

Dynamic Business Networks: A Headache for Sustainable Systems Interoperability

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Abstract. Collaborative networked environments emerged with the spread of the internet, contributing to overcome past communication barriers, and identifying interoperability as an essential property. When achieved seamlessly, efficiency is increased in the entire product life cycle. Nowadays, most organizations try to attain interoperability by establishing peer-to-peer mappings with the different partners, or in optimized networks, by using international standard models as the core for information exchange. In current industrial practice, mappings are only defined once, and the morphisms that represent them, are hardcoded in the enterprise systems. This solution has been effective for static environments, where enterprise and product models are valid for decades. However, with an increasingly complex and dynamic global market, models change frequently to answer new customer requirements. This paper draws concepts from the complex systems science and proposes a framework for sustainable systems interoperability in dynamic networks, enabling different organizations to evolve at their own rate.

Keywords: Interoperability, Model Morphisms, Complexity, Dynamic Networks, Sustainability.

1 Introduction

In today's networked economy, strategic business partnerships and outsourcing have become dominant business paradigms evidencing a tremendous increase in trade and investments between nations. This fact is evidenced by the globalization phenomena, which is entering a third era where the world becomes a tiny flat place and information can be exchanged and applied innovatively across continents, independently of races, cultures, languages or systems [1]. Also, mass-customization has become a major business hub replacing mass-productions, with trends changing their focus from technology and product-driven to market and customer-driven [2], [3], thus increasing trade and information exchange.

This evolution has provided consumers a fundamental role on supply chains. Reliability and rapid delivery of defect-free products to customers is no longer seen as a competitive advantage, but as a requirement [4], [5]. Competitive markets are becoming increasingly complex and dynamic and the traditional way of doing business does not provide the expected efficiency [6]. Indeed, in most cases, a single

company cannot satisfy all customers' requirements. It needs to streamline its supply chain (SC), and collaborate actively with partners to create valued networks between buyers, vendors, and suppliers [7]. Once, individual organizations battled against each other, but today the war is waged between networks of interconnected organisations [8], e.g. SCs. Therefore, to succeed in this collaborative but at the same time competitive environment, enterprise systems and applications need to be interoperable, i.e. be able to share technical, and business information seamlessly within and across organisations, and must be adaptable to different network environments at all product life cycle (PLC) phases [6], [9]. A proven approach to deal with interoperability relies on the usage of dedicated knowledge models and international standards acting as information regulators among organizations, and covering many industrial areas and activities, from design to production and commercialization¹ [10].

However, achieving that inside heterogeneous networks, such as SCs, is still an ongoing challenge hindered by the fact that they are, intrinsically, composed by many distributed hardware platforms, software tools and ICT. Even some standardisation groups are developing specific solutions to provide national capabilities, when the full potential benefits could only be achieved if interoperability was underpinned by a coherent set of open, and internationally accepted ICT standards [9], [11].

Nevertheless, considering that the above issues are overcome and research successfully applied in industry, an emergent problem for seamless interoperability is rising, i.e. its sustainability within collaborative industrial networks: Retail and manufacturing systems are constantly adapting to new market and customer requirements, thus answering the need to respond with faster and better quality production; New organizations are constantly entering and leaving collaboration networks, leading to a constant fluctuation and evolution of business networks and system models; In addition, even standards need to be adjusted from time to time. All these factors are making interoperability difficult to maintain.

After providing an overview on the state of the art research and applied solutions for interoperability achievement within industrial networks, this paper addresses the non-linear problem of the network stability maintenance. Concepts from the complex systems science are analysed and applied on top of the most advanced state of the art interoperability practice to elaborate a heuristic framework where dynamism is tolerated, thus allowing automatic readjustments in the information flows without the need to reprogram the full systems.

2 Interoperability on Global Business Networks

Global business networks are suffering from the delocalisation phenomena, with suppliers and manufacturers moving their production networks to countries with cheaper human efforts or skill competences. Nowadays, worldwide non-hierarchical networks are characterized by non-centralised decision making. This, increases the autonomy of hub organizations, enabling different rules and procedures for decision

¹ FP6-507482 Knoeledge Web, FP6- 507590 CrossWork, FP6-507626 NO-REST, FP6-507601 SPIDER-WIN, FP6-507849 ATHENA, FP6-508011 InterOP, and others.

making within the same supply chain, but decreases the effectiveness in terms of integration and interoperability, which is defined as ‘the ability two or more systems or components have to exchange information and to use the information that has been exchanged’ [12] [13]. Paraphrasing Steve Ray, Division Chief at the National Institute of Standards and Technology “Supply chains are plagued with uncertainty (...) Most goods are still handed-off through faxes, phone calls, paper documents, and a wide range of proprietary or standard-based electronic exchanges” [14].

Indeed, interoperability has become the R&D target of many public and private programmes to address the above situation. To better describe the evolution of this domain, the authors classify current practices under the four following categories.

2.1 Slack Interoperability

Most of the information being exchanged through the internet is not much more than untagged text, which might be acceptable for human reading or to large-scale electronic libraries, but is useless for e-business [15]. In B2B relationships it is expected that computer systems are able to communicate with the minimum human intervention possible, thus maximizing efficiency and time-to-market.

The authors classify as slack interoperability, all communication sets (C_s) where there is no previous understanding between the sender and receiver. All electronic messages (m) exchanged between the two different organizations requires a corresponding “request for clarification” (rc) from the receiver side (see eq. 1), a response from the sender (r), and in some cases a set of actions normally involving human intervention (ha).

$$\forall m \in C_s, \exists rc, r \in C_s: m \Rightarrow rc \wedge r \tag{1}$$

$$\Delta t(C_s) = \sum_{i=0}^n \Delta t(m_i) + \sum_{i=0}^n \Delta t(rc_i) + \sum_{i=0}^n \Delta t(r_i) + \sum_{i=0}^n \Delta t(ha_i) \tag{2}$$

This is highly inefficient since the total time spent on the communications among two organizations is given by the sum of four operands, and as expressed in eq. 2 (n = total messages exchanged), is increased with the time spent on the clarifications, responses and human interventions. Slack interoperability does not improve over time, and subsequent communications between the same organizations result in the same costs, i.e. no knowledge is stored and there is always the need to redo the entire clarification process.

2.2 Unregulated Interoperability

As stated before, enterprise systems and applications need to be interoperable to achieve seamless operational and business interaction, and create networked organizations [16]. However, as illustrated by Fig. 1, organizations are traditionally focused on peer-to-peer relationships, thus disregarding the overall collaboration need of the network. Each organization tends to use its own data format and business rules, and handles as many mappings as the number of business partners. The fig. illustrates an extreme case where all organizations need to communicate with all the others.

Unregulated interoperability is quite efficient for networks of two or three organizations. However, it becomes unbearable for large networks, demanding a considerable financial effort, and producing an excessive workload for the software engineers responsible for the definition of the model morphisms (*MMs*) that enable communications (*Cs*) [17]. Each e-message (*m*) exchanged between two different organizations requires an initial effort to establish a mapping (*map*) among the models used by both (see eq. 3). Each time a new organization enters the collaborative network causes an increase of the total number of mappings (*map(x)*) of the network according to eq. 4, but unlike slack interoperability, the knowledge regarding the transformation is stored within the systems and the major time consumption is concentrated at the first business interaction, i.e. at the time of the mapping establishment.

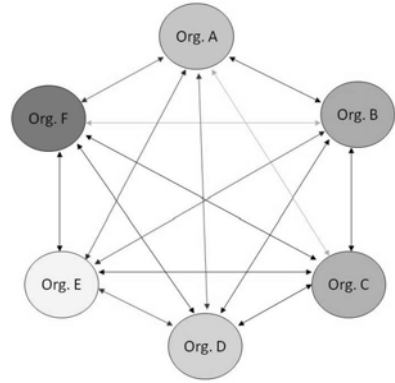


Fig. 1. Unregulated Interoperability

$$\forall m \in Cs, \exists ! map \in MMs : m \Rightarrow map \tag{3}$$

$$\forall x \in \mathbb{N} : map(x) = \begin{cases} 0, & x = 1 \\ map(x - 1) + (x - 1), & x > 1 \end{cases} \tag{4}$$

$$\Delta t(Cs) = \Delta t(map) + \sum_{i=0}^n \Delta t(m_i) + \sum_{i=0}^k \Delta t(rc_i) + \sum_{i=0}^k \Delta t(r_i) + \sum_{i=0}^k \Delta t(ha_i) \tag{5}$$

When comparing the total time spent on communications (given by eq. 5) with the previous eq. 2, one might think that it has increased. However, that is not true since the request for clarifications (*rc*), corresponding responses (*r*) and human interventions (*ha*) are significantly reduced, being 'k' a limit lower than the total number of messages in the communications among two organizations within the network (*n*).

Despite being the most common interoperability practice in industry, especially among SME's, the costs of establishing a new mapping in unregulated interoperability is preventing the enlargement of networks, thus slowing the organizations expansion. Only through the adoption of harmonized and rigorous strategies is possible to break this barrier [18], [19].

2.3 Standard-Based Interoperability

Standardization rapidly became an evident priority adding efficiency to unregulated interoperability. Several dedicated reference models covering many industrial areas and related application activities, from design phase to production and commercialization, have been developed enabling industrial sectors to exchange information based on common models [20] [21].

In that sense, one of the most important sets of standards for representation of product information in industrial environments is ISO 10303, commonly known as the Standard for the Exchange of Product Model Data (STEP) [22]. It encompasses standards for several industrial sectors as the automotive, aircraft, shipbuilding, furniture, construction, and others. When using standards as the reference format for information exchange (Fig. 2), organizations only need to be concerned with a single morphism, i.e. the one describing the mapping among its internal system model and the standardized one being used in the communication. Therefore, for each message (m) exchanged between two different organizations, a single mapping (map) is required (see eq. 3).

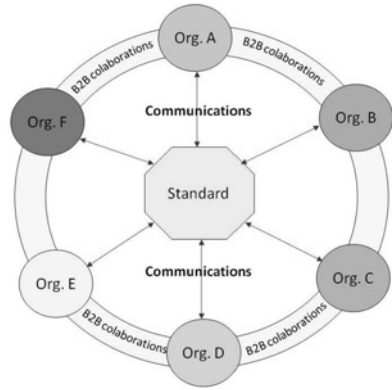


Fig. 2. Standard-based Interoperability

The major advantage comparing with unregulated interoperability concerns the total amount of mappings required within the network. As expressed by eq. 6, the total mappings ($map(x)$) correspond to the number of organizations (x). In this case, the collaboration effect is maximized and when a new organization enters the network, only needs to do a one-time effort of integration with the standard model. The remaining ones have no extra work.

$$\forall x \in \mathbb{N} : map(x) = x \tag{6}$$

$$\Delta t(Cs) = \Delta t(map) + \sum_{i=0}^n \Delta t(m_i) + \sum_{i=0}^j \Delta t(rc_i) + \sum_{i=0}^j \Delta t(r_i) + \sum_{i=0}^j \Delta t(ha_i) \tag{7}$$

Concerning the total time spent on the communications between organizations (given by eq. 7) with eq. 5 from unregulated interoperability, one might think that it is the same. However, that is not true since the request for clarifications (rc), corresponding responses(r) and human interventions (ha) are significantly reduced, being ‘ j ’ a limit lower than ‘ k ’, which is also lower than the total number of messages in the communication (n). Here, all the clarifications are related with domain semantic issues, not with the morphisms syntax, since they follow a standardized structure.

2.4 Semantic Interoperability

Interoperability is not a characteristic exclusive to ICT systems. On the contrary, it should be homogeneous throughout the network, crossing all enterprise levels, from the human knowledge, to business processes, down to plain data [16].

Unfortunately, that is not yet completely accomplished, and not addressed by standard-based interoperability [23]. To this envisaged level, the authors refer as semantic interoperability. It is defined by two kinds of knowledge: tacit knowledge, that people carry in their minds, providing context for people, places, ideas, and

experiences; and explicit knowledge that has been or can be articulated, codified, and stored in certain media, e.g. a standard [24]. It is because of the first, i.e. the human knowledge involved in businesses, that the previously described interoperability practices still require requests for clarification, and human actions need to be accounted in the total communications time. As an example, each stakeholder can have its own nomenclature and associated meaning for their business products. Therefore the information exchanged, even if sharing the same structure as in the standard-based interoperability, still may not be understood by all business partners [25]. Semantic annotation, semantic enrichment and knowledge mediation using domain ontologies are the current state-of-the-art research to address the above issues [25], [26], [27], [28]. Only when these challenges are accomplished, complemented with the usage of a standard, and applied in industry, seamless interoperability will become a reality.

$$\forall m \in Cs, \exists! map, ontomap \in MMs : m \Rightarrow map \wedge ontomap \quad (8)$$

$$\forall x \in \mathbb{N} : map(x) = 2x \quad (9)$$

$$\Delta t(Cs) = \Delta t(map) + \Delta t(ontomap) + \sum_{i=0}^n \Delta t(m_i) \quad (10)$$

As evidenced by eq. 8 and eq. 9, the number of mapping within the network will be more than in standard-based interoperability. This is because in addition to the morphism expressing the mapping (*map*) between the organization's model and the standard model, there is also the need to map (*ontomap*) the organization's semantics to a domain ontology, which is common to the collaboration network [29], [30]. The total time spent on the communications between two organizations (given by eq. 10) is heavily reduced when comparing with the previous practices, since having the domain semantics integrated, clarifications will no longer be required, and the communications set (*Cs*) automated. If semantic integration is done with other type of interoperability, other than the standard based, then the equations might not apply.

3 Sustainable Systems Interoperability

In the global market, companies and the networks which they are part of, tend to follow a dynamic and evolutionary behaviour as in complex adaptive systems (CAS), exhibiting similar properties: heterogeneous agents, interaction, autonomy, ability to learn, self-organization, melting zone, and coevolution [31], [32]. Organizations wish to adapt themselves accordingly to the market demands and the availability of new systems and applications, or just by reusing existing ones introducing new requirements and corrections (e.g. to adapt themselves to a new client or making part of a new marketplace). However, adaptation also builds complexity [33]. As a consequence of these adaptations, models and semantics change, resulting in harmonization breaking, and introducing a new dimension to interoperability research: sustainable interoperability.

3.1 Harmonization Breaking

It is a well-established fact that in classical sciences, like physics, certain phenomena can be described in exactly the same way even if experiments are carried out under different observational circumstances. This means that the laws describing the phenomena display similar results for similar inputs, i.e. symmetries, or symmetric behaviour. Yet, experiments have proven that in extreme circumstances small fluctuations acting on a system may cause it to cross a critical point and evidence an unexpected behaviour. This disorder is designated as symmetry breaking, and is a characteristic of complex behaviour [34].

Drawing a parallelism with the collaboration networks addressed in this paper, the behaviour evidenced by organizations can be characterized similarly. After interoperability is first established, the set of organizations within a network demonstrate stability exchanging e-messages following established laws (i.e. morphisms). Therefore, networks display symmetry. However, as explained before, that may change according to new market requirements. If just one of the network members adapts to a new requirement, the harmony is broken, and the network begins experiencing interoperability problems. Therefore, the authors designate harmonization breaking, as the interoperability behaviour equivalent to symmetry breaking from classical sciences.

3.2 Collaboration Networks and Complex Adaptive Systems

Cybernetics and systems thinking are well established in management literature. However, they are limited in scope to the boundaries of a system and by the perspective of management. Cybernetic systems operate at the level of basic processes that are relatively undisturbed, and systems thinking is an approach to problem solving when substantial changes have occurred in processes, viewing disruptions as parts of an overall system. However, neither can deal with major environmental changes of collaborative networks. Real dynamic systems are too complex to manage in a traditional manner [35]. The information age has highlighted the complex nature of systems, which move between ordered and disordered states, and networked organizations are an emerging logical form for organizing [36].

Over the past decades complexity theory has become a broad ranging subject appreciated in a variety of ways. The study of CAS has become the ultimate interdisciplinary science, focusing its modelling activities on how microstate events, whether particles, molecules, human agents, or firms, self-organize into emergent aggregate structure [37]. With roots in many disciplines such as evolutionary biology, non-linear dynamical systems, and artificial intelligence, modern theories and models of CAS focus on the interplay between a system and its environment and the co-evolution of both [31]. Models of CAS can be used to explore how large-scale (macro) order is shaped by the characteristics of local (micro) interactions, i.e. how different patterns of local interaction and organization adaptive behaviour impact the overall network behaviour and performance [38].

In the context of collaboration networks, the macro or networked system would refer to a set of organizations that collectively supply, sell, or produce a given part or product. The micro, or individual system is the organization itself, and the

environment would consist of end consumer markets that exert demand for the products and services. CAS can be used to analyse how intervention strategies on the network evolution, namely attempts to shape local interaction patterns and mappings, affect the network interoperability sustainability.

3.3 Heuristic Framework for Network Stability Maintenance

Complexity science has been largely used as an analytic framework for organizational management, and recently has also been acknowledged as a framework for the design of information systems [39], [40]. It offers a powerful set of methods for explaining non-linear, emergent behaviour in complex systems, such as CAS which are presumed to be capable of autonomously adapting to environmental changes. However, some available literature makes very clear that CAS result in non-linear behaviour with some probability of butterfly events spiralling into positive and negative extremes [32]. To avoid that, context awareness is demanded in support of intelligence (Integration Intelligence Layer). Monitoring and decision support systems must be considered in the construction of a framework that implements sustainable interoperability in cooperation networks (see Fig. 3).

Such a framework must exhibit: (1) discovery capabilities, detecting when new system is added, or updated in the network, thus creating harmonisation breaking; (2) Learning and adaptability, i.e., after detecting the harmonization breaking a learning process should be triggered to learn more about the changes occurred and the nodes adaptation required; It should enable the adaptation of systems and the optimization of the maintenance process, using knowledge representation technologies, applied to the model management domain, namely dynamic model morphisms. (3) Transient analysis, to understand how a network, as an integrated complex system will suffer from the transient period, and how it affects the overall behaviour; (4) Notification, informing in what way should the network nodes react, so that they obtain information for the needed adaptations, in order to enable that the system, as well as the entire network, evolve for the new interoperable state. The evolution and adaptation of each node of the network should be executed, supported by the study and analysis of the transient periods the proposed modifications could cause in the systems, both at individual and global level.

Sustainable interoperability cannot just appear from scratch. It needs to build on previous practices such as semantic interoperability, complementing them with sustainability techniques. It adds some extra time on the total time spent on the communications (C_s) between two organizations (eq. 11), since in addition to eq. 10, it is now required to account for the time spent on the sustainability recovery cycle. However, on the long-run it pays off. The network becomes immune to external phenomena that otherwise would produce serious costs in production lines and SCs becoming paralysed if a major player was affected by the harmonization breaking.

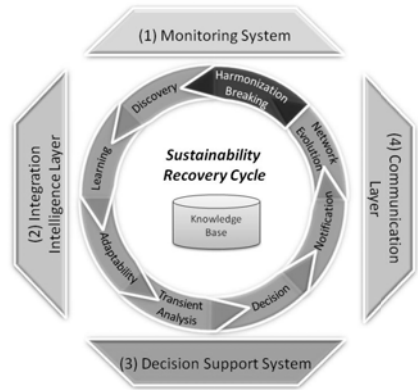


Fig. 3. Sustainable Interoperability Framework

$$\Delta t(Cs) = \Delta t(map) + \Delta t(ontomap) + \sum_{i=0}^n \Delta t(m_i) + \Delta t(recl) \quad (11)$$

4 Conclusions and Future Work

The net effect of cheap communications is a perception that individuals and organizations have to deal with a world that is increasingly dynamical, complex and uncertain, and that their actions may have unintended consequences that impact on other parts of the world [41]. Indeed, supply chains are plagued with uncertainty, and systems interoperability has become an important topic of research in the latest years.

Evolving from slack to unregulated interoperability, and then from standard-based to semantic, nowadays organizations have plenty of solutions that help establishing an efficient business partnership. Electronic communications are the basis for automation and efficiency. However, that is lost when just a single organization changes its information structures or semantics, causing the collaboration network to begin evidencing interoperability problems, i.e. harmonization breaking.

The theoretical framework that is emerging based in complexity science appears to have relevance as an orienting device for entrepreneurship and sustainable interoperability research. Interpreting knowledge of the organizations domain through a metaphorical language of complexity may provide building blocks for explaining behaviour in terms of complex adaptive systems [42]. Evolvable systems imply ontology-based process-specific modularity at fine granularity with local intelligence and a distributed control solution [43]. Hence, the internal environment of the organization and its information system can create the adequate response to the external environment. For that to happen, both human workforce and information systems need form an adaptive resource [40]. Therefore, there is a need for a heuristic framework capable of capturing environment knowledge and relate human choices and preferences, using monitoring and decision support.

An early version of this framework is presented in this paper. Similarly to what occurs in the model-driven development (MDD) architectures, meta-information and technologies related to transformation automation are considered. The application of these adaptive techniques will also enable the characterization of the current system status concerning morphisms and evolutionary transitions.

However, the major complexity associated to the study of the properties of complex systems is that the associated models, drive to non-linearity, which in turn, drives to difficulties in the system's study and in predicting their behaviour. In this context and part of future work, at the system microscopic level, prediction could be seen as a proposal for the automatic adaptation of the network morphisms, i.e., the point-to-point readjustments among the different systems, answering to the harmonization breaking. Thus, the framework envisages to include learning capabilities, monitoring, diagnostic and prognostic based on the operations history and interventions of the involved systems. It allows a control and optimization process of future adaptations, monitoring the individual evolution of each networked system, as well as the dynamics of the entire network.

The research to be developed will establish the scientific and technological basis to enable different system nodes, belonging to a collaborative network, evolve at their own time, and keep being interoperable on the network they want to be part of.

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