, grounded in natural and behavioural science, as well as socio-technical systems, Resilience Engineering, cybernetics and knowledge management theory. Rooted in abstract artefact design science, Section 3 describes the general steps adopted for building the proposed conceptual framework. The section then describes the entities and the relationships among each plane and variable. Section 4 further explains the significance of the proposed conceptual framework discussing its applicability and its added value. Lastly the conclusions summarize the outcome of the work, and the potential paths for future research.

2. Literature review

When we are interested in overall behaviours of a set of interrelated entities, we conceptually isolate them from the rest of the world, then we call system the former and its environment the latter. Since everything is somehow connected (i.e. the system also relates to its environment), the one who performs the analysis determines the system itself in the moment when he/she sets the boundaries of the analysis. In practice, we are accustomed to think about a system's goals and purpose in teleological terms (Dekkers, 2017a). Varying the observation scale and/or the analysis breadth changes what should be considered within the system's boundaries and, accordingly, it might result in pointing out different system's purposes and goals. This concept is of particular interest for the scope of this paper, especially in light of the definition of CSTS, as sketched in Fig. 1.

The notion of "system" is a social construct which subsumes several relationships (i.e. ties) between entities (i.e. subparts) expressed in various forms. Starting from these entities' relationships, system analysts are interested in explaining, controlling, foreseeing their overall evolution or in performing some generic speculative explorative activities upon the system itself. Such activities are in general as harder as higher is the number of the subparts, and the number and varieties of ties (Cilliers, 2010; Dekker et al., 2013). The identification of the interacting components is in itself difficult. They are connected in intricate, multiple, non-linear ways, so that the evolution that originates from them is unpredictable, even chaotic (Branlat and Woods, 2010). The many variables involved act concurrently begetting an intricately non-linear behaviour, in which causes and effects are usually afar in space and time (Lineweaver et al., 2013). A complex system typically manifests a fractal self-organization, in which sub-components are in turn complex systems with specific local properties, aims and purposes, i.e. systems of systems with the potential for "emerging" events (Cotsaftis, 2009; Erdi, 2008). The so-called complex adaptive systems are able to modify their emerging behaviours in order to adapt to the surrounding environment and sometimes even modify it (Dekkers, 2017b; Miller and Page, 2007).

Socio-technical systems represent a remarkable example of complex adaptive systems, in which social and technical elements directly and indirectly influence each other in a reciprocal way both to continue to exist (i.e. to maintain homeostasis) and to pursue the purposes for which they were instituted (Davis, 1977). It is incorrect to think of the technical and social parts as two clearly distinguishable subsystems (Flaherty, 2019). These two souls are so closely interconnected that the execution of the internal processes is influenced both by technology and by people who use it (Di Maio, 2014). This synergistic action of the social and technological sides is so deeply rooted into work activities (Emery, 1993) that its imprint was even recognized among coal miners, whose work underwent changes and developments with the industrial revolution (Trist and Bamforth, 1951).

The manifest evolution of socio-technical systems is represented by the CSTSs, as already suggested in the introduction. The notion of CSTS is here used to depict systems that involve complex interactions between humans, at different social levels, machines, data-accessing and data-processing software services, and environmental aspects (Baxter and Sommerville, 2011; Monostori et al., 2016b). In a CSTS, the analysis of autonomous or semi-autonomous machines demands for specific knowledge creation/conversion. Under Industry 4.0 paradigm, research has focused on knowledge-based interactions among smart objects, humans and other actors participating in value co-creation (Dragicevic et al., 2019). For example, these latter scholars propose a framework for knowledge dynamics where smart objects are capable of learning, adjusting and acting in the environment by mimic human decision-making. However, humans still handle machine-generated data and information independently and use these results in a complementary way, creating connections through tacit acts.

Because of their intrinsic adaptive nature, CSTSs do not tend to possess functionally stable parts, rather generating dynamic behaviours. Consequently, systems' observability is reduced, even considering the role of the observer (i.e. the analyst) as a component affecting - and being affected - by the system itself (Dekkers, 2017c).

Focusing on the cyber portion of a CSTS, it appears evident how CSTSs require an even deeper detail of analysis about the work is conducted, especially in terms of information flows. Exploring a work domain through different perspectives is one of the pillars of Resilience Engineering for socio-technical systems (Bueno et al., 2019). It has been acknowledged how these varieties bring together multiple complementary information, which should be explored to fully capture the status of the system (De Vries, 2017; Patriarca and Bergström, 2017). Two of the main dimensions for this analysis are commonly labelled as Work-As-Done (WAD), or Work-As-Imagined (WAI) (Hollnagel, 2017a). Resilience Engineering suggests investigating the gap between WAI (a theoretical representation of work activities) and WAD (the activities as actually done) to find potential criticality, in a proactive sense. Other work varieties do exist as well, considering finer granularity levels for their representation, i.e. Work-as-Disclosed, and Work-As-Prescribed (Moppett and Shorrock, 2018).

In light of this multi-dimensional unit of analysis, and locally rationale representations of work, analyses should be systemic to fully capture the complexity of the respective information flows (Rizun and Shmelova, 2017). Asymmetry in information exchange may reflect in asymmetric decisions. Often, an informative misalignment hinders the communication between the workers at different ends of the same process (i.e. blunt-/sharp-end), as well as between analysts and operators themselves. Moreover, the complex nature of CSTS can also generate collective cognitive impairment phenomena, akin to corresponding individual psychological issues (e.g. organizational cognitive dissonance (Vanderhaegen and Carsten, 2017)). Even if the impact of these problems could be in principle lessen by acquiring new knowledge (Ruault et al., 2013), this latter is hampered by the limited information actually conveyable.

To this extent, CSTSs express features that characterize them as an even more promising staging area for the application of Resilience Engineering principles. In CSTSs, information should be indeed carefully distributed and analysed in relation to knowledge transfer and management processes. Modern research on organizational theory consistently focuses on strategic impact on performance and its capability to produce long-term sustainable competitive advantage (Nonaka et al., 2014; Zack et al., 2009), enhancing management activities (Alavi and Leidner, 2001), and influencing assets and processes (Brantianu, 2016).

In this research stream, particular relevance is acquired by the knowledge creation and conversion process (Alavi and Leidner, 2001). For a CSTS, knowledge creation at organizational level aims at generating new knowledge through collaborative processes and experiences stored otherwise separately in individuals' minds. Connecting this aim with Resilience Engineering principles, it appears evident how analysing and supporting this creation is a hard challenge considering the difficulty in capturing people' minds, interpreting them unambiguously, or even formalize them by pure logical reasoning (Alavi and Leidner, 2001).

The most relevant theoretical contribution on the interpretation and analysis of organizational knowledge management is the SECI model (Nonaka et al., 2000), which develops the view of knowledge-as-a-flow. Acknowledging the complexity of a CSTS, knowledge can be captured, codified, transmitted, and used by means of dynamic and continuous processes. The SECI model further exploits such flows, distinguishing between explicit knowledge and tacit knowledge, at individual, intra-organization and inter-organizations levels, where the notion of tacit knowledge is based on the theory of tacit dimension (Polanyi, 1983). The tacit dimension of human knowledge is also internalized both in the conscious and unconscious mind, and, as such, it represents a level of understanding that cannot be fully externalized. Therefore, a transformation of tacit into explicit is not a complete pure transformation of what was intended, for example, by the originator of a message. The act of understanding is an emergent phenomenon where higher dimensional meanings are generated from lower dimensional particulars within the dynamics of a tacit knowing.

In the context of (inter-)organizational knowledge management, it has been specified that explicit knowledge is easily expressed, stored and reused, and it can be transmitted in various forms, mostly written such as handbooks and procedures (Nonaka et al., 2000). On the other hand, tacit knowledge consists partly of technical skills and partly of agents' mental models, beliefs and perspectives that cannot be easily articulated. This idea is linked to different varieties of a work domain, as prescribed by Resilience Engineering principles (Hollnagel, 2017). In the SECI model, tacit and explicit knowledge are mutually complementary entities, interacting in a spiral model of evolving knowledge creation by individuals of the organization, up to inter-organizational relations. Each iteration of the spiral is achieved by means of four steps of knowledge conversions: socialization, externalization, combination and internalization. The first step, socialization, is a social process representing the transfer of tacit knowledge between individuals through observation, imitation and practice (empathizing). Then, externalization is triggered by dialogue or collective reflection as an individual process to translate tacit knowledge into documents and procedures (conceptualizing). Subsequently, combination is a social process that allows to reconfigure bodies of explicit knowledge through adding, combining and categorizing (modelling), and, lastly, internalization is an individual process to translate explicit knowledge into individual tacit knowledge by putting the model into practice (practicing). Thus, knowledge is created by means of continuous and dynamic social knowledge acquisition processes, enabled by physical, virtual, cultural, and emotional components as context in motion (Nonaka's ba concept), and constituting a fractal organization structure (Nonaka et al., 2014). This fragmented knowledge is strictly related to the multifaceted representations of work, and thus should be studied jointly.

On this basis, the conceptual framework proposed in this research builds upon knowledge dynamics grounded on the SECI model, in which multiple actors constantly elicit, create, transfer, and interpret information. Differently from knowledge classification frameworks available in the literature, this research proposes a classification of the knowledge objects based on their content, their abstraction level, and the knowledge owner. This research abandons oversimplistic causality credo and bimodal representations of reality (Hollnagel, 2012) in favour of a multifaceted perspective able to encompass a diverse set of varieties of human and cyber work (Moppett and Shorrock, 2018). These latter are modelled starting from the conversion types of the SECI model, and further extended to include the purposeful structure of a CSTS.

3. The conceptual framework

This section firstly presents the generic building steps of the conceptual framework, developed following (Jabareen, 2009); then it shows the specific framework items, providing an in-depth description of their inter-relationships.

3.1. Building steps

The method proposed by (Jabareen, 2009) is particularly helpful for the purpose of this research, since the proposed framework relies on different bodies of knowledge, mainly ascribed to socio-technical systems, CSTS, Resilience Engineering, and knowledge representation. The team included six researchers with mixed background and expertise: four in industrial engineering and resilience management, and two in computer science and knowledge management. The work has been conducted in form of individual documental studies, and a number of focus groups to facilitate theoretical saturation in conducting thematic analysis, and to foster discussions on the emerging concepts (Breen, 2006).

With respect to the content of this paper, 8 different phases can be described as follows:

Phase 1. Mapping the selected data sources

The purpose of this phase was the identification of relevant sources able to represent available knowledge on the topic. This scoping review process (O'Keeffe et al., 2015) relying on Scopus, Google Scholar, and Web of Science, has been conducted to identify key factors related to the concepts of socio-technical systems, cyber-physical systems, cyber-socio-technical systems, knowledge representation, knowledge engineering, knowledge management, and resilience. The majority of these contributions has been gathered in the literature review section, taking value from the multi-disciplinary research team involved in the research.

Phase 2. Reading and categorizing of data

This phase aimed at categorizing the data by discipline and by a scale of importance. The task has been conducted combining qualitative judgements on the publication fora, authorship, and recency, as well as relevance in terms of citations among each discipline being investigated. The data being investigated referred mainly to conceptual factors, abstract artefacts which subsequently concurred to constitute the foundations for the conceptual framework. Qualitative assessments have been based on prioritizing relevant journals in the field (Safety Science, Cognition, Technology and Work, Reliability Engineering and System Safety, IEEE journals, etc.), as well as contributions authored by eminent authors for both Resilience Engineering and knowledge management.

Phase 3. Identifying and naming the concepts

This phase aimed at extracting concepts from selected literature, which in the first iteration were sometimes contradictory and/or partly overlapping.

Phase 4. Analysing in-depth and categorizing the concepts

This phase aimed at deconstructing each concept, to identify its main attributes, assumptions, and role within the knowledge field and thus ensure representative labels, and unambiguous associated descriptions.

Phase 5. Integrating concepts

This phase allowed reducing the number of concepts to be represented by integrating the ones obtained in Phase 4 that presented common features or generating new concepts that could better summarize some of the previously identified ones.

Phase 6. Synthesis, and re-synthesis and making it all make sense

This phase is then the core of the building phase. It has been iteratively applied to ensure the emergence of a general framework from the analysis, via repetitive syntheses and re-syntheses run by different researchers individually, in sub-groups, and in group.

Phase 7. Validating the conceptual framework

The framework has been initially validated among the researchers, then shared among informal discussion with academic colleagues and then submitted as early results in other conferences and workshops to check for validation among scholars acting as outsiders (Costantino et al., 2020a, Costantino et al., 2020b; De Nicola et al., 2020). The

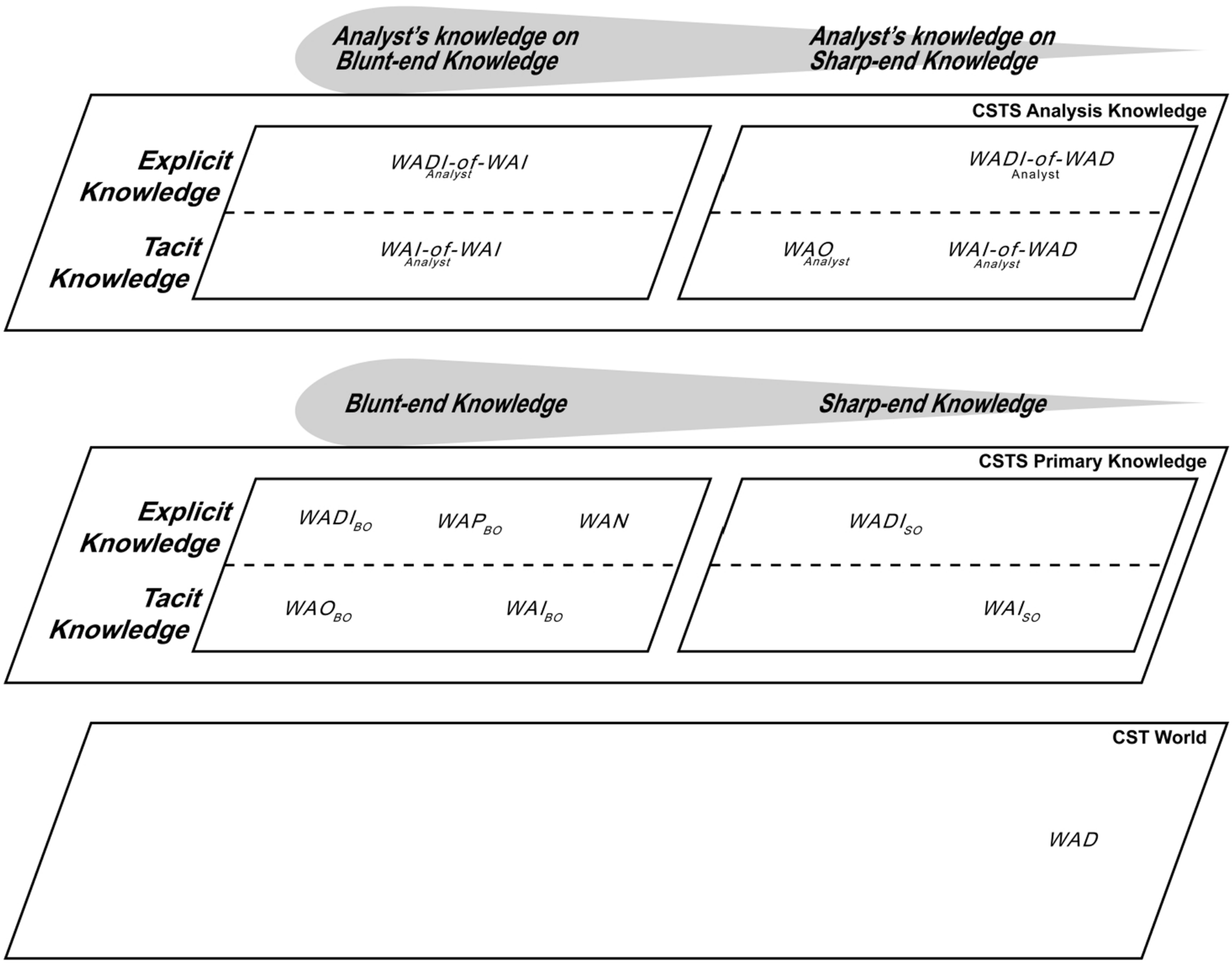

Fig. 2. Knowledge structure and knowledge entities of the WAx conceptual framework for the analysis of CSTSs.

framework has been presented and extensively discussed at an international workshop on socio-technical systems (6th International Workshop on Socio-Technical Perspective in Information Systems development). The presentation motivated several discussions during and after the workshop, following the process that is generally known as dependability by qualitative researchers (Anfara et al., 2002). This step has been conducted to challenge critiques from peers and increase the reliability of the work, also motivating the development of a more robust conceptual structure, and a graphical refinement for a more appealing representation.

Phase 8. Rethinking the conceptual framework

This phase is proposed to highlight the inherent incompleteness of a framework dealing with a multi-disciplinary concept, which requires a dynamic revision incorporating new insights, comments and literature.

Note that the framework presented in this work is the outcome of the first 7 phases.

3.2. Detailed description

The conceptual framework is constituted by (i) knowledge structure, (ii) knowledge entities, and (iii) knowledge dynamics which are the basic elements for the definition of a knowledge model for CSTSs. Knowledge structure and knowledge entities are shown in Fig. 2 while knowledge dynamics is incrementally presented in section 3.2.3. with Additional information are provided in Appendix A (at a graphical level) and Appendix B (at a detailed level).

3.2.1. Knowledge structure

The knowledge structure is made of three constituent elements: (i) **levels,** representing *where* knowledge is located, (ii) **knowledge types**, i.e. in which form (*how*) knowledge is preserved and (iii) **agency**, i.e. the agent who is responsible for the knowledge.

(i) Levels

The levels represent where knowledge is positioned. They are *CST (Cyber-Socio-Technical) world*, *CSTS primary knowledge*, and *CSTS analysis knowledge.*

The ground level, i.e. CST *world* is where knowledge is actually used to achieve the CST functional purpose. It is the real world that can be considered as a space where system operations, performed by humans, organizations, technical and cyber artefacts take place. These operations are ultimately unobservable in their entirety, but reasonable estimation can be reached via direct observation by humans or indirect ones by technology (i.e., sensors or software).

The first level, i.e. CSTS *primary knowledge* is where knowledge of the CST system is explicitly or tacitly created, shared, integrated and applied by blunt-end or sharp-end agents. Such knowledge includes organizational goals, rules, procedures, norms, beliefs, mental models, constraints, etc.

The second level, i.e. the *CSTS analysis knowledge* is where knowledge of the CSTS is acquired, integrated, elaborated and used by an analyst to pursue an analysis of the system (e.g., safety-oriented, efficiency-oriented, or a combined one in line with Safety-II concepts (Hollnagel, 2012)).

(ii) Knowledge Types

The knowledge types represent how knowledge is preserved. To this purpose we refer to the Unified Model for dynamic knowledge (Nonaka et al., 2000). This model classifies knowledge as explicit and tacit. Explicit knowledge can be expressed in formal and systematic language and shared in the form of data, scientific formulae, narratives, specifications, standards, manuals, models, programming codes or other multimedia materials. This can be processed, transmitted and stored. Tacit knowledge concerns subjective insights and perspectives, beliefs, intuitions, hunches, ideals, values, emotions, competencies and is not explicitly shared in formal and systematic language. For this reason, it is not directly and completely accessible to others except the information's owner.

(iii) Agency

The framework proposed here assumes a holistic perspective over CSTSs as emerging result of other complex self-adaptive subsystems, made up of organizations, teams, people, artefacts, which are organized in a recursively fractal way. Due to cybernetics, it is particularly relevant the concept of "agency" as a purpose-directed entity performing efficient means-ends actions (Craig et al., 2014).

In such framework there is a process and two subsystems that relate to it: the one proximal to the process (SO, i.e. sharp-end operator) and the one distal (BO, i.e. blunt-end operator). A third subsystem (Analyst) may act on the processes metacognitively. The Analyst represents an agent who analyses the system according to some properties (e.g. safety, efficiency). The Analyst can be external to the system (e.g. a third-party agent) or could be someone internal (e.g. an internal auditor) who observes some features of the system itself to gain insights on system's performance. It is worth noticing how the actions performed by the Analyst (even if in the form of interviews or observations) have the potential to affect some of the information flows in the system (e.g. stimulating thoughts, and to some extent updating the corresponding mental models). Therefore his/her actions are not fully independent from the behaviour of the system and should be studied jointly (Dekkers, 2017c).

For example, a SO is usually the one who has a direct relationship with the process being analysed (e.g., a worker on an assembly line); a BO is the one who has a stake in the system but does not operate directly on it (e.g., the production manager responsible for the production process); while an Analyst could be a performance observer (e.g. a safety or a compliance auditor).

The framework remains fractal and consistent at any level of the functional hierarchy, when a sharp-end operator may be constituted by a team of operators, and the blunt-end generally expressed by the middle-managers. Even more, a BO subsystem can be a guidelines-maker organization (e.g. WHO), a SO an implementing organization (e.g. a Hospital), and the Analyst a third-party consulting company (e.g. a research group). On this basis, the framework respects also the principles of Joint Cognitive Systems (JCS) considering co-agency as a basic unit of analysis (Woods and Hollnagel, 2006a, Woods and Hollnagel, 2006b). Depending on the resolution and the scope of the analysis, the fractal nature of the WAx framework allows considering humans and cyber-physical artefacts separately, or jointly, i.e. assigning a collective agent to the relevant co-agents.

Regardless of the resolution level, the associated knowledge to each agent can be regarded as explicit or tacit, depending on whether the perspective on the system might be assumed correspondingly internal or external. Generally, functioning processes of living beings are regarded as ultimately inaccessible, i.e. tacit. For cyber-agents, sometimes it might be doable (and useful) to inspect them, and therefore treat part of the knowledge associated with them as explicit. For similar reasons, at macro level, shared knowledge associated with an organization is usually considered explicit, yet several aspects of organizations are opaque and then related fragments of information remain tacit.

In the context of inter- and intra-organizational knowledge management, these treats lead to have resilience emerging at different levels, i.e. micro-meso-macro. Such properties become the usual unit of analysis for a CSTS analyst, who in turn may have both blunt-end and sharp-end knowledge. Hence, blunt-end knowledge is interpreted as the CSTS knowledge created, owned, stored, applied and shared within the system, and communicated by a blunt-end operator. On the other hand, sharp-end knowledge is part of the system knowledge created, owned, stored, applied, and shared within the system, and communicated by a sharp-end-operator.

Note that even within the same level of system hierarchy, blunt-end/sharp-end agency is possibly recursive. For example, a production manager who is a BO in the analysis of the assembly line operation process, becomes the SO in case the process being analysed is the development of a production plan. Consequently, in this case the BOs will be (e.g.) the area manager, who is more distant from the process. Similarly, when studying the nitty gritty details of an assembly products sub-process (e.g. a robotic-assisted loading and unloading) the SO may be the cyber-physical artefact, while at the blunt-end the operator is the one who prescribes the actual work conditions, impacting the internal process model of the artefact itself. This latter is labelled as the software mental model in the sequel of the paper to keep coherence among the atomic agents involved in the WAx framework.

3.2.2. Knowledge entities

The knowledge entities represent different knowledge dimensions, i.e. what knowledge is referred to. In particular, the unit of analysis for a CSTS is the various forms of a work domain, especially in case Resilience Engineering is embraced as a dominant research perspective. The representations of work depends on the dimension being investigated and on the perspective used for the analysis (Adriaensen et al., 2019; Pollock, 2015). The knowledge entities in the conceptual framework are largely based and extended on the varieties of human work as proposed on Moppett and Shorrock (2018).

- *Work As Imagined* (WAI) expresses the mental models conceiving work related activities, where work is then a possibility (i.e. as imagined can be done either in the past, present or future) or a belief (i.e. how we imagine others execute their activities, but also how we think we execute ours);
- *Work As Prescribed* (WAP) encompasses the available prescriptive aspects of work within the organization responsible for the process being investigated, usually following different degrees of formalization at task or job level (e.g.) procedures, checklists, standards, or job descriptions, prescriptive training.
- *Work As Normative* (WAN) encompasses external normative and prescriptive regulations external to the CSTS– varying in degrees of formalization – such as laws, rules, international standards, governmental safety procedures.
- *Work As Done* (WAD) is the actual activity only partially accessible, as carried out in the working environment. Since the environment is usually dynamic, unstable and unpredictable, this variety is usually different from what has been imagined or even prescribed.
- *Work As Disclosed* (WADI) represents what system agents convey, explain or espouse about work, consciously or unconsciously. The disclosure of work is for the most tailored to the purpose of the message and to what the audience is – or it is assumed it is – expecting. More or less deliberatively, it is affected by the interaction with the audience. However, a portion of the communication is independent of the agent's will, i.e. both redundant and conflicting signs disclosed during the processes convey information richer than that one intended in principle by the agent. In a CSTS, this variety of work also encompasses the role of cyber artefacts that disclose data on process activities they are executing.
- *Work As Observed* (WAO) is referred to the mental model of an observation of the work. Even if assuming naturalistic observations, when referring to human components, the WAO is expected to be biased both by the mental model of the observer and by the

Hawthorne effect (i.e. a modification of worker's behaviours who are conscious of being observed) (Sedgwick and Greenwood, 2015).

The knowledge entities included in the WAx framework are shortly introduced in Table 1. These will be further described in the next sections of the paper and explored in the Appendix B in terms of structural and dynamical properties.

3.2.3. Knowledge dynamics

Knowledge dynamics refers to the elements dealing with the description of how knowledge is created and converted among different knowledge entities. This dynamic includes *foundational knowledge conversion activities* and *knowledge conversion drivers*. The former ones represent the activities that make knowledge creation and knowledge conversion possible, while the latter represent the explanatory factors connected to knowledge development, i.e. explain how it is converted.

(i) Foundational knowledge conversion activities

Foundational knowledge conversion activities allow knowledge conversion between two knowledge entities, as largely inspired by (Nonaka et al., 2000).

- *Socialization* (*Tacit-to-Tacit, different agents*): the activity that involves the sharing of tacit knowledge between individuals.
- *Introspection (Tacit-to-Tacit, same agent)*: the conscious or unconscious examination of one's own tacit knowledge, as taken at an individual level.
- *Externalisation (Tacit-to-Explicit)*: this activity requires the expression of tacit knowledge and its translation into comprehensible forms interpretable by external agents.
- *Combination (Explicit-to-Explicit)*: the activity referred to the conversion of explicit knowledge into other variants of explicit knowledge.
- *Internalisation (Explicit-to-Tacit)*: the activity related to the conversion of explicit knowledge into tacit knowledge.
- *Conceptualization (Action-to-Tacit):* the activity related to the creation of tacit knowledge from aspects related to real work actions in the CST world.
- *Reification* (*Tacit-to-Action*): is the activity of bringing tacit knowledge into action (e.g. translating a mental model of a process activity into the actual operating tasks).

Note that *Introspection, Reification and Conceptualization* are activities that have been added to extend the original framework by (Nonaka et al., 2000) for the purpose of CSTS analysis. Furthermore, an additional *meta*-activity is relevant for the purpose of the knowledge analysis, which is the *Influence.* This latter represents the effect played by an agent when eliciting knowledge, due to his/her own pre-existing tacit knowledge. Differently from the previous ones, this activity does not relate directly to the knowledge entities, it rather affects the conversion process of a knowledge conversion activity between two entities. Influence takes account of the afore-mentioned preconceptions and communication effects.

Table 1
Knowledge entities included in the WAx framework.

Knowledge entity acronym	Short description
WAD_{SO}	Work As Done by the Sharp-end Operator
WAI_{SO}	Work As Imagined by the Sharp-end Operator
WADI_{SO}	Work As DIsclosed by the Sharp-end Operator
WAP_{BO}	Work As Prescribed by the Blunt-end Operator
WAN	Work As Normative
WAI_{BO}	Work As Imagined by the Blunt-end Operator
WAO_{BO}	Work As Observed by the Blunt-end Operator
WADI_{BO}	Work As DIsclosed by the Blunt-end Operator
$\text{WAI}_{\text{Analyst}}$-of-WAI	Tacit knowledge (WAI) on the WAI created by the Analyst
$\text{WADI}_{\text{Analyst}}$ -of-WAI	Explicit knowledge (WADI) on the WAI as disclosed by the Analyst
$\text{WAO}_{\text{Analyst}}$	Work As Observed by the Analyst
$\text{WAI}_{\text{Analyst}}$-of-WAD	Tacit knowledge (WAI) on the WAD created by the Analyst
$\text{WADI}_{\text{Analyst}}$-of-WAD	Explicit knowledge (WADI) on the WAD as disclosed by the Analyst

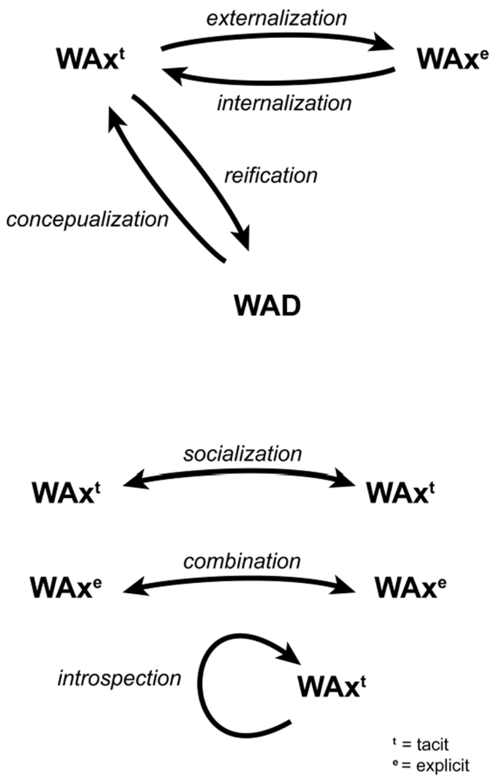

Fig. 3. How foundational knowledge conversion activities connect knowledge entities.

Fig. 3 depicts how foundational knowledge conversion activities apply to a generic knowledge entity WAx, throughout its tacit (WAx^t), explicit (WAx^e), and enactment (WAD) states. In our framework, WAx^t may thus represent WAI and WAO knowledge entities and WAx^e may represent WAP, WAN and WADI knowledge entities. Socialization affects WAx^t knowledge of different agents, and combination operates on different explicit representations of WAx.

(ii) Knowledge conversion drivers

Foundational knowledge activities can be driven by a combination of multiple drivers, both deliberative and accidental. An accidental driver is a knowledge conversion originated by an interpretation activity subject to information losses, misunderstandings, and subjective interpretations. Using a thermodynamic metaphor, accidental drivers refer to inescapable thermodynamic energy dispersion (in this case knowledge dispersion) present in every process. As such, we acknowledge that every knowledge transformation has a higher or lower accidental conversion, which leads to information loss.

Deliberative drivers can be classified via a set of *ETTO drivers* representing the motivating factor connected to a deliberative knowledge conversion due to ETTO (Efficiency-Thoroughness Trade-Off) principle (Hollnagel, 2009). An ETTO-driven conversion is always originated by the willingness of a subjective contribution to a knowledge conversion. We use the notion of ETTO to explicitly represent the intention of selecting the most thorough alternative in scenarios characterized by the limitedness of resources.

These transformations can be further detailed based on different deliberative choices, as follows:

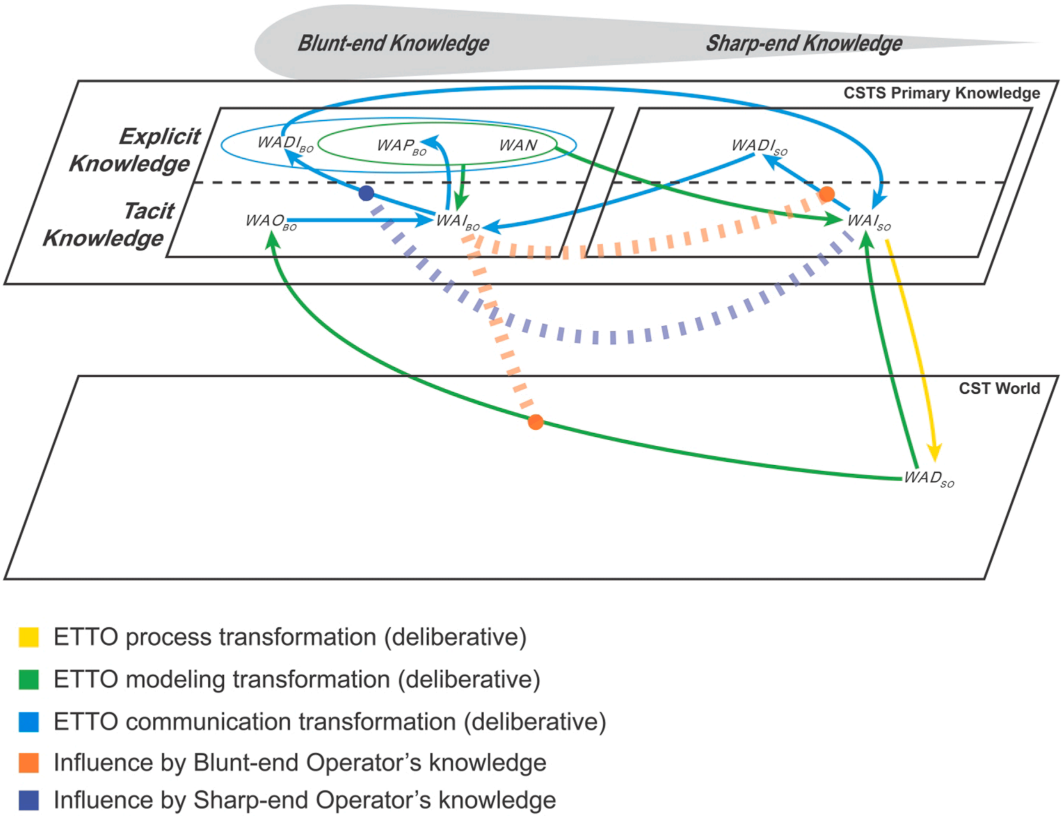

Fig. 4. Part of the WAx framework concerning the knowledge flow that relates to the CSTS Primary Knowledge.

- *The ETTO process driver* represents the ETTO motivating factor necessary to achieve a well-defined objective in specific contextual conditions. This is dependent on the process being analysed (e.g. skipping a delayed formal authorization for process activation in a machine to ensure process execution).
- The *ETTO modelling driver* represents the ETTO motivating factor caused by specific modelling choices (e.g., decision of a modelling perspective and/or formalism, selection of a modelling formalism, use of modelling best practices, selection of a model abstraction level). One example could be the adoption of the Functional Resonance Analysis Method (FRAM) (Patriarca et al., 2020) instead of the Business Process Model and Notation (BPMN). This is a deliberative modelling choice specifically helpful when dealing with safety-related issues in socio-technical systems. Similarly, an ETTO modelling driver could refer to the usage of tally counts for the occurrence of certain pre-identified behaviours during a naturalistic observation.
- The *ETTO communication driver* represents the motivating factor connected to a ETTO deliberative knowledge conversion driven by specific communication goals, or affected by the expectation on the knowledge conversion (e.g. hiding parts of the process not compliant with the existing laws and regulations, deliberatively provide more or less details on some aspects).

3.2.4. Knowledge model

The knowledge model details how knowledge flows from and towards multiple CSTS knowledge entities, with respective agencies. The conceptual framework can be explored from multiple starting points, as fully detailed in Appendix A and Appendix B.

To ease the description and interpretation of the knowledge model, the overall framework shown in Appendix A has been split into two projections based on two different levels of the structure. Fig. 4 shows knowledge conversions that involve BOs and SOs and lead to the creation of the CSTS primary knowledge on the works of the organization. Then, the focus in Fig. 5 is on the knowledge conversions referred to the creation of CSTS Analysis Knowledge based on the CSTS Primary Knowledge and on the CST world. In line with a resilience-oriented analysis of a CSTS, this perspective refers to the interaction between a BO and an Analyst with the aim, for this latter, to acquire knowledge on the WAI, as a key element towards the understanding of real work practices conducted by a SO.

Knowledge flow for the creation of CSTS Primary Knowledge

As described in Section 3.2.2, we distinguish between the tacit knowledge of the WAI owned by the blunt-end-operator, named WAI_{BO}, and the tacit knowledge of the WAI owned by the sharp-end-operator, named WAI_{SO}. Such a difference is partially motivated by tacit-to-explicit-to-tacit knowledge conversions during a socialization activity between a blunt-end and a sharp-end-operator. Disregarding purposeful malicious intents, the sharp-end interpretation of the explicit entities is always affected, to a certain extent, by entropic accidental knowledge degradation.

Table 2 displays the WAI_{SO} in a template with three sections including respectively: the corresponding name and acronym; the structure (i.e., level, knowledge type, and agency); and the dynamics (i.e., related foundational knowledge activity and knowledge conversion drivers). A complete list of templates for each knowledge entity has been included in Appendix B.

The WAI_{SO} comes from an internalisation of WAN and of WAP_{BO}, which, in turn originates from an externalisation of WAI_{BO} and, as such, can be affected by a deliberative ETTO communication transformation.

More in detail, both WAP_{BO} and $WADI_{BO}$ are knowledge entities produced by an externalisation activity by the BO, via tacit-to-explicit individual knowledge conversions from WAI_{BO}. In particular, the externalised WAP_{BO} includes organizational documental activities (e.g. procedures), but also verbal prescriptive knowledge (e.g. as prescribed during training-on-the-job). WAP_{BO} is generated for the purpose of the

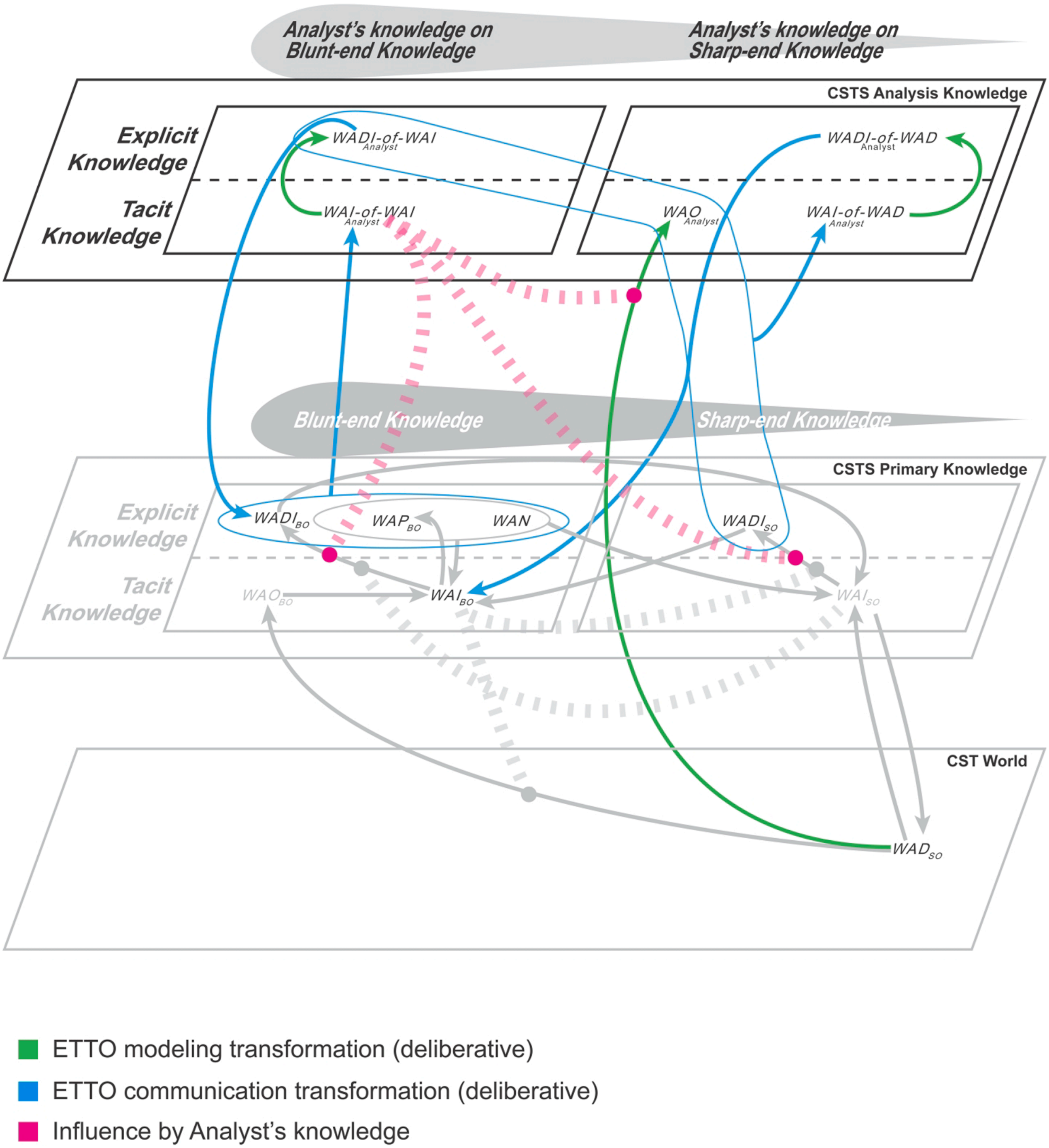

Fig. 5. Part of the WAx framework highlighting the knowledge flow that relates to the CSTS Analysis Knowledge.

operational activities carried out by the system, regardless of the analysis being performed. The WADI$_{\text{BO}}$, other than being the result of deliberative ETTO communication adaptation by the blunt-end-operator (i.e. what the blunt-end-operator is actually able and willing to describe) may be affected by inherent distortions of entropic nature, too.

The internalisation of WAN and WAP$_{\text{BO}}$ can be realized by means of both accidental entropic distortions and deliberative ETTO modelling transformations.

The creation of WAI$_{\text{SO}}$ is also affected by the internalisation of the WADI$_{\text{BO}}$, where this internalisation is in turn influenced by the WAI$_{\text{SO}}$ itself. About the WADI$_{\text{BO}}$, it is worthy clarifying how the WADI$_{\text{BO}}$ could also differ depending on the influencing entity WAI$_{\text{SO}}$, and as such drives to different ETTO communication conversions.

The WAD$_{\text{SO}}$, i.e. work-as-done at the sharp-end, corresponds to the perceivable actions of the process under investigation in the real world. When performed by humans as a reification of the tacit knowledge of the sharp-end operator (i.e. WAI$_{\text{SO}}$) this work may differ from the WAP$_{\text{BO}}$ or WAN. It rather results from real-time trade-offs required to deal with both the complexity of the operating scenario and the conflicting goals arising during work practices, in light of a local rationality principle (Hollnagel, 2010). This reification is the result of an ETTO process-driven conversion, besides the inherent accidental entropic conversion.

The WAI$_{\text{SO}}$ is also continuously modified by real work practices, i.e. by means of ETTO modelling conceptualizations of WAD$_{\text{SO}}$, or by other sharp-end operators' tacit-to-tacit socialisation.

When performed by a cyber artefact, the WAD$_{\text{SO}}$ is still a reification

Table 2
Knowledge entity template concerning the WAI$_{SO}$.

Work As Imagined by the Sharp-end Operator (WAI$_{SO}$)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Tacit
Agency = SO
DYNAMICS
WAI$_{SO}$ is an **internalisation** of (**WAP** and **WAN**) by **SO** with driver **EM**
WAI$_{SO}$ is a **conceptualization** of **WAD**$_{SO}$ by **SO** with driver **EM**
WAD$_{SO}$ is a **reification** of **WAI**$_{SO}$ by **SO** with driver **EP**
WADI$_{SO}$ is an **externalisation** of **WAI**$_{SO}$ by **SO** with driver **EC**, influenced by **WAI**$_{Analyst}$**-of-WAI**
WADI$_{SO}$ is an **externalisation** of **WAI**$_{SO}$ by **SO** with driver **EC**, influenced by **WAI**$_{BO}$
WAI$_{SO}$ is an **internalisation** of **WADI**$_{BO}$ by **SO** with driver **EC**
WAI$_{SO}$ influences **WADI**$_{BO}$ **externalisation** of **WAI**$_{BO}$ by **BO** with driver **EC**

Table 3
Knowledge entity template concerning the WAI$_{Analyst}$-of-WAI.

Tacit knowledge on the WAI created by the Analyst (WAI$_{Analyst}$-of-WAI)

STRUCTURE
Level = CSTS Analysis knowledge
Knowledge type = Tacit
Agency = AN
DYNAMICS
WAI$_{Analyst}$ **of-WAI** is an **internalisation** of (**WADI**$_{BO}$ and **WAP**$_{BO}$ and **WAN**) by **AN** with driver **EC**
WADI$_{Analyst}$**-of-WAI** is an **externalisation** of **WAI**$_{Analyst}$**-of-WAI** by **AN** with driver **EM**
WAI$_{Analyst}$**-of-WAI** influences **WADI**$_{BO}$ **externalisation** of **WAI**$_{BO}$ by **BO** with driver **EC**
WAI$_{Analyst}$**-of-WAI** influences **WADI**$_{SO}$ **externalisation** of **WAI**$_{SO}$ by **SO** with driver **EC**
WAI$_{Analyst}$**-of-WAI** influences **WAO**$_{Analyst}$ **conceptualization** of **WAD**$_{SO}$ by **AN** with driver **EM**

of the WAI$_{SO}$, which, in this case, is the computational activity of the machine for executing the task (WAD$_{SO}$). The prescribed WAP$_{BO}$ can generate an opaque software mental model, which is then translated into a WAD$_{SO}$. This latter has the potential of being unexpectedly different from what would have been expected by the WAP$_{BO}$, as a result of entropic and ETTO process conversions transformed via a reification, when dealing with (e.g.) a set of intertwined inputs from the environment, not explicitly controlled in the WAP$_{BO}$ (i.e. by the programmer's point of view).

The WAD$_{SO}$ conceptualized in the WAI$_{SO}$ can then be disclosed by the sharp-end operator to generate another explicit knowledge entity, i.e. the WADI$_{SO}$, by means of an externalisation from WAI$_{SO}$. This externalisation applies to both purely human work, and to cyber work. In this latter case, the WADI$_{SO}$ can be interpreted as logs generated by the artefact itself, once there is a request from the operator.

Knowledge flow for the creation of CSTS Analysis Knowledge

The upper level of the conceptual framework refers to the knowledge creation by an analyst, by means of knowledge-based interactions with blunt-end and sharp-end operators. Note that this situation can refer to a process analysis for safety and/or efficiency purposes where, in general terms, three different agents play different roles. Furthermore, here this flow model is cyclic as the WAD, in the representation eventually disclosed by the analyst, i.e. the WADI$_{Analyst}$-of-WAD, or even the disclosed WAI, i.e. WADI$_{ANALYST}$-of-WAI, may contribute to enrich and modify blunt-end operator's knowledge on the work domain, and consequently, affect the other work varieties.

In the framework, the tacit knowledge on the WAI created by the analyst is named WAI$_{Analyst}$-of-WAI, as discussed in Table 3.

The socialization among the two agents is here realized and enriched by two knowledge conversions, namely externalization activities by the blunt-end operator followed by an internalisation by the analyst. More in detail, the WAI$_{Analyst}$-of-WAI is the result of the analyst' internalisation from the set of explicit possible descriptions of the work domain: WAN, WAP, and WADI$_{BO}$.

The way WADI$_{BO}$ is conveyed may further diverge from WAI$_{BO}$ also due to the influence of the WAI$_{Analyst}$-of-WAI during the socialisation activity between the blunt-end operator and the analyst.

Parallel to the WADI$_{BO}$, the WADI$_{SO}$ may diverge from the WAI$_{SO}$ as the outcome of the socialisation activity with the analyst. This socialisation can be affected on the one hand by the knowledge the sharp-end operator is actually able and willing to provide (externalisation), and on the other hand, on the limitedness of the analyst's own biased knowledge of the process. This logic applies to cyber artefacts as well. The analyst may indeed affect the WADI$_{SO}$ asking for (e.g.) data log to support or belie his/her WAI$_{Analyst}$-of-WAI, or simply provide ineffective log requests.

At a later stage, the WAI$_{Analyst}$-of-WAI is something that needs to be translated and communicated by the analyst, in a way that is representable and usable. WADI$_{Analyst}$-of-WAI is thus a conveyable representation, i.e. a model, which results from an individual own tacit-explicit conversion originating from the WAI$_{Analyst}$-of-WAI. This externalisation is driven by a deliberative ETTO modelling transformation, played by the analyst to address specific performance analysis needs (e.g. granularity, approximations, purpose of the analysis, recipient's needs). The WADI$_{Analyst}$-of-WAI can already represent a result of the CSTS analysis, since it supports the identification of various possibilities and beliefs on the process. When communicated to the blunt-end operator, it may affect his/her WAI$_{BO}$, in the ETTO communication-driven internalisation process run by the blunt-end operator. Furthermore, the WADI$_{Analyst}$-of-WAI often constitutes an entry requirement for the analyst's combination required to later generate his/her representation of the actual work, i.e. of the WAD$_{SO}$.

Both for human and cybernetic operators, the WAD$_{SO}$ can be observed by the analyst during a conceptualization with the sharp-end-operator, thus generating the WAO$_{Analyst}$. However, this latter entity might be affected by bias from pre-existing tacit knowledge, i.e. WAI$_{Analyst}$-of-WAI, especially in those cases where the observation is performed by the same analyst.

An intertwined internalisation/introspection activity is performed by the analyst to build tacit knowledge about the WAD$_{SO}$, which results in the creation of his/her new tacit knowledge entity, i.e. the WAI$_{Analyst}$-of-WAD. This latter originates from an entropic combination of WADI-of-WAI$_{Analyst}$ and WADI$_{SO}$ explicit knowledge, and by an individual entropic tacit-to-tacit introspection with the previously constructed WAO$_{Analyst}$. At this stage, when converting tacit knowledge to build an explicit version of it, i.e. a model, some deliberative ETTO modelling transformations are applied, causing possible differences between WAI$_{Analyst}$-of-WAD and WADI$_{Analyst}$-of-WAD, whose distance is reflected by the assumptions of the model and potential accidental information conversions.

Feedback knowledge flows from WAD

The feedbacks originating from the WAD$_{SO}$ to work-as-imagined varieties belonging to different agents can be explored as well through the framework. Such feedback may occur both at CSTS primary knowledge level, as a result of direct observations of the actual work by the blunt-end-operator, and at CSTS Analysis knowledge level for the observations as well.

More specifically, the WAD$_{SO}$ activates a conceptualization activity by the blunt-end-operator, thus generating a tacit WAO$_{BO}$. Such entity then causes an introspection for the blunt-end-operator tacit knowledge, which leads to a revision of the initial WAI$_{BO}$. On the other hand, the WAO$_{BO}$ is influenced by the WAI$_{BO}$, even considering the incoming knowledge respectively from the WADI$_{Analyst}$-of-WAI and the WADI$_{Analyst}$-of-WAD, is internalised by the blunt-end operator via an ETTO communication driver.

A similar conceptualization of the work as performed by the sharp-end operator (WAD$_{SO}$) is performed by the sharp-end operator himself and the analyst via ETTO communication drivers to generate

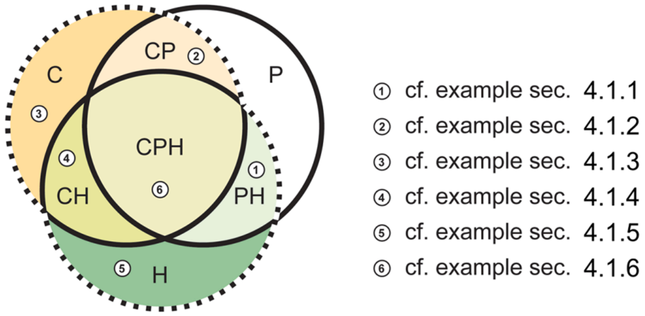

Fig. 6. Coverage of the examples with respect to the CSTS scope.

respectively the WAI_{SO} and the $WAO_{Analyst}$. This latter is in turn influenced by the $WAI_{Analyst}$-of-WAI, as progressively observed during actual work practices.

The logic applies to cyber artefacts when the mental model of the software (e.g. a control algorithm) is updated based on the feedback obtained from the sensors working on the controlled process, then leading to different actions carried out by the actuators.

4. Discussion

The WAx framework frames different varieties of CST work by combining different theories (i.e. natural behavioral science, Resilience Engineering, cybernetics) under a common knowledge representation framework, inspired by Nonaka's SECI model.

4.1. Applying the WAx framework to different CSTSs

In the following paragraphs, we present some examples of application of the WAx framework. Fig. 6 summarizes the proposed examples and their coverage on the variety of possible types of systems covered by the notion of CSTS. The examples regard, respectively, a physical-human system (section 4.1.1), a cyber-physical system (section 4.1.2), a cyber system (section 4.1.3), a cyber-human system (section 4.1.4), a social system (section 4.1.5), and two cyber-physical-human systems (section 4.1.6) respectively concerning an industrial production process and a service industry.

4.1.1. Physical-human system: The blacksmith

For convenience, one can consider first a simple activity as the use of a hammer, representing the WAD. A BO, the team manager, provides the SO (the blacksmith) with instructions for forging iron ($WADI_{BO}$). The SO receives different feedback contextually to the activity carried out and adapts to it by processing them (WAI_{SO}): she/he hears the sound of the blows, perceives the hammer in her/his hand, feels its weight and the inertia forces propagating across her/his arm and observes what she/he is doing. She/he evaluates her/his coordination during the gesture's execution, modulates her/his action controlling the progress of the nail inside the material. Hence, in this case, the sharp-end operator performs an ETTO process transformation. This is the simplest examples of a CSTS, in practice degenerated into a human-physical system (cf. Fig. 6, PH).

4.1.2. Cyber-physical system: A smart home system

The second example concerns a smart home system, which can be analysed from a cyber-physical perspective. We can consider an Intelligent Virtual Assistant constantly monitoring the soundscape in search of natural language to interpret (e.g. "Alexa!" or "Hey Google!"). Firstly, it needs a microphone (transductor) to scan the different emitting sources and secondly it must be capable of differentiate them. These transduced signals by the Intelligent Virtual Assistant are generally not accessible by users, but feeds the cyber-agent's mental model, i.e. its WAI_{BO}. This sends a command ($WADI_{BO}$) to a smart lamp, which plays the role of the SO. This latter receives the command, analyses it through its mental model (WAI_{SO}) and reifies it into actions (e.g.) by switching on the lights in a dining room (WAD). Such knowledge conversion could be prone to an accidental knowledge transformation due to (e.g.) a power or a signal drop. This system refers to the case where the system is actually restricted to technical components, still decomposing its cyber and physical parts (cf. Fig. 6, CP).

4.1.3. Cyber system: Social influence in Twitter

This example regards a cyber system inspired by the functionalities of some existing Twitter bots, currently available in the social network and discussed as well among the scientific community (Veale, 2015). @MetaphorMagnet is an AI bot that generates metaphorical insights (in this case, it can be interpreted as the $WADI_{BO}$) using its knowledge-based stereotypical properties and norms, which play the role of the BO's mental model (WAI_{BO}). Another bot named @MetaphorMirror (which could be the SO) uses these metaphors to generate news tweets (WAD_{SO}) by means of its mental model (WAI_{SO}). In this case, an ETTO communication transformation happens. Finally, a third bot named @WhatisTrending plays the role of the Analyst. It scans all the posted tweets, analyses them, included those posted by @MetaphorMirror, and creates reports on the trending ones. Depending on the mental model (WAI-of-$WAD_{Analyst}$) of @WhatisTrending, and its potential awareness of the fake nature of posts written by @MetaphorMirror, the reporting by @WhatisTrending (WADI-of-$WAD_{Analyst}$) might be fairly different, avoiding potential social manipulation (Cresci, 2020). This example describes a full cyber system, where the artefacts assume even a social dimension for knowledge transformation (cf. Fig. 6, C).

4.1.4. Cyber-Human system: Drone traffic management

This example regards an air traffic management scenario, which is inspired by a recent work concerning interactions between human operators and autonomous, automated, and manual control systems (Lundberg and Johansson, 2020). In details, it deals with a decision-making process where a human and a cyber-physical system play joint roles. The automatic air traffic management system for drone city traffic plays the role of the BO and provides automated decisions ($WADI_{BO}$) to adjust the amount of traffic based on its mental model (WAI_{BO}). The human operator plays the role of SO by monitoring the automation's decisions on the flights to be denied take-off clearance, and in case, by overruling (approving/cancelling) the same decisions on a drone-by-drone basis. The final decision based on the previous experience and knowledge owned by the operator (WAI_{SO}) will be what is then reified into real work practices (becoming the WAD_{SO}). In case the operator changes automation's decision, he/she performs an ETTO process transformation. This way, the system can be considered a cyber-human system, since the technical details subsumed to the technical artefacts are out of scope for the purpose of the analysis (cf. Fig. 6, CH).

4.1.5. Human system: Bridge management

This example concerns a maritime bridge management process (WAD) as inspired by a technical report (Hederstrom, 2015), exploited focusing on the human agents. The example shows the recursive and fractal nature of the WAx framework. The operations director acts as the BO and is in charge of overviewing the entire bridge operation, ensuring that it is carried out in accordance with company procedures (WAP and WAN). He/she provides guidelines ($WADI_{BO}$) to other members of the bridge team, which includes a navigator, a co-navigator, an administrator, a lookout, and a helmsman. The bridge team can be firstly considered collectively as the SO (at a lower granularity level), while finer resolutions may be identified with individual agents. Its members collaborate passing explicit knowledge ($WADI_{SO}$) related to planned actions, intentions, and orders. This collaboration can be prone to both accidental and deliberative knowledge transformation types, and for the purpose of the analysis can be considered as a full human system (cf. Fig. 6, H).

4.1.6. Cyber-Physical-Human systems

In addition to the previous examples, which provide some extreme conditions of applicability for the WAx framework in different types of CSTSs, it is convenient to explore the framework in light of a more intricate combination of agents, i.e. a cyber-physical-human system (cf. Fig. 6, CPH).

Still adopting the notion of CSTS, it is also worth noticing how the examples referred to a cyber-physical system (cf. section 4.1.2), as well as the one referred to a cyber-human system (cf. section 4.1.4), are actually cyber-physical-human systems as well, if the scope of the analysis is respectively extended towards physical parts and human agents. Nevertheless, for the purpose of clarification about the real scope of the WAx framework for CSTSs, this section includes two additional examples, respectively about industrial production and service systems.

Industrial processes

The WAx framework can describe even more complex tasks at team level, e.g. a manufacturing line for surface finishing of delicate products (e.g. ceramics). In such case, the workers represent the (collective) sharp-end operator. Imagine that the top management (BO) wants to transfer this task to a specialized cyber artefact agent to increase efficiency. Then, before repositioning the staff, the management instructs an analyst to observe the work (i.e. $WAO_{Analyst}$) with the intention of understanding the operators' task to be transferred (if possible) to a cyber-physical agent, i.e. a robot. Even if there is only one professional (e.g. analyst/programmer), he/she plays different roles in the two following moments: first the role of analyst, where he/she tries to build a mental model of the work ($WAI_{Analyst}$-of-WAD); then, the role of BO who uses his/her own mental model (i.e. the same $WAI_{Analyst}$-of-WAD which becomes WAI_{BO}) to make the instructions explicit in the coding activity, that will be then make explicit via a WAP_{BO}.

In such example, the analyst/programmer's task will need to be performed observing the workforce both naturalistically ($WAO_{Analyst}$) and through socialization (i.e. through a Tacit-To-Tacit conversion).

It is important to note that this analysis must be carried out before the relocation of the labor force, since the latter is in possession of knowledge. This latter, if not transferred in time, can be lost in a potentially irrecoverable way. This situation is frequent in industrial contexts where top management is increasingly trying to automate processes traditionally carried out by humans, (e.g.) welding or painting. It may happen that the behavior of the robot results in some misalignments with actual operational needs, as a result of conceptualisation/observation errors of the analyst reflected in his/her mental model ($WAI_{Analyst}$), which in turn are reflected in the mental model of the robot (WAI_{SO}) via the mis-aligned WAP_{BO}.

Service Industry

Healthcare processes represent a highly investigated complex system: see for example the reconstruction of a patient's medical history, the handover during shift changes, the externalization of knowledge in e-Health Record to make this latter available and usable by both other physicians, not necessarily physically present, and cyber-artefacts.

In this context, we can refer to the case in which the patient loses part of his cognitive abilities after he/she has undergone a general anesthesia (e.g. post-operative delirium). Here, the process is the delivery of care, the BO is the physician(s), the SO is the nurse(s) and the patient's relative(s) is the Analyst(s).

The physicians' knowledge (WAI_{BO}) is indeed fundamental since the timelier the recognition of the symptomatology is, the better and faster the instructions given to the nurse(s) WAP_{BO}, to be integrated with normative knowledge (WAN) in order to reduce the iatrogenic damage (WAD_{SO}). It is quite common that the patient's relatives are among the first recognizers of the signs related to the acquired cognitive deficit, therefore they behave just like analysts on the process of delivering care by the nurse. The observation by relatives of the care delivery is essentially a conceptualization (i.e. Action-to-Tacit) resulting in a $WAO_{Analyst}$. The relatives create a $WAI_{Analyst}$-of-WAD which is affected by their $WAI_{Analyst}$-of-WAI (as the care delivery is imagined), and the $WAO_{Analyst}$, and the knowledge obtained by the nurse $WADI_{SO}$. In turn, the $WADI_{Analyst}$-of-WAD has the possibility to update the physician's mental model (WAI_{BO}) and recursively modify the care delivery itself, via the above-mentioned control loop.

4.2. Integrating cyber components in CSTSs

The WAx framework regards autonomous agents as "black-box" models (i.e. as systems whose knowledge is tacit and accessible only by means of their inputs and outputs), at least at a certain abstraction level. However, at lower abstraction levels, their work can be interpreted in a complex way, as for human operators, pushing towards a recursive application of the WAx framework itself. The triadic relationship BO/SO/Analyst can be understood indeed as repeatable at different levels. When dealing with the design of a cyber-artefact however, it may be necessary to refine knowledge conversions among the triad. In this case, the cyber-agent cannot be modelled as a black box, since some knowledge conversions would concern explicit data transmission that remain accessible by the user or by the artefact itself. Opening the black-box requires to render explicitly the transduction/measurement conversions and implementation activities: Transduction (Action-to-Explicit, same agent), and Actuation (Explicit-to-Action, same agent). The former refers to the measurable activity involving the translation of one's own sensory perceptions into manageable signals. This is a specification of the already presented Conceptualization conversion. The latter, i.e. actuation, reflects the activity involving the translation of manageable signals into effective actions. When this is not the case, this conversion reverts to Reification. Both these activities remain meaningful only when sensory perceptions are made accessible at a higher hierarchy level.

Transduction and actuation stress the cybernetic dimension of the WAx framework and permit interpreting the difference between the various knowledge conversion drivers not only in teleological terms (Kroes, 2012). Basically, the chain of explicit knowledge conversions ultimately result in an action through effector transducers called actuators. The cyber-agent must be designed to manage its own signals; hence these latter are potentially measurable at system level by the analyst, i.e. the $WAO_{Analyst}$ (explicit knowledge types in the SECI model). Note that accessing the transduction signals is not the same as accessing the symbolic state of the cyber-agent (WAI_{SO}), which remains largely tacit. What the sharp-end operator knows, yet unconsciously, is what she/he/it perceives and feels about her/his/its work, which is the result of countless transduction steps (more or less faithful) of perceptions related to the activity concerning the WAD_{SO}. These complicated transductions become emergent when looking at the system in more abstract terms. For humans, the different nerve signals activate complex neural activation patterns in the operator's mind that can no longer be traced back to the original elementary signal (Cappy, 2020; Stevens, 2013). Similar phenomena have been observed in cyber-artefacts as for the deep dreaming effect in convolutional neural networks (Keshavan and Sudarshan, 2017; Kim et al., 2017; Szegedy et al., 2015). Symbols possessed by a cyber-agent might include symbolic representation of environment, sense-of-agency, and even more complex cognitive concepts (Dennett, 1998; Hafner et al., 2020; Leijnen, 2012).

In our conceptual framework such complex and continuous process is subsumed by the knowledge conversion activity named interiorization, a transformation going up in abstraction, toward the representation (WAI) of WAD. The abstractions consist of meta-processes (cognitive processes on cognitive processes) that can be considered ETTO models, in which the concept of information translates from the entropic to the semantic meaning (Haken and Portugali, 2015).

Focusing onto the elementary conversion activity which starts from sensors, the ETTO driver – if yet interpreted in teleological terms – has the sole modelling purpose of minimizing the entropic noise effect, at least as assumed by Information or Signal Theories (Battail, 2014a). At this level of granularity, the various nuances of ETTO lose much of their relevance since the process is the communication itself. Using the previous example of an Intelligent Virtual Assistant, the design of its transductors (e.g. the microphone) aims at maximizing just the signal-to-noise ratio (Battail, 2014b). In this sense, the WAx framework follows the approach of classical cybernetics (Conant and Ross Ashby, 1970; Maturana and Varela, 1980) as far as the single operator is concerned, while when interpreted at a socio-technical level, for example, it can be traced back to the viable system model (Beer, 1994; Craig et al., 2014).

More generally about social systems, the way WADI is conveyed by a human agent may further diverge from the agent's WAI especially in case the former is obtained via surveys, or structured interviews. This is an example of the influence of $\text{WAI}_{\text{Analyst}}$-of-WAI over the externalisation by the operators. Similar phenomenon arises in case of semi-structured or open-ended interviews, but to a generally minor extent. In this way, the WAx framework clearly depicts and presents those contrasting forces and their effects on systems knowledge. Furthermore, more specifically oriented to safety science, it remains relevant to note how there could be an accident informational conversion between the $\text{WAI}_{\text{Analyst}}$-of-WAI (or WAD) and the $\text{WADI}_{\text{Analyst}}$-of-WAI (or WAD). This situation may happen in those cases where the analyst adopts a model without fully comprehend its assumptions, or where he/she grounds his/her work on an untested model with over-simplified taxonomies and reductionist categories, rather than driving the modelling choice from a deeper understanding and observations of real work practices (Rae et al., 2020).

5. Conclusion

The conceptual framework proposed in this document remains valid for a large variety of socio-technical systems, considering its fractal and recursive nature. This means that the framework applies to organizations and systems affected by modern challenges of digitalization, usually referred to Industry 4.0. Encompassing many different fields and domains, this research tries to define a bridge between a resilience-centred management, and approaches rooted in knowledge representation theories. This is a tough challenge, especially considering previous work conducted in these two domains, not explicitly dealing with each other. Such a challenge limited the nature of the framework to trade-off the complexity of underlying concepts with the simplicity of their representation and interpretation for future usage. To this extent, (e.g.) we selected the SECI model, even though there could have been other approaches to be used; and we identified abstract agents in the graphical representation of the framework, without defining their individual or collective nature.

Anyway, the core idea behind the WAx framework is to show how safety scientists and safety analysts should unveil the complex intertwined dimensions of knowledge in a CSTS. Knowledge management comes here to provide a deeper understanding of Resilience Engineering principles and their applicability in domains largely dominated by informative systems, as for CSTSs. Our framework is intended to generate an uncomfortable feeling with reductionist, over-simplistic approaches, or ontological alchemy referred to apparently objective numbers used for safety indicators (Dekker and Nyce, 2015). Besides few exceptions, there is no simple, linear, deterministic relationship between a work context and the actual work outcome, because of the multiple varying interactions among the numerous actors, equipment, working procedures and organizational processes. There is no clear and omni-comprehensive procedure, valid for any possible scenario of a work setting, which is able to prescribe any task with full operational low-granularity details. Actions are more of less implicitly demanded to operators' adaptation, especially in more complex operating conditions (Patriarca and Bergström, 2017).

Nevertheless, further developments are still needed. The framework remains at a conceptual level, and it is expected to be an abstract support to promote critical thinking, to motivate deeper investigation of work practices, to support further methodological developments. Such a target may be achieved abandoning traditional reductionist approaches and embracing systemic research dimensions that are possibly based on dedicated ontologies to support multi-faceted knowledge elicitation, systematic information gathering, collection and analysis.

This idea remains valid even more in systems where the integration of cyber-physical artefacts with humans, teams and organizations is reshaping the work environments. Even though the purpose of the framework originates in the safety management area, the scope and the applicability of the proposed structure remains valid for both security as well as other performance management systems.

The framework constitutes an opportunity to emphasize the need for a deeper understanding of the interaction between different entities and their implications for performance management. From a scientific perspective, it sheds lights on how the framework might reduce dissonance among the mental models of different agents, as well as between their explicit representations (procedures, standards, checklists, etc.). From a social perspective, the focus on observed and disclosed work is intended at empowering employees, supporting a resilient leadership and ensuring that the criticalities experienced in real working practices are communicated and shared (Seidel and Saurin, 2020). This knowledge sharing fosters organizational management, avoiding information dissonance that may consequently hamper safety issues, and create opportunities for leaner and smoother operations.

The key to organizational learning considers adaptation as a source of success, rather than a punishable non-compliance act. The WAx framework stress the role of gathering information related to adaptive, local behaviours while limiting the investigation bias as a crucial factor to ensure organizational success in spite of dynamic behaviours and operating settings. To this extent, even though the WAx framework builds largely upon safety literature, it s validity spans on opportunities to increase system resilience at large.

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Appendix A. – The WAx framework

See (Fig. 7).

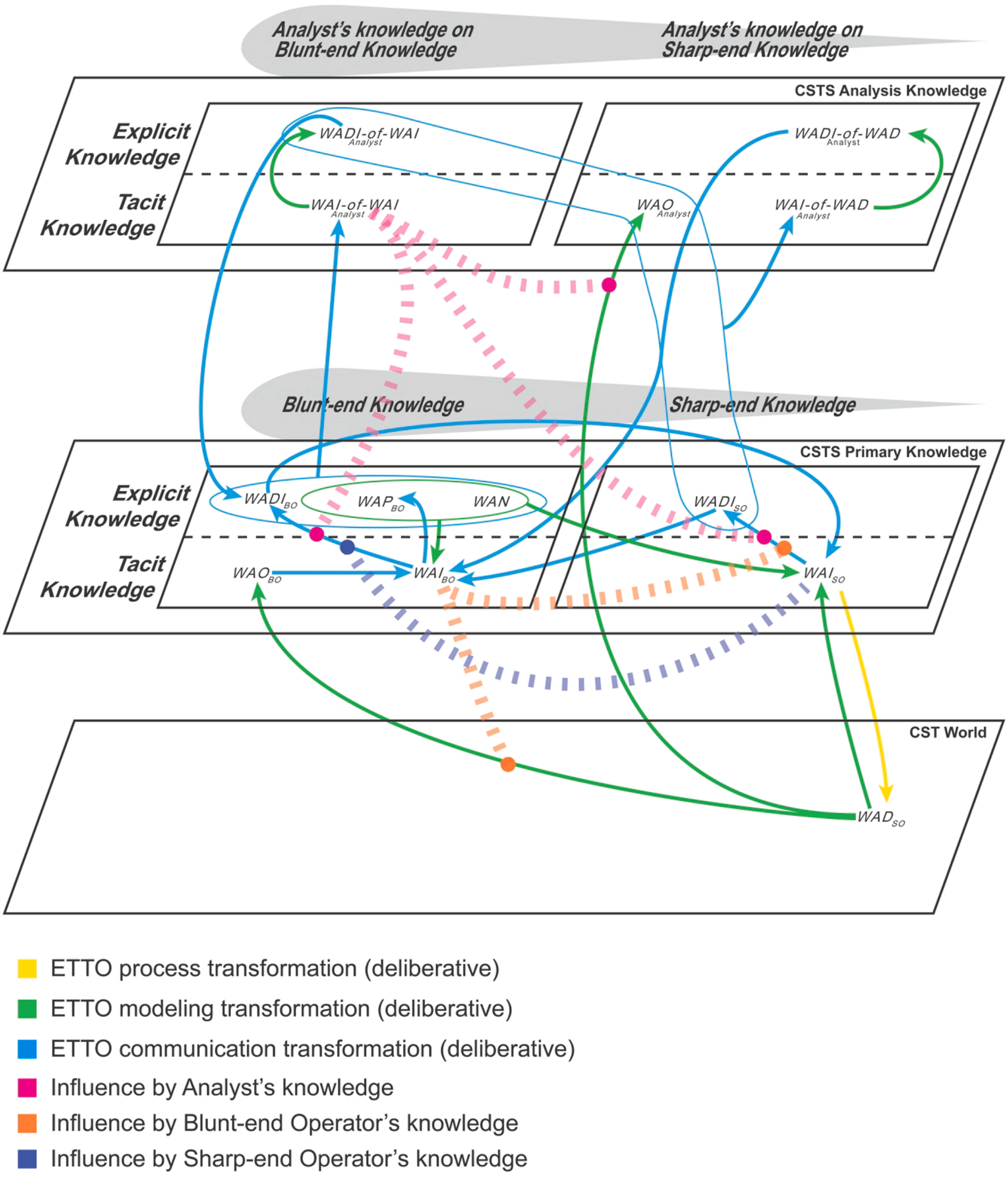

Fig. 7. The conceptual framework for the analysis of CSTS.

Appendix B. – Details of the WAx framework

Each knowledge entity is presented in a template with three sections including respectively: the corresponding name and acronym; the structure (i.e., level, knowledge type, and agency); and the dynamics (i.e., related foundational knowledge activity and knowledge conversion drivers).

Work As Done by the Sharp-end Operator (WAD$_{SO}$)
STRUCTURE Level = CST World Agency = SO DYNAMICS **WAD$_{SO}$** is a **reification** of **WAI$_{SO}$** by **SO** with driver **EP**

(*continued on next page*)

(*continued*)

Work As Done by the Sharp-end Operator (WAD$_{SO}$)

WAI$_{SO}$ is a **conceptualization** of **WAD$_{SO}$** by **SO** with driver **EM**
WAO$_{BO}$ is a **conceptualization** of **WAD$_{SO}$** by **BO** with driver **EM**, influenced by **WAI$_{BO}$**
WAO$_{Analyst}$ is a **conceptualization** of **WAD$_{SO}$** by **AN** with driver **EM**, influenced by **WAI$_{Analyst}$-of-WAI**

Work As Imagined by the Sharp-end Operator (WAI$_{SO}$)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Tacit
Agency = SO
DYNAMICS
WAI$_{SO}$ is an **internalisation** of (**WAP** and **WAN**) by **SO** with driver **EM**
WAI$_{SO}$ is a **conceptualization** of **WAD$_{SO}$** by **SO** with driver **EM**
WAD$_{SO}$ is a **reification** of **WAI$_{SO}$** by **SO** with driver **EP**
WADI$_{SO}$ is an **externalisation** of **WAI$_{SO}$** by **SO** with driver **EC**, influenced by **WAI$_{Analyst}$-of-WAI**
WADI$_{SO}$ is an **externalisation** of **WAI$_{SO}$** by **SO** with driver **EC**, influenced by **WAI$_{BO}$**
WAI$_{SO}$ is an **internalisation** of **WADI$_{BO}$** by **SO** with driver **EC**
WAI$_{SO}$ influences **WADI$_{BO}$** **externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**

Work As DIsclosed by the Sharp-end Operator (WADI$_{SO}$)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Explicit
Agency = SO
DYNAMICS
WADI$_{SO}$ is an **externalisation** of **WAI$_{SO}$** by **SO** with driver **EC**, influenced by **WAI$_{Analyst}$-of-WAI**
WADI$_{SO}$ is an **externalisation** of **WAI$_{SO}$** by **SO** with driver **EC**, influenced by **WAI$_{BO}$**
WAI$_{BO}$ is an **internalisation** of **WADI$_{SO}$** by **BO** with driver **EC**
WAI$_{Analyst}$-of-WAD is (an **introspection** of **WAO$_{Analyst}$** by **AN** and a **combination** of (**WADI$_{Analyst}$-of-WAI** and **WADI$_{SO}$**) by **AN**) with driver **EC**

Work As Prescribed by the Blunt-end Operator (WAP$_{BO}$)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Explicit
Agency = BO
DYNAMICS
WAP$_{BO}$ is an **externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**
WAI$_{SO}$ is an **internalisation** of (**WAP$_{BO}$** and **WAN**) by **SO** with driver **EM**
WAI$_{BO}$ is an **internalisation** of (**WAP$_{BO}$** and **WAN**) by **BO** with driver **EM**
WAI$_{Analyst}$ of-WAI is an **internalisation** of (**WADI$_{BO}$** and **WAP$_{BO}$** and **WAN**) by **AN** with driver **EC**

Work As Normative (WAN)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Explicit
Agency = BO
DYNAMICS
WAI$_{SO}$ is an **internalisation** of (**WAP$_{BO}$** and **WAN**) by **SO** with driver **EM**
WAI$_{BO}$ is an **internalisation** of (**WAP$_{BO}$** and **WAN**) by **BO** with driver **EM**
WAI$_{Analyst}$ of-WAI is an **internalisation** of (**WADI$_{BO}$** and **WAP$_{BO}$** and **WAN**) by **AN** with driver **EC**

Work As Imagined by the Blunt-end Operator (WAI$_{BO}$)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Tacit
Agency = BO
DYNAMICS
WAI$_{BO}$ is an **internalisation** of (**WAP$_{BO}$** and **WAN**) by **BO** with driver **EM**
WAP$_{BO}$ is an **externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**
WAI$_{BO}$ is an **internalisation** of **WADI$_{SO}$** by **BO** with driver **EC**
WAI$_{BO}$ is an **introspection** of **WAO$_{BO}$** by **BO** with driver **EC**
WAI$_{BO}$ is an **internalisation** of **WADI$_{Analyst}$-of-WAD** by **BO** with driver **EC**
WAI$_{BO}$ is an **internalisation** of **WADI$_{Analyst}$-of-WAI** by **BO** with driver **EC**
WADI$_{BO}$ is an **externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**, influenced by **WAI$_{Analyst}$-of-WAI**
WADI$_{BO}$ is an **externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**, influenced by **WAI$_{SO}$**
WAI$_{BO}$ influences **WADI$_{SO}$** **externalisation** of **WAI$_{SO}$** by **SO** with driver **EC**
WAI$_{BO}$ influences **WAO$_{BO}$** **conceptualisation** of **WAD$_{SO}$** by **BO** with driver **EM**

Work As Observed by the Blunt-end Operator (WAO$_{BO}$)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Tacit
Agency = BO
DYNAMICS**WAI$_{BO}$** is an **introspection** of **WAO$_{BO}$** by **BO** with driver **EC**
WAO$_{BO}$ is a **conceptualization** of **WAD$_{SO}$** by **BO** with driver **EM**, influenced by **WAI$_{BO}$**

Work As DIsclosed by the Blunt-end Operator (WADI$_{BO}$)

STRUCTURE
Level = CSTS Primary knowledge
Knowledge type = Explicit
Agency = BO
DYNAMICS
WADI$_{BO}$ is an **externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**, influenced by **WAI$_{Analyst}$-of-WAI**
WADI$_{BO}$ is an **externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**, influenced by **WAI$_{SO}$**
WAI$_{SO}$ is an **internalisation** of **WADI$_{BO}$** by **SO** with driver **EC**
WAI$_{Analyst}$ of-WAI is an **internalisation** of (**WADI$_{BO}$** and **WAP$_{BO}$** and **WAN**) by **AN** with driver **EC**

Work As Imagined, as Imagined by the Analyst (WAI$_{Analyst}$-of-WAI)

STRUCTURE
Level = CSTS Analysis knowledge
Knowledge type = Tacit
Agency = AN
DYNAMICS
WAI$_{Analyst}$ of-WAI is an **internalisation** of (**WADI$_{BO}$** and **WAP$_{BO}$** and **WAN**) by **AN** with driver **EC**
WADI$_{Analyst}$-of-WAI is an **externalisation** of **WAI$_{Analyst}$-of-WAI** by **AN** with driver **EM**
WAI$_{Analyst}$-of-WAI influences **WADI$_{BO}$ externalisation** of **WAI$_{BO}$** by **BO** with driver **EC**
WAI$_{Analyst}$-of-WAI influences **WADI$_{SO}$ externalisation** of **WAI$_{SO}$** by **SO** with driver **ECWAI$_{Analyst}$-of-WAI** influences
WAO$_{Analyst}$ conceptualization of **WAD$_{SO}$** by **AN** with driver **EM**

Work As Imagined, as Imagined by the Analyst (WADI$_{Analyst}$ -of-WAI)

STRUCTURE
Level = CSTS Analysis knowledge
Knowledge type = Explicit
Agency = AN
DYNAMICS
WADI$_{Analyst}$-of-WAI is an **externalisation** of **WAI$_{Analyst}$-of-WAI** by **AN** with driver **EM**
WAI$_{BO}$ is an **internalisation** of **WADI$_{Analyst}$-of-WAD** by **BO** with driver **EC**
WAI$_{Analyst}$-of-WAD is (an **introspection** of **WAO$_{Analyst}$** by **AN** and a **combination** of (**WADI$_{Analyst}$-of-WAI** and **WADI$_{SO}$**) by **AN**) with driver **EC**

Work As Observed by the Analyst (WAO$_{Analyst}$)

STRUCTURE
Level = CSTS Analysis knowledge
Knowledge type = Tacit
Agency = AN
DYNAMICS
WAI$_{Analyst}$-of-WAD is (an **introspection** of **WAO$_{Analyst}$** by **AN** and a **combination** of (**WADI$_{Analyst}$-of-WAI** and **WADI$_{SO}$**) by **AN**) with driver **EC**
WAO$_{Analyst}$ is a **conceptualization** of **WAD$_{SO}$** by **AN** with driver **EM**, influenced by **WAI$_{Analyst}$-of-WAI**

Work As Done, as Imagined by the Analyst (WAI$_{Analyst}$-of-WAD)

STRUCTURE
Level = CSTS Analysis knowledge
Knowledge type = Tacit
Agency = AN
DYNAMICS
WAI$_{Analyst}$-of-WAD is (an **introspection** of **WAO$_{Analyst}$** by **AN** and a **combination** of (**WADI$_{Analyst}$-of-WAI** and **WADI$_{SO}$**) by **AN**) with driver **EC**
WADI$_{Analyst}$-of-WAD is an **externalisation** of **WAI$_{Analyst}$-of-WAD** by **AN** with driver **EM**

Work As Done, as DIsclosed by the Analyst (WADI$_{Analyst}$-of-WAD)

STRUCTURE
Level = CSTS Analysis knowledge
Knowledge type = Explicit
Agency = AN
DYNAMICS
WADI$_{Analyst}$-of-WAD is an **externalisation** of **WAI$_{Analyst}$-of-WAD** by **AN** with driver **EM**
WAI$_{BO}$ is an **internalisation** of **WADI$_{Analyst}$-of-WAD** by **BO** with driver **EC**

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