Exploring the notion of situation for responsive manufacturing systems specification issues

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Abstract: Responsiveness in manufacturing is a key challenge for facing open-ended changes more and more enhanced by the increasing development of easy-to-use digital technologies. However, the control of a given situation into wholeness by a respondent system is raising design issues to make cooperating together the many entities of the Human, digital and physical parts interleaved in a related world-of-interest in order to reach and maintain common goals. This paper provides an overview of some relevant works for attaining a situated perspective of the responsiveness of a system to be engineered with simplexity. This property of living beings is more particularly explored for the cognitive orchestration of the interdisciplinary knowledge assets, which are cooperatively involved in a project system in order to frame a given situation examined with a system perspective.

Key Words: situation, system, responsiveness, simplexity, knowledge-enhanced interoperability, systems engineering

1. RESPONSIVENESS TO A SITUATION

Responsiveness is presented by (Monostori et al. 2015) as one of the key challenges that manufacturing systems have to face for coping the complexities of manufacturing environment. In (Váncza et al. 2011), the authors argued that responsiveness is one of the cornerstones of a resilient manufacturing system that (Levalle et Nof 2017) recommend being rather than being robust to deal with unforeseen events perceived “a posteriori” in the real as systemic failures (Boardman et Sauser 2013).

Examining the circumstances under which manufacturing systems must be responsive leads to an interest in situations in which humans are involved and for which they required services to them. Thus, our main hypothesis is that situations shape the responsiveness of manufacturing systems and their study involves control knowledge assets beyond traditional ones to a priori design them for the unexpected (Valckenaers et Van Brussel 2015) (Noran, Romero, et Zdravkovic 2014) as well for the resilience in order to face these complexities revealed too often a posteriori.

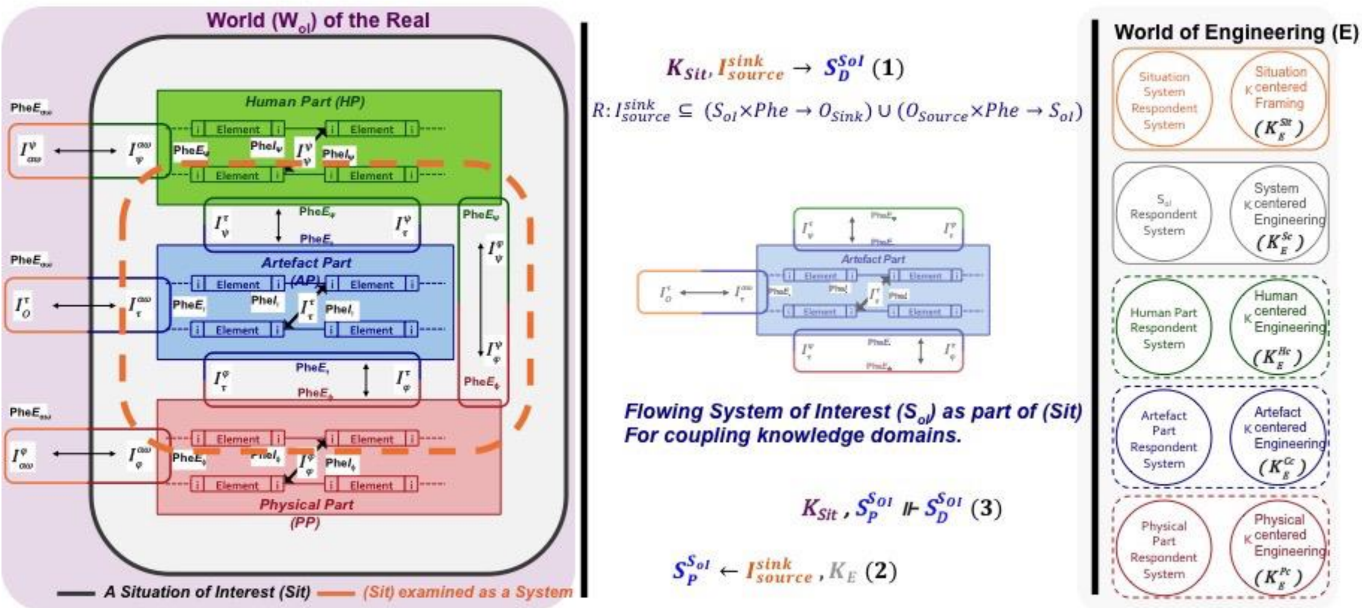

Figure 1 *Cognitive heuristics for framing a Situation System to be controlled*

2. SITUATION FRAMING KNOWLEDGE

The aim of this section is to give an overview of the notion of situation available in the scientific literature in order to provide key knowledge elements for responsiveness issues.

2.1. Scientific context of the notion of situation

The awareness of situation has been brought into the foreground when system design paradigms had to shift from artifact-centered to user-centered (Boy 2005) and now to cognitive frameworks (Rolls 2013) in order to better understanding a priori situations in which Humans are involved. For example, situation is a central unit of analysis for information science in order to better understanding the behavior of humans when seeking information (Cool 2001). Situation awareness (Endsley 2016) is an important construct for practitioners in human factors in order to be aware of how a human involves in his environment (Millot 2015). In the manufacturing domain, the awareness of situation is rather considered for safety reasons as a requirement for automating system (Cormier, Phan, et Ferrie 2015).

2.2. Designating a situation

The notion of situation refers to a timely combination of objects whose states are becoming available, in particular circumstances, for humans. Thus, the meaning is that a situation commits in its totality a set of objects for achieving some goals as required by humans. Situations are of different kinds as argued by (Boy 2015). Thus, if states of objects are available but not yet perceptible by human, the situation is said to be available for that humans. When humans perceive these states, the situation is called a perceived situation. A perceived situation is named desired if it is from goal-driven behavior nature or it is named expected if it is from an event-driven behavior nature. Situation awareness (Endsley 2016) is the capability of a human to perceive objects in his environment, to understand the situation and to project future status of these objects before to make any decision that occurs, according to (Boyd 1995), in a cycle of observe-orient-decide-act (OODA) loop. However, designating situations of interest may early impact the specification of stakeholder's requirements to which manufacturing systems will have to respond. For example, let's consider a Human-Artifact parts (I_{AP}^{HP}) interaction (Figure 1). Thus, telling "a field operator requests the service of a logic controller to perform his tasks every day in a workshop" is a working situation that commits in its totality a human part interacting with an artifact part and that reflects a user intention for acting. Telling "The controller logic should be automatically synthesized from a plant model" is a control situation underlying a designer intention to improve the service. Right coupling both makes the targeted situation operational.

2.3. Defining a situation

Among many others definitions, that of (Zask 2008) contains relevant knowledge elements for responsiveness issues *A situation is defined as being all moments during which an interaction between a living being and an environment takes place in the form of a reciprocal action* :

- Humans are constitutive of situations as they construct them by intention for serving some goals (Berthoz et Petit 2006).
- Situations are designated as timely moment during which interactions between at minimum a human (e.g. a control operator) and at minimum an object (natural or artefactual) will be in the form of a reciprocal action.
- A situation presents a dynamical character. It implies to consider constitutive objects of a situation but also the set of interactions between these objects. Interactions are the popular systemic word for expressing that phenomena interact between objects source and objects sink according to a logic of effects (Ducrocq 1996). Typically, phenomenon designates events that result from reciprocal actions and that are perceptible by a sentient being (Ken Wilber in (Mella 2009)), meaning that phenomena are implicitly required by Humans as setting of the dynamics of the situation.
- According to (Hall et Rapanotti 2005), a phenomenon belongs to two different domains. In the causal domain, phenomena are perceived as deterministic and predictive, and can be controlled in an ordered manner by humans. For control purposes, these phenomena must be "visible" by all constitutive elements of the situation of interest. In the biddable domain, phenomena are perceived as unpredictable, pointing out the relationships between a situation and its environment. Here, phenomena are totally hidden or eventually perceived but not understood, but, in any case, having an influence on a situation. For responsiveness purposes, these external phenomena to the situation are those linked to change and uncertainties.
- A situation is said to be operational as long as it meets the expectations of its stakeholders such as those who are constitutive of it, those who exploit its results, those who maintain it, those who diagnose it. When a situation no longer meets their expectations, it is considered as problematic in general (Schutz et Luckmann 1973), incidental - when the causes of the degradation are identified thanks to specific procedures that aim to restore it - or disrupted - because associated to unexpected events not identified - (Journé et Raulet-Croset 2008). In any case of problem or opportunity for improving the normal functioning of a situation, a situation gets its stakeholders involved to define and to interpret what has happened and to envisage the actions to be taken to restore its normal functioning.

For illustration, defining the above-told working situation consists in (Figure 1, left):

- Making visible the constitutive parts of a situation of interest such as a field operator (HP), a logic controller (AP) and a controlled equipment as the physical part (PP) processing a flowing valuable object for which is required a situation of interest that commits in its totality $HP, AP \; and \; PP$,
- Making appearance of the phenomena of interest resulting from cause-effect relationships between the related parts such as a sound sending by the flowing object and sensing by a field operator for physical-physiological phenomena ($\mathrm{Phe}E_{\Phi}, \mathrm{Phe}E_{\Psi}$)

stimulating the interaction between physical and human parts (I_{φ}^{ψ}); digital signal sending by the controller and sensing by the flowing object for physical-artefactual phenomena ($\mathrm{Phe}E_{\Phi}$, $\mathrm{Phe}E_{\mathrm{T}}$) enhancing the interaction between physical and artifact parts (I_{φ}^{τ}); green lighting displaying by the controller for artefactual phenomena ($\mathrm{Phe}I_{\mathrm{T}}$) enhancing interactions between elements of the artifact part (I_{τ}^{τ}) and sensing field operator for physiological-artefactual phenomena ($\mathrm{Phe}E_{\Psi}$, $\mathrm{Phe}E_{\mathrm{T}}$) enhancing the interaction between human and artifact parts (I_{ψ}^{τ}),

- Making sense of the phenomena of interest ($\mathrm{Phe}E_{\alpha\omega}$, $\mathrm{Phe}E_{\Psi}$, $\mathrm{Phe}E_{\mathrm{T}}$, $\mathrm{Phe}E_{\Phi}$) resulting from cause-effect relationships enhancing unpredictable interactions ($I_{\alpha\omega}^{\psi}$, $I_{\alpha\omega}^{\tau}$, $I_{\alpha\omega}^{\varphi}$) that must be contained between HP, AP *and* PP and the environment,
- Identifying at least one object of interest as source of the controlling intention (such as Operation-Chief or R&D Chief Engineer) into wholeness in order to maintain or to improve what is essential (product life-cycle) with some togetherness (digital connectivity between operation and engineering).
- Diagnosing a disrupted situation resulting from operators' cognitive load because of disruptive representations between reality and engineering and thus, satisfying an opportunity-oriented requirement as twin technology to connect them.

2.4. Synthesis

This literature strengthens that the notion of situation remains under debate in many scientific disciples. We depict in (Figure 2) some essential knowledge elements we consider to be of interest for engineering disciplines, especially for responsive control issues.

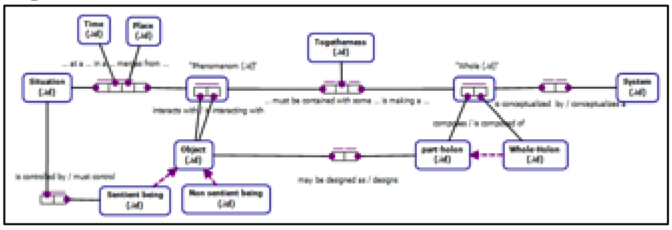

Figure 2: Cognitive fact-oriented model[1] of the essential knowledge elements for defining a situation

First, in the reality domain, a special focus must be paid on the triggering relationship between phenomena and situation. It must also be pointed out that the designation in a wholeness manner of the effects or the causes of facts perceived as complex that occur in a situation is termed by the "popular system". This primary conceptualization reflects that at least a constitutive sentient being is conscious of a required togetherness of constitutive objects for controlling the phenomena occurring in a living or desired situation.

Then, in the engineering domain, (Kuras 2006) argued that the notion of Holon (Koestler 1978) designates a pattern that contains our conceptualization of the duality whole-part of our reality. This is an important point for the framing process of a situation of interest in order to giving sense earlier to what a situation commits in its totality as a coherent whole and what is from its environment. Thus, this vision lead us to frame a situation by extending according to three interleaved layers as recommended by (Galara 2006) for plant operation control. Each of these layers distinguishes respectively Human, Physical and Artifacts holons as parts of greater Holons (i.e. the designer for an artifact) (figure 1, left), each of which can be source or sink of emerging phenomena.

Finally, the human capability to build by detour (Berthoz 2009) a cognitive control in order to find alternatives solutions to complex problems is addressing both the tangible and non-tangible domains of the reality (figure 1, left) and of the engineering (figure 1, right). Thus, it is no longer suitable to partition the whole knowledge continuously acquired between the many actors involved in these two intricately linked domains for situation responsiveness issues.

3. SITUATION SYSTEM SPECIFICATION KNOWLEDGE

This knowledge continuum needs to share a common framework of understanding and framing a situation specified as a system by bringing together essential elements for cognitive control.

3.1. Systems Thinking approach

The body of knowledge to think and to act situations in terms of systems is subject of variety of approaches since the early times of Systemic (Pouvreau 2013) and its relationship to cybernetics (Wiener 1948)(Forrester 1961) to recent works of the world-wide community in Systems Engineering (BKCASE Editorial Board 2017). (Lawson 2010) recently coped with the what-is questioning by focusing on why we make a system? in order to respond to a situation system, when two or more elements become related together resulting in a problem or an opportunity to a desirable or postulated situation. This coupling relationship between the domain of the reality and the domain of engineering points out the feedback that a respondent system has to maintain in order to bind into wholeness a targeted situation system. The recursive and iterative process in the engineering domain consists in making available relevant interdisciplinary knowledge assets to be instantiated for a respondent system. A control element is the first of the two or more elements that are engineered together in order to compose a required responsive respondent system. Cooperative control engineering as well as traditional automatic control are only ones of the interdisciplinary knowledge instantiated all along the situation system understanding for engineering a responsive system.

Relevant systems thinking knowledge assets can be diagrammed in a form of system thinker's tree (Allegro et Smith 2016), systemigrams (Boardman et Sauser 2013), causal-loop diagrams … in order to make visible the dynamics of the situation system under designation, specially reinforcing and balancing loops to explore "what if" questions for making visible (Ponto et Linder 2011) the

[1] http://www.ormfoundation.org/

related dynamics of a situation. A special attention must be paid on the modeling holistic completeness, which can be systematically guided by the architectural "conceptagon" framework ordering twenty-one system thinking concepts into seven triads (Boardman et Sauser 2013). Even if currently used for a system-of-interest definition, this pragmatic framework may be of-interest to check the system completeness of a situation. For example, the triad {Interior, Boundary, Exterior} enables to frame the boundaries surrounding a situation system. For illustration, applying this heuristic to the previous manufacturing working situation enables to frame the workshop as a situation system surrounded by a plant …which can be part of a wider system of systems requiring to pay attention on triad {emergence, holarchy (instead of hierarchy), openness}. For responsiveness issues, the triad {Inputs, Transformations, Outputs} exhibits the role of the flowing object as holon-product giving being to the situation system as addressed by (Morel et al. 2007)(McFarlane 2003).

Nevertheless, the problem-oriented and solution-oriented specifying nature of the coupling relationship must be more formally addressed to completely align the interdisciplinary knowledge reflecting the situation system under designation with disciplinary knowledge, such as control.

3.2. Problem frames approach

In (Jackson 1997), the author evoked the notion of situation within the problem frames approach relating to systemic issues in software engineering and in a large extent to cooperative control and systems engineering. In this approach, a situation is related to our reality, our world of interest (W_{oI}), as the source of requirements (R) to express conditions over phenomena that must be controlled by a related artifact (AP) under specification. These requirements of interest (equation 1) contain optative properties to express what the artifact must do under the assertion that other indicative properties are controlled in some extend by the situation itself or which must be contained in case of biddable effects (Hall et Rapanotti 2005). Proof has been given (Gunter et al. 2000) that the requirements specification result (S) can be formally validated only when the resulting artifact is testing with relevant knowledge (K) on real conditions with respect to shared measurable properties (equation 2).

$W_{oI}, S \vdash R$ *(Equation 1);* $K, S \vdash R$ *(Equation 2)*

It should be note that these works point out that the requirements contain an informal designation part for capturing fuzzy and/or unpredicted phenomena of (W_{oI}) before to be formally grounded for a specification.

Later, (Jin 2006) underlines the interest of system thinking paradigm in order to well state problems to be solved in (W_{oI}) by well understanding (K) to elicit (R) for problem-oriented descriptive specification (S_D) according to:

$K, R \rightarrow S_D$ *(Equation 3)*

Here, (R) stipulate how a required artifact (AP) must stand in (W_{oI}) by designating phenomena ($\mathrm{Phe}E_{\mathrm{T}}$) it must exhibit for establishing interactions ($I_{\tau_{source}^{sink}}$) with source and sink objects (O_{Source}, O_{Sink}) of its environment in order to enact a given situation within (W_{oI}). Thus, (R) specifies interactions requirements according to *(Equation 3')*:

$$I_{\tau_{source}^{sink}} \subseteq (AP \times \mathrm{Phe}E_{\mathrm{T}} \rightarrow O_{Sink}) \cup (O_{Source} \times \mathrm{Phe}E_{\mathrm{T}} \rightarrow A)$$

Thus, (S_D) in an open-ended change situation is dependent of relevant knowledge on both what can close the situation for control issues and on what can contain the situation for responsiveness (among other) issues. By extent (Morel et al. 2014), for systems engineering domain, a solution-oriented prescriptive specification (S_P) is dependent in response of relevant interdisciplinary engineering knowledge (K_E) according to:

$S_P \leftarrow R, K_E$ *(Equation 5)*

It must be noted that, in (Hall et Rapanotti 2005), the authors assert that the prescription in (W_{oI}) must express indicative properties related to human-(AP) interactions specification (UI) and the knowledge and the behavior specification (I) of an human as a constitutive element of the given situation, together with (S_D) according to:

$W_{oI}, S_D, I, UI \vdash R$ *(Equation 5')*

The related specification processes (Figure 1) results from refinement iterations (Bouffaron 2016) all along a system project life cycle between interdisciplinary knowledge that are respectively source of problem-oriented verified specification (Equations 3 and 3') and sink of solution-oriented verified specification (Equations 5 and 5') until a contractual validation (Equation 2).

3.3. Synthesis

Elements of this framework of framing a situation system are constitutive of our generalized specification process orchestrating by detour into togetherness, interdisciplinary knowledge required by respondent systems to problems observed in the real. Thus, the knowledge (K_{Sit}) of what any stakeholder (HP) desires to be true revealed by interactions (I_{source}^{sink}) in a situation (Sit) in a related world-of-interest (W_{oI}) implies a descriptive specification ($S_D^{S_{oI}}$) revealing optative properties of what (a system of interest S_{oI}) is required (1). In turn, the requested engineering domain knowledge (K_E) prescribes a prescriptive specification ($S_P^{S_{oI}}$) enacting not only optative properties to be controlled but also some other indicative one which must at least be contained in the required situation system (2).

1) $K_{Sit},\ I_{source}^{sink} \rightarrow S_D^{S_{oI}}$

3) $K_{Sit}, S_P^{S_{oI}} \nVdash S_D^{S_{oI}}$

2) $S_P^{S_{oI}} \leftarrow I_{source}^{sink}, K_{Sit}$

Note that a proof (3) of the related validation {⊧} and verification {← →} requirements specification process (Fanmuy, Fraga, et Llorens 2012) must be performed, for example by execution of the overall interdisciplinary models together relatively to TRL (Technology Readiness Level) levels. This initial requirement specification process is refined continuously between all involved knowledge assets.

4. SITUATION SYSTEM INTERDISCIPLINARY CO-SPECIFICATION

The cognitive role of a system architect to manage the overall actors involved to engineer a respondent system is all the more recurring to orchestration issues that new digital technologies are becoming available to conduct the interdisciplinary exchanges of documents as well of models.

4.1. Knowledge-based orchestration

This orchestration metaphor (Dillenbourg 2011) must not mask that a specification partition has not been composed a priori but has collectively to be so a posteriori all along a system project life cycle. Thus, the main difficulty is to translate any requesting human intention into a model of understanding for another required domain of knowledge. It must be noted that the responding knowledge for any specifications may be very different from the perceived one. To cope with possible interoperability concerns and depending of the steps of a project, natural binary language[2] or system-oriented language[3] or domain-oriented language (Retho 2015) may be used. To contain another difficulty to make interoperable a variety of knowledge and know-how, the overall SE orchestration performs currently standardized engineering processes in a recursive, iterative and concurrent manner according to project templates, with the possible drawback to limit human capabilities (Nugent et Collar 2015) for creating solutions by detour as previously addressed for controlling a situation. Also, to cope with this possible technics interoperability concerns, we argue in (Bouffaron et al. 2014) that any engineering actors must be orchestrated with their own means around a common bus of executable co-specification enhanced by the available technologies to wholly digitalize model based systems engineering process.

4.2. Heuristics-based orchestration

We illustrate the heuristic nature of the overall specification situation system process by a particular partition relating to a cyber physical-like situation (Figure 1).

Differently from traditional automation system engineering, first coupling interactions may be between a requesting (K_{Sit}) and a possible responding knowledge domain in framing a situation (K_E^{Sit}) perceived as able to satisfy into wholeness the descriptive requirements specification (S_D^{SoI}) of some problems related to some facts (I_{WoI}^{Sit}) affording some lack of order in a given situation. It must be noted that the intermediate validation ($K_{WoI}, S_P^{SoI} \vDash S_D^{SoI}$) is not yet that formal addressed by the entailment relationships of the problem frame approach.

This early prescriptive requirement specification may be translated to a Systems centered Engineering Knowledge domain (K_E^{Sc}) in the form of SySML requirements and use case diagrams.

According to an acquired knowledge (McFarlane 2003) (Morel et al. 2003), the respondent (K_E^{Sc}) points out the interest of an architectural pattern making of the active flowing object the "controller" of the overall (S_P^{SoI}) by wearable technologies for IoT-based responsiveness issues.

(K_E^{Sc}) may orchestrate some intermediate requirements specifications with SySML activity and sequence diagrams for mission issues to Artefact centered Engineering Knowledge domain (K_E^{Cc}) for automatic control synthesis or SySML state chart diagrams in return, depending of verification or execution issues (Zaytoon et Riera 2017).

To reassess some possible uncertainties related to human to machine interactions beyond machine to machine digital interactions, (K_E^{Sc}) must pay a special attention on the contain of (I_{AP}^{HP}) in order to exhibit the interleaved phenomena as the junction of good/service/affordance for properties measurability purposes. (K_E^{Sc}) may orchestrate the requesting descriptive specification with the Human centered Engineering Knowledge domain (K_E^{Hc}) by instantiating (equation 3') in order to be aware of the phenomena to be checked in (I_{AP}^{HP}). We have previously addressed in (Bouffaron et al. 2014) that such physic-physiological interaction might be specified with SySML internal block diagrams before to be executed for whole SoI specification issues.

To reassess the SoI behavior under specification with regards to possible open-ended changes with the world of interest, (K_E^{Sc}) explores some unordered facts, which may occur beyond the system boundary by orchestrating specification relationships with the Situation centered Engineering Knowledge domain (K_E^{Sit}). In turn, (K_E^{Sit}) frames the related situation system in order to sketch the trend of reinforcing loops with regards to the balancing loops of the previous automata for resilient issues. And so on … Note that any knowledge may directly orchestrate some intermediate requirements specifications with other ones in order to decrease the cognitive load of the system architect.

4.3. Technology-enhanced orchestration

The increased maturity of collaborative technologies enhances new model based systems engineering practices enabling the orchestration of the specification partition around a unique and extensible digital platform. For that purposes, for example, interdisciplinary knowledge and their related activities reflecting the set of logical relationships of the co-specification heuristics can be implemented by the mean of cognitive solutions available in the form of widgets (forum, blogs, files, libraries, …) available in digital workplace[4]. In order to make better the "right job right" (Fanmuy, Fraga, et Llorens 2012), common environments of co-simulation are becoming available to wholly digitalize the

[2] ormfoundation.org
[3] sysml.org
[4] IBM connections, IBM.org

interdisciplinary systems engineering, from ideation to integration and validation through the architectural design of a solution and its components. The main advantage is to facilitate the exchange and the execution as a whole of the set of models built in their own domain of knowledge[5].

Standardized openness interfaces[6] are used for computer simulations to develop complex situation system models. Such executable co-specification environment has been put into practice in (Bouffaron et al. 2014) (Bouffaron 2016) with a set of execution models closed to the elements depicted in (figure 1, left).

4.4. Synthesis

A main advantage of this technology-enhanced orchestration is to cope with major knowledge interoperability issues by enhancing individual knowledge. The essential of the collective knowledge between the many involved actors can be shared in a common language, such as the de-facto standardized SysML. Openness of domain-oriented environments, such those related to systems dynamics modeling, is required for whole system executable situation-system modeling.

5. CONCLUSION

We argue in this paper that the current meaning of a requirement specification is not sufficient to investigate what me be "hidden" or may happen relating to phenomena as source-sink of interactions to be at least contained. The journey in the situation system landscape is orchestrated by detour between the tangible world of reality knowledge and the intangible world of interdisciplinary representations knowledge and know-how as addressed by the scenario in section 4.2. Note for illustration that the orchestration metaphor is more related to a "jazz band" because of the partition writing on the fly. Situation and system are conceptually associated in real life for technology-enhanced opportunity as well as for emerging systemic failures. The interleaving of the Human, digital and physical worlds envisioned by the IoT and CPS concepts required to reassess a priori some uncertainty of a targeted situation system. Despite that remains under debate in many scientific communities, the understanding of the notion of situation is not sufficiently a knowledge asset to be acquired for acting in the early steps of a project system. In view of that, a possible explanation is in the informal aspect of the design process to look outwards as well as in the lack of systemic attitudes. Thus, we have proposed a mental scheme based on a knowledge-based framework to be used individually as a cognitive heuristics in an interdisciplinary collaborative technology-enhanced environment. So, as engineers are first students, this overall vision is put into learning practices for some time now (Morel et al. 2014). For example, the targeted situation may be that of teaching responsiveness issues. Conversely, this vision is also put into practice with a research group working at distance on the essential artifacts of systemic and its relationship with cybernetics. For example, the focus may be on the matter-energy related to flowing objects in order to maintain the togetherness between the interacting physical, artefactual and human parts of an existing large-scale situation-system having exhibited systemic failures. Even if others applications domains are explored, such IoT-based catering, we are still in an un-mature phase of this research and education project requiring to bridge informal and formal representations, included for situation-system specification validation by co-execution of models.

[5] 3DS.com© Dassault Systèmes

[6] www.fmi-standards.org

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