Dynamic Behavior Control of Interoperability: An Ontological Approach

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Abstract: The obligation to become more competitive and effective in providing better products and services requires enterprises to transform from traditional businesses into networked businesses. One of the challenges faced by a network of enterprises is the development of interoperability between its members. Transformations in this context are usually driven by Enterprise Interoperability (EI) problems that may be faced. In order to quickly overcome these problems, enterprises need characterizing and assessing interoperability to be prepared to establish means for collaboration and initiate corrective actions before potential interoperability problems occur and then be obliged to make unprepared transformations that may be costly and induce unmanageable issues. In this paper, we define an integrated metamodel for interoperability using DEMO. The proposed metamodel is based on an Ontology of Enterprise Interoperability (OoEI) and concepts from a maturity model for interoperability while taking into account principles from Enterprise Dynamic Systems Control (EDSC) domain. It allows to understand and control the dynamic behavior of interoperability between companies.

1 INTRODUCTION

Historically, progress occurs when entities communicate, share information, and together create something that could not be achieved alone. Moving beyond people to machines and systems, interoperability is becoming a key factor of success in all domains.

Interoperability seems to be a straightforward concept. However, there is no common definition or shared comprehension of it. Each expert defines and understands interoperability, according to his domain. To deal with this research gap, the Ontology of Interoperability (OoI) was proposed to formalize the interoperability domain while defining also problems and solutions pertaining to it(Naudet et al., 2010). As interoperability is a general issue that is tackled through many different domains such as military, software, information systems, modeling, organizations or health, the OoI was based on the General System Theory (GST) (Von Bertalanffy, 1968) to have a general consensus that stay applicable to any interoperability domain. The OoI was thereafter extended to the Enterprise domain by defining the Ontology of Enterprise Interoperability (OoEI) (Guédria and Naudet, 2014), where an enterprise is also considered as a system. Indeed, any organizational system is subject to be controlled and is compliant with the concepts from GST, as referred by Enterprise Dynamic Systems Control (EDSC) (Guerreiro and Tribolet, 2013) (Guerreiro, 2012).

The EDSC principles are grounded in the belief that, during operation time, actors perform different actions from the ones that have been prescribed for them. Considering the models definition as *ex-ante*[1], and operation as *ex-dure*[2], EDSC checks if *ex-dure* complies with *ex-ante*. Other solutions, *e.g.* regulations enforcement, check compliance between *ex-post*[3] and *ex-ante*. Therefore, when a non compliant situation is found, EDSC cannot take any actions. It is too late to avoid the situation. EDSC acts at run-time, observing the reality and checking continuously if it complies with prescriptions. When a non compliance situation is found, EDSC acts with a change in the operation, or, if the situation is innovative a change in the prescriptions.

Growing globalization, competitiveness and rising environmental awareness are driving many companies to control their interoperability strategy. Nu-

[1]before the execution
[2]during execution
[3]after the execution

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merous models, methodologies, tools and guidelines exist that can help an organization, an enterprise, or more generally a system, to develop interoperability and improve the way it operates with others. Developing interoperability requires considerable costs and efforts. Characterizing and measuring interoperability, allows an enterprise to define its needed interoperability and to plan the migration path to reach it. This has become a significant research challenge over the past few years and maturity models have been developed in response to this challenge. Numerous maturity models have been developed for different purposes, some of which are dedicated to the interoperability domain. A survey of the most known ones has revealed that, in most cases, existing maturity models focus on one single facet of interoperability (data, technology, conceptual, enterprise modeling, etc.). In this research work, as we propose to have a general view of the Enterprise Interoperability (EI) domain, we will be based on the Maturity Model for Enterprise Interoperability (MMEI). MMEI was defined in (Guédria et al., 2015) and was used as a main input to the standardization work carried out in CEN TC 310/WG1 and ISO TC 184 SC5/WG1 to become later a standard maturity model for enterprise interoperability (CEN 11345-2). The particularity of this maturity model is to be defined based on existing models and to have a systemic view of the enterprise.

In this paper, we propose to use the EDSC principles to define a conceptual model that integrates concepts from the OoEI meta-model and the MMEI maturity model. This will allow to diagnose interoperability problems and simplify the assessment process by having the required information. This will in particular help enterprises in diagnosing interoperability problems while assessing their ability to interoperate and to prevent actions to undertake. The remainder of the paper will be the following: the research context and some preliminaries that are needed to understand the main contribution of the paper are presented in section 2. In section 3, we propose the meta model resulting from the integration of the OoEI and concepts from the MMEI. Section 4 concludes and perspectives for future work are then given.

2 RELATED WORK

Generally speaking, interoperability is the ability of two or more systems or components to exchange information and to use the information that has been exchanged (IEEE, 1991). When this ability is not achieved, interoperability becomes a problem that must be solved.

Solutions to interoperability problems can be characterized according to interoperability approaches defined in (ISO, 1999). EI problems can be localized into interoperability barriers and characterized by EI concerns, as defined in the Framework for Enterprise Interoperability (FEI). FEI has been initially elaborated in INTEROP NoE (D. et al., 2007) and is now published as an international standard (ISO 11354 - 1). It defines a classification scheme for interoperability knowledge according to three dimensions:

- Interoperability concerns, defining the content of interoperation that may take place at various levels of the enterprise (i.e. data, service, process, business).
- Interoperability barriers, identifying various obstacles to interoperability in three categories: conceptual, technological, and organizational.
- Interoperability approaches, representing the different ways in which barriers can be removed (i.e. integrated, unified, and federated)

The first two dimensions, interoperability concerns and barriers, constitute the problem space of enterprise interoperability (EI) (Chen, 2006). In order to avoid such problems, enterprises need to know their strengths and weaknesses in terms of interoperability in order to undertake corrective actions and be prepared to potential interoperations. This is the purpose of the interoperability assessment which can be performed either as part of a continuous improvement initiative, or as part of an analysis approach.

2.1 Ontology of Enterprise Interoperability (OoEI)

The first attempt to define the interoperability domain was made by (Rosener et al., 2004), where a model for defining interoperability as a heterogeneous problem induced by a communication problem was proposed. On the basis of these research efforts, the Ontology of Enterprise Interoperability (OoEI) (Guédria and Naudet, 2014) as an extension of the Ontology of Interoperability (OoI) (Naudet et al., 2006) was developed using the Ontology Web Language (OWL). The OoEI aims at formally defining Enterprise Interoperability (EI) while providing a framework to describe problems and related solutions pertaining to the interoperability domain.

Interoperability exists because there are at least two *Systems* and a *Relation* between them. The *relation* is of primary importance and is the source of interoperability problems (Rosener et al., 2005). A *System* is defined as a set of interconnected parts, having a *Structure*, a *Function*, an *Objective* and a *Behav-*

ior (Giachetti, 2010). These concepts are necessary to understand a system.

The OoEI was defined based on the FEI (Chen and Daclin, 2005) (Guédria and Naudet, 2014). It describes systems as interrelated subsystems: A *System* is composed of *SystemElement*s, which are systems themselves, and *Relation*s. The *Relation* concept formalizes the existing relationships inside a system, which is the source of the occurrence of interoperability problems.

An enterprise is considered as a complex system in the sense that it has both a large number of parts and the parts are related in ways that make it difficult to understand how the enterprise operates and to predict its behavior (Giachetti, 2010).

Dealing with EI requires considering the enterprise from a general perspective, taking into account not only its different components and their interactions but also the environment in which it evolves and the interface through which it communicates with its environment. The *Interface* is a *SystemElement* through which a connection between the *System* and its *Environment* can be established. It also represents the systems boundaries.

The establishment or diagnosis of EI has led to identify the different operational levels that are concerned: *Business*, *Process*, *Service* and *Data* interoperabilies (i.e. the EI concerns as defined by FEI). Interoperability is implemented as a subclass of the *Problem* concept. Problems of interoperability exist when there is a relation, of any kind, between incompatible systems in a super- system they belong to or system they will form. An exhaustive description of the OoEI can be found in (Guedria, 2012).

2.2 Maturity Model for Enterprise Interoperability (MMEI)

Generally speaking, a maturity model is a framework that describes for a specific area of interest a number of levels of sophistication at which activities in this area can be carried out (Alonso et al., 2010). In our case, the specific area of interest is EI. The MMEI has been proposed in (Guédria et al., 2015). It takes into account existing maturity models while extending to the whole domain of EI.

When an enterprise wants or needs to work or collaborate with other enterprises, different tools such as guidelines or metrics might be useful in order to ensure proper interoperation at all levels of the enterprise system. MMEI allows companies to evaluate their interoperability potentiality in order to know the probability that they have to support efficient interoperation and to detect precisely the weaknesses that are sources of interoperability problems. In this section we present an overview of the MMEI model with a brief description of its levels. The complete description of the model can be found in (Guédria et al., 2015).

The proposed model differs from all other maturity models dedicated to interoperability so far. It is intended to cover the three interoperability levels (conceptual, technological, organizational) which are used to classify the barriers in FEI (Chen, 2006), at each of the EI concerns (business, process, service, data). MMEI defines five levels of interoperability maturity. Each one of the maturity levels is described based on a simplified version of the Framework of Enterprise Interoperability (FEI) that contains only two basic dimensions ”interoperability barriers” and ”enterprise interoperability concerns”. Table 1 provides a general view of the MMEI model with its contents. Each one of the five maturity levels is an instantiation of this general view with an evolution of the content regarding the evolution of the level.

2.3 Enterprise Dynamic Systems Control

General Systems Control Concepts. From the perspective of classic control concepts (Franklin et al., 1991) the system that we propose to control is the execution of the business transactions. The purpose of a control system is to react whenever the disturbance affects the behavior of the system or whenever a new input is established. In other words, when the system is not producing the desired output for the imposed input. Control act in the input at the same time as the disturbance is affecting the system.

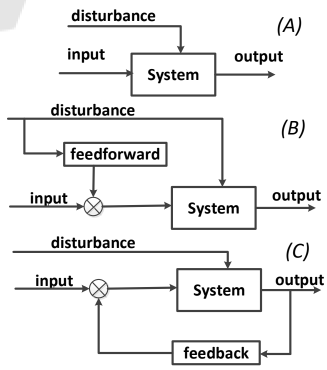

Figure 1: Design pattern of control systems. (A) without control, (B) feed forward control and (C) feedback control.

Figure 1 depicts classical design patterns for a control system. In the top, (A), it shows a system that is not controlled. The disturbance always affects the output delivered by the system. In this pattern, it is

Table 1: General view of MMEI levels structure.

	Conceptual	Technological	Organizational
Business	Business models, enterprise visions, strategies, objectives, policies	Infrastructure, technology	Work methods, business rules, and organizational structure
Process	Processes models	Tools supporting processes modeling and execution	Responsibilities, Process management and rules
Service	Services models	Tools supporting services and applications	Responsibilities, service and application management and rules
Data	Data models, (semantic, syntax)	Data storage and exchange devices	Responsibilities, data management and rules

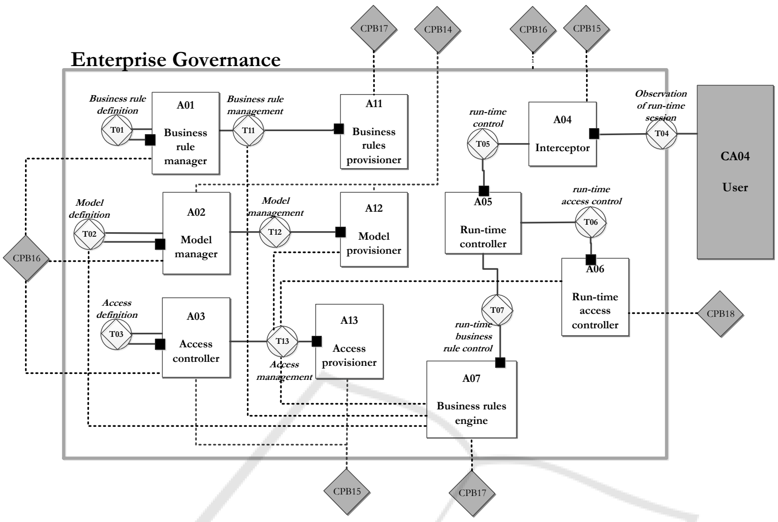

Figure 2: DEMO Organizational Construcional Diagram for Organizational control (adapted from (Guerreiro, 2012)).

not possible to guarantee the behavior of the system output. In the middle, (B), a feed forward pattern that shows that the system input changes accordingly with the actual disturbance. Therefore, the system dynamics it not included in the control actuation. At the bottom of Figure 1, (C), a feedback control pattern calculates the system input accordingly with the actual misalignment obtained between the output and input. In this pattern, the control actuation calculation takes into consideration the disturbance and the system dynamics. Because the system output depends on the disturbance imposed in the system and on the system dynamics itself. Moreover, to produce results, all systems control requires the capabilities of observation and actuation (Guerreiro, 2014).

Organizational Control. In the scope of an organization, control is performed implicitly and the overall organizational system maintains its stability involving all the actors, without a clear identification of which parts are controlled and which parts are controllers. Thus, our position paper states that control *(i)* is not always either explicit or analytical, as cybernetic control approaches are, *(ii)* it is not possible to predict all the business transactions conditions to control before execution due to the high number of possible combinations that could happen at run-time and *(iii)* the identified deviation from the stable state is sometimes incorporated as organizational innovation. Keeping in line with the scientific contributions of (Beer, 1979) (Bertalanffy, 1969) an organization is a huge non deterministic state machine, *i.e.* non mechanic, composed by a set of systems that play a complex intertwined orchestration, played fundamentally by the actors, humans and computers. Besides the machinery used by the organizations, actors are humans with action freedom and act accordingly with their purposes and orchestrations (Winograd, 1986), organized in a social system. The organization existence is revealed while this social system performs actions.

It is commonly agreed, since foundational works in this area (Le Moigne, 1994), that control requires the capabilities of observation, decision and control actuation. It is an ongoing Plan-Do-Check-Act policy. However, in some complex system's contexts the observation and the actuation is only partial. The organization cannot be aware about everything that exists, neither by the abilities that are made available to change.

Design of Organizational Control. The DEMO Organizational Construcional Diagram (OCD) depicted in Figure 2 designs the ontology of a given solution regarding the actors, the production banks, the coordination banks, the boundary and the information flow. The OCD is an adaptation from (Guerreiro, 2012). Figure 2 is textually described as follows. Control observations are enforced by T04. T03 and T13, specify and change, the involved actor roles. T02 and T12 specify and change the state space and transition space of the organizational system. An information link exists between A12 and T13 to obtain the access configuration from the organizational system' models during the configuration phase of the references. The A07 has three information links to the T11, T12 and T13. They correspond to the control action of changing a model and are taken when any misalignment occur. T11 corresponds to a self-change in a business rule. T12 corresponds to a change in the organizational system model to be controlled, and the model manager performs it. T1 corresponds to a change in the access management. T05 enforces control by the mean of the business rules. CPB16 refers to the Period that the enterprise control is being considered, by other words, the period where control is valid, hence an information link exists with Organizational control boundary.

3 METAMODEL FOR ENTERPRISE INTEROPERABILITY CONTROL AND IMPROVEMENT

3.1 Integration of OoEI with MMEI Concepts

The structure of MMEI is based on a simplified version of FEI where we can find the EI concerns (i.e. Business, process, service and data) and interoperability barriers (i.e. conceptual, technological and organizational), as depicted by table 1. These concepts can also be found in the OoEI (Naudet et al., 2008) . Moreover MMEI and OoEI follow a systemic view (Von Bertalanffy, 1968).

The content of each cell of the table 1 can be related to the OoEI as shown in Figure 3. The OoEI concepts are presented with white ellipses while concepts related to the MMEI model are presented with gray color. Based on the OoEI and MMEI review, three main dimensions of EI are considered: Interoperability aspects (conceptual, organizational and technical), Interoperating entities, also known as EI concerns in FEI (business, process, service and data) and Interoperability barriers (Conceptual, Organizational, Technological). These are represented by the three concepts: *InteroperabilityAspect*, *InteroperabilityConcern* and *InteroperabilityBarrier* respectively. These are all modeled with their different constituents represented here as dimensions describing *Enterprise Interoperability*, as shown in figure 3. Within the context of EI, interoperability problems are represented by the *InteroperabilityBarrier* concept. The term barrier is defined as an incompatibility, obstructing the sharing of information and preventing exchanging services (Chen and Daclin, 2007). The establishment of interoperability (with its three aspects) consists of removing identified barriers (conceptual barrier, organizational barrier or/and technological barrier). Hence each *InteroperabilityBarrier* is related to the corresponding InteroperabilityAspect (see figure 3). For each OrganizationalBarrier, the criteria that need to be verified are the definition and compatibility of the Responsibilities, Work methods, Business rules, Organization structure and strategy, as defined by the MMEI model (see table 1). This is represented by the concepts *Responsibilities*, *Work methods*, *Business rules*, *Organization structure* and *strategy* which are considered by the *Organizational Barrier*. Similarly, the concepts of *Business model*, *Process model*, *Service model* and *Data model* are concerned with the *ConceptualBarrier* and the concepts of *IT infrastructure*, *IT tools* supporting *data storage* and *Exchange devices* are concerned with the *TechnologicalBarrier*.

This model can be used thereafter to have the required knowledge to assess the EI of the considered enterprise. The gray MMEI concepts (gray ellipses) in the figure 3 presents the requirements and related information that need to be verified. For example, in order to assess the EI at organizational level, some of the requirements that assessors have to verify are whether responsibilities supporting business, process, service and data interoperability concerns are properly defined and that are compatible with those used within the enterprise environment.

3.2 Integrating Enterprise Dynamic Control

Given the metamodel presented in the previous subsection (summarized by Figure 3), we propose to enforce it using the Enterprise Dynamic Systems Control (EDSC) (Guerreiro, 2012) principles. This enforcement is explained using an examplification case study of two companies (Company 1 and 2) that are interoperating. The idea is to have a master controller (Interoperation control) that is able to change access

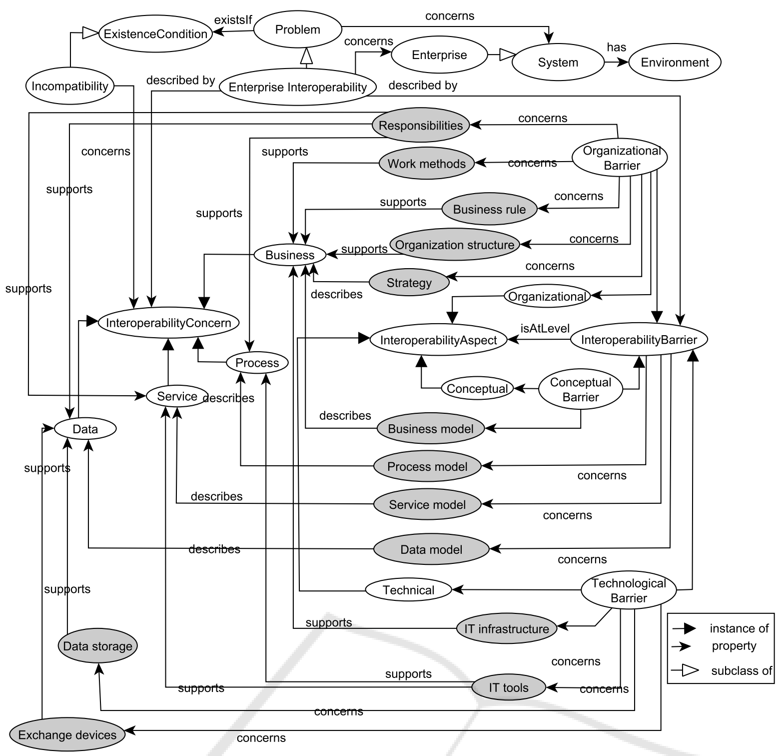

Figure 3: Extract of the integrated model.

control configuration in both companies, when any unexpected observation occurs in the business transactions between them. The EDSC pattern presented in Figure 2 is herein used to express the controlled systems of each company and the interoperation controller. EDSC is a generic pattern that could be used for expressing the control of any type of system. Each company is at the same time an internal controller and a controlled system by the interoperation control. EDSC pattern is terefore used to ground the systems behavior' description.

In the right part of Figure 4 is depicted two companies that are interoperating with the business transactions T-101 and T-102. Some business transaction execution is being performed. A more complex network could be considered, yet, for demonstration purposes it is simplified. The execution of the T-101 and T-102 are **observed** by the CA04 composite actor, using a DEMO information link. Here, the interoperation control **checks** whether the observed information complies with the access rules that were provisioned. When the observations are not complaint with the previous configurations for access definition, another information link is used to change the access data bank of the correspondingly Company 1 and 2. This **action** changes the CPB15 with an access revokation or grant to the execution of T-101 and T-102.

4 CONCLUSIONS AND FUTURE WORK

In this paper, we have proposed an integration of the Maturity Model of Enterprise Interoperability (MMEI) concepts into the ontology of Enterprise Interoperability (OoEI) while taking into account the Enterprise Dynamic System Control (EDSC) principles. The integration was facilitated by the systemic basis of the considered principles and models. The integrated model allows to have the required knbowledge for the interoperability assessment and save human efforts in gathering information and validating it for each assessment. This will facilitate the diagnosis of interoperability problems and a better control of the behavior of the considered enterprise. This is facilitated by the nature of the OoEI which were conceived in a problem solving perspective and the EDSC principles. Future work are planned to improve this first version of the integrated model in order to implement a tool for automatic assessment. This will be supported by the automatic assessment process developed in (Guédria et al., 2015) and based on fuzzy rules and linguistic variables. It can be also complemented by a proposition of solutions to interoperability problems by using best practices that were developed for the MMEI (Guédria et al., 2015).

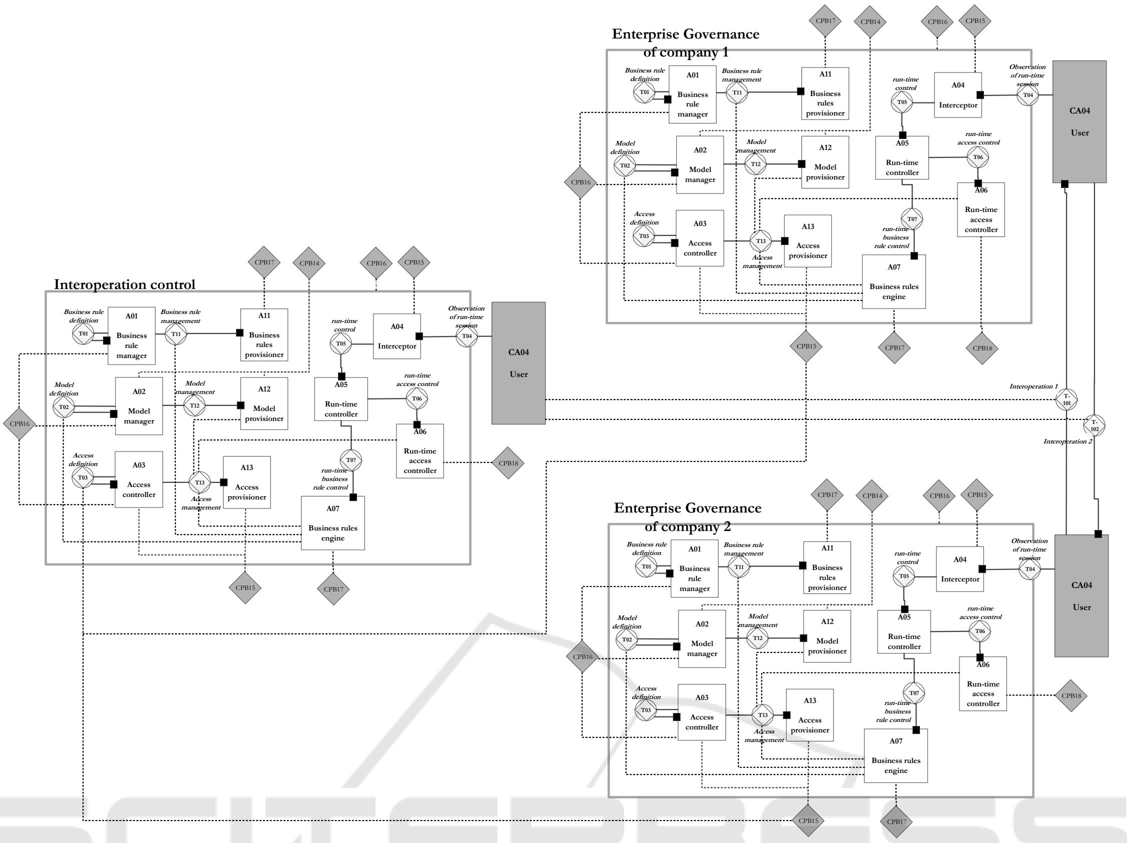

Figure 4: Interoperation using the EDSC pattern.

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