Submitted to the IFAC World Congress, Toulouse, France, 9 - 14 July, 2017

An Enterprise Operating System for the Sensing, Smart, and Sustainable Enterprise

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Abstract: To be competitive in the digital era, enterprises need to become sensing to be aware of their context, smart in taking decisions, and sustainable regarding social, environmental, and economic issues. Reference models can guide the enterprise engineering process in such direction. However, the implementation of the enterprise models, generated with reference models, depends on the integration of enterprise resources, which is not always possible due to the diversity of tools and applications needed within each business process. This paper proposes an Enterprise Operating System (EOS) to effectively handle the execution of enterprise models by integrating a diversity of functionalities. The goal of an EOS is to manage the resources (i.e. humans, applications, and machines) of an enterprise to fulfill its operation. The Sensing, Smart and Sustainable Enterprise Reference Model (S^3E-RM) is proposed to guide the implementation of the EOS. This reference model uses the viewpoints defined in the Reference Model of Open Distributed Processing (RM-ODP), i.e. enterprise, information, computation, engineering, and technology. The EOS presented has been successfully applied in more than 27 industry sectors, including government.

Keywords: Enterprise Operating System, Digital Enterprise, Sensing Enterprise, Reference Model, Enterprise Engineering, Enterprise modelling.

1. INTRODUCTION

In the digital era, advances in Information and Communication Technologies (ICTs), such as big data analytics, cloud computing, social computing, and cyber-physical systems, allow enterprises to become part of the hyperconnected world to improve their business operations. Enterprises can become digital systems that use their sensing possibilities to be aware of their context and use knowledge to take smarter decisions that lead to sustainability. This vision of the enterprise is referred as the S^3-Enterprise (Sensing, Smart, and Sustainable) (Weichhart et al., 2016). Although this vision promises that enterprises have the capabilities necessary to compete in the digital era, tools and methods are needed to guide the evolution of nowadays companies and the creation of new S^3- Enterprises.

Enterprise engineering is the discipline in charge of studying the methods and tools to design and maintain an integrated state of the enterprise (Kosanke et al., 1999). Within the field of enterprise engineering, enterprise models were created to capture enterprise content, structure and requirements to improve integration. The creation of particular enterprise models can be eased using reference models. The reference models provide reusable structures common to many enterprises. Reference models have been used to analyze, create and design particular models for the S^3-Enterprise (Chavarria-Barrientos et al, 2016).

Today, enterprise models are built for the purpose of analysis, understanding, and design. The next step after enterprise modeling is to be able to execute these models to really affect the processes, decisions, collaborations, and interoperations within the enterprise or Collaborative Networked Organization (CNO) (Camarinha-Matos et al., 2009). For such purpose, there is a need for Enterprise Operating Systems (EOSs) that act as an interface between enterprise resources that perform business processes and enterprise managers that decide how the processes will be executed (Chen et al, 2015).

This paper presents an Enterprise Operating System that allows the execution of enterprise models. The vision of the EOS is described in section 2. Related developments are identified. Then, an EOS is presented (section 3) as a proposal to fulfill such vision. The methodology and tools used to leverage its use are explained. Finally, the evaluation of such EOS (section 4) and conclusions (section 5) are stated.

2. THE VISION - ENTERPRISE OPERATING SYSTEM

An EOS is a system capable of monitoring enterprise resources and operations in order to dynamically allocate resources to required activities (AMICE, 1993; Chen et al., 2015). The goal is that diverse resources connected by the EOS work as ‘one’. According to the conceptual architecture presented by Youssef et al. (2016), an EOS contains five major components.

- Enterprise Resource Management (ERM): dynamically monitors the status of enterprise resources. It searches and allocates suitable resources to business operations.
- Enterprise Process Management (EPM): executes and coordinates business processes defined by business managers and EOS internal processes.
- Enterprise Information Management (EIM): manages, protects and supports information and data exchange between the resources connected to the EOS.
- Presentation Management (PM): is a set of services with appropriate interfaces that allow enterprise resources (i.e. humans, applications, and machines) to connect to EOS and receive/send information.
- Interoperability Management (IM): is a set of services that provide necessary mapping between heterogeneous resources to make them interoperable through EOS.

Although the term EOS appeared in the last decade, the concepts and objectives that it implies have been developed before. The EOS concept appeared at the end of the 1980s in the form of an Integrating Infrastructure (IIS), within the CIMOSA architecture (AMICE, 1993). After that, in the 1990s, CEN TC310 WG1 elaborated ENV 13550 EMEIS (Enterprise Model Execution and Integration Services) to express capabilities of environment for developing executing and integrating enterprise models on an open IT-based platform (Chen and Vernadat, 2004).

Enterprise IT infrastructures have been proposed (e.g. OMG CORBA, OSF DCE or more recently Enterprise Service Buses) to support integration and interoperability of enterprise applications. However, they do not implement enterprise models nactment. Then, the direct model execution was proposed by E2E under the concepts of OMG MDA, enterprise models are executed without transforming them to code.

Developments related to EOS, include the ERP (Enterprise Resource and Planning) systems connecting MES (Manufacturing Execution Systems). An example is the open ERP ODOO (https://www.odoo.com), which implements several types of business applications, e.g. customer relationship management, finance, Web services, product lifecycle management, etc. However, an EOS must also impact processes at the strategic level of the enterprise.

Existing works cover certain requirements stated in the vision of the EOS. Each of them with different focuses. Although it was a step in the development of EOS, new studies must include more EOS characteristics. Examples of works that help in directing such developments are the framework proposed by Oztadzadeh and Rahmani (2010), which is based on the Zachman Framework, and the conceptual and technical architectures described by Youssef et al. (2016). Youssef's architecture was tested using simulation in a banking and finance environment.

3. LOVIS ENTERPRISE OPERATING SYSTEM

LOVIS (http://lovis.company/) is a company that helps its customers improve their business value by aligning the business processes to the strategy and supporting them with cloud-based business technology. One of the products offered is an Enterprise Operating System, LOVIS EOS, that aims at substituting the traditional ERP systems.

After listening carefully to the clients, the LOVIS company determined eight characteristics as the requirements that make an EOS unique among other enterprise applications:

- Reflect reality. Nowadays, many enterprises adjust the inputs to their enterprise applications in order to match system requirements. As a consequence, data capturing become complex and the data analytics made is biased. In contrast, an EOS must be designed to capture the reality of the enterprise.
- Universal enterprise software. An EOS software must be the same for all countries and industries but configurable to special needs. Thereafter, the communication among different supply chains is eased, allowing the creation of CNOs.
- Ready to use, configurable, and scalable. Current enterprise applications need specific code development each time a client requires to expand, modify, or include a functionality during the implementation. An EOS is ready to operate from the first day and it adapts to the enterprise logic without programming.
- Non-stop natural workflow. In order to provide reports or synchronize processes, some enterprise applications need to be stopped, causing reworks and delays in business operations. An EOS must be designed for non-stop operation so business processes, such as accounting, can be derived at any time and immediately.
- Online & Realtime Transactional Operation. In order to get a valid and up-to-date information anytime, each transaction must be made into the application by the person that is in charge of it and in the moment that it happens. So, the information that reflects this transaction enters the database naturally, it is validated and its effects are applied upon all related transactions.
- Integrated database. Other application vendors provide a diversity of applications with different databases. As a consequence, the integrity of information is compromized. An EOS must have an integrated database that can be used to implement real-time data analytics.
- Business process orientation. Traditional module-oriented applications generate islands of information affecting the operation flows. To really support the operations of the enterprise, an EOS must be guided by the business processes (Vernadat, 2007).
- Full availability. To provide ubiquity, users must be able to access the EOS from a variety of devices in different situations. Due to the hyperconnectivity enabled by the Internet, cloud-based solutions can realize the ubiquity requirement. In addition, an EOS must be available 24 hours, all days of the year.

Such characteristics have been accomplished by LOVIS EOS. Furthermore, the use of reference models leverages the execution of the EOS since they assist in creating the particular enterprise models to be implemented. The Sensing, Smart, and Sustainable Enterprise Reference Model (S^3E-RM) is proposed to support the complete enterprise engineering process.

3.1 Enterprise Reference Model

ISO 15704 and ISO 19439 provide the set of concepts that allow users to document the enterprise reality with the help of enterprise models. Reference models are used to assist the development of enterprise models, providing reusable reference models and designs of human roles, processes, and technologies (IFIP-IFAC Task Force, 1999).

Molina et al. (2014) proposed the Sensing, Smart, and Sustainable – Enterprise Reference Model (S^3E-RM), which has the purpose of assisting developers in the following tasks:

1. Identify the enterprise requirements to support the concepts of Sensing, Smart, and Sustainable Enterprise

2. Guide the design and implementation of the enterprise system itself

3. Organize the process of implementation (people, methods, and tools) to evolve the Sensing, Smart and Sustainable system towards the desired level of integration and automation.

The reference model is based on the five viewpoints stated in the Reference Model of Open Distributed Processing (ISO/IEC 10746 RM-ODP). Each viewpoint allows the description of the enterprise entity from a different perspective (See Fig. 1).

The enterprise viewpoint sets the objectives of the enterprise, the business concept and the strategies are selected. The information viewpoint allows capturing the information and knowledge that is important to take better decisions when engineering an enterprise. The computation viewpoint allows the design of the core business processes and competencies. The engineering viewpoint guides the implementation of design using an e-HUB to provide e-services, e-applications, and e-technologies. Finally, the technology viewpoint focuses on the selection of the technology to support the system. Further description of the viewpoints can be found in the cited articles (Molina et al., 2014; Chavarria-Barrientos et al., 2015; Chavarria-Barrientos et al., 2016).

The reference model has been implemented in more than 70 cases made by undergraduate students at Tecnologico de Monterrey. It has been proved to be ease of use and straight forward. As stated by Chen et al. (2008), the simplicity is a desired characteristic, since the reference model can be understood and actually followed by developers.

The S^3E-RM has been also used for modeling collaborative networks, and formally described using the Unified Modelling Language (UML). In addition, action-research methodology has been used as a methodology for instantiation allowing a systematic development of viewpoints for particular enterprises (Chavarria-Barrientos et al., 2016). However, the execution of enterprise models is necessary to guarantee that the enterprise engineering process is applied in a satisfactory way. Such execution can be achieved with the LOVIS EOS by mapping the developments in the viewpoints. The next subsection explains it in detail.

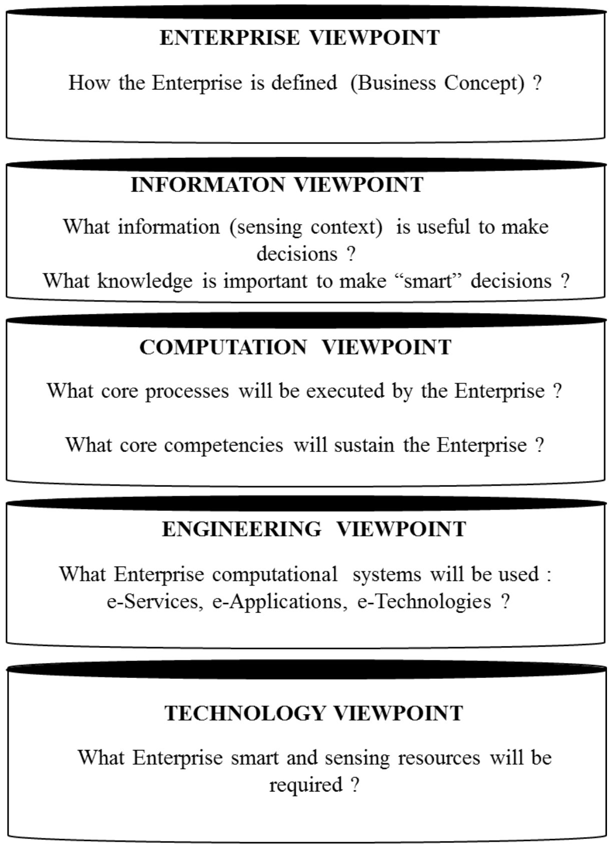

Fig. 1. Sensing, Smart, and Sustainable Enterprise Reference Model

3.2 S^3E-RM implemented by LOVIS

The objective of the enterprise viewpoint is to establish the business concepts. This viewpoint is used to capture the necessities and goals of LOVIS EOS clients. Interviews are conducted between the client and LOVIS company. Meanwhile, the information obtained is captured through the business model canvas (Osterwalder and Pigneur, 2010), the competitive strategy, value chain strategy, and production strategy. The canvas includes nine building blocks that represent the value proposition, customer channels, relationships, customer segments, key resource, key activities, and key partners. The set of strategies determine the core processes and core competencies. By capturing this information, the LOVIS company is able to understand the client's perspective of the business. After, the vision of the client's company is established to determine the business goals. Such goals are used to create a set of Key Performance Indicators (KPIs), usually related to profit, time, customer satisfaction, and opportunity cost. The KPIs are used to effectively measure the evolution of the company through its business goals when using LOVIS EOS.

The information viewpoint aims at capturing all the information items needed for the enterprise operation. Inside the LOVIS EOS, the information is distributed into catalogs, documents, lists, and classifiers (Fig. 2). The catalogs comprise accounting (e.g. financial accounts, projects), entities (e.g. suppliers, clients, debtors, warehouses), and materials (e.g. finished goods, work in process, raw material, services). These catalogs represent what is done in a transaction, who does it, and what is moved in it. The documents stored are related to business activities, examples are payments, charges, production orders, inventory receiving, purchase orders, etc. The lists indicate a sequence of related information, for example, lists of prices and Bills of Materials (BOMs). Finally, the classifiers indicate the different arrangements needed for business processes (e.g. region, colors, sizes, routes).

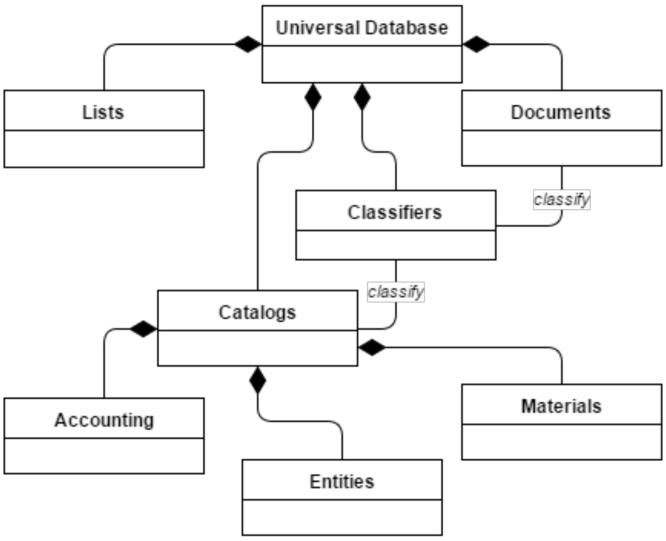

Fig. 2. Information viewpoint for LOVIS EOS

These components ease the construction of a universal database. Furthermore, the process done by the EOS when new data arrives guarantees that all the information within the database is valid, integral, and up-to-date at every moment. First of all, the data is captured in the system by the person who is performing the operation of the business process. Before the data generated enters the database, it is validated and its effects are applied to all related data. The relationship among data is captured in a set of user defined rules (knowledge model). As a consequence, aggregate data calculations are performed immediately. The procedure data is following, provides features such as real-time analytics and derived accounting.

The computation viewpoint allows the description of the core business processes. The first step is the identification of the business processes. According to Browne et al. (1999), eight core business processes comprise the activities inside an organization i.e. Co-Creation, Co-Engineering, Customer Relationship Management, Supplier Relationship Management, New Product Development, Obtaining Customer Commitment, Order Fulfillment, Customer Service. These processes are used as a reference when identifying the activities done in each industry sector.

An important part of the business process engineering is the modeling, which can be done with several tools that include Unified Modelling Language (UML) sequence diagrams, Unified Enterprise Modelling Language (UEML) (Vernadat, 2002), Business Process Modelling Notation (BPMN) and platforms that support it, e.g. ARIS Toolset (Davis, 2001). For the LOVIS EOS the mapping is achieved through workflow diagrams (Fig. 3) that include representations of features directly related to the EOS. Thereafter, the process models generated are used to make a straightforward configuration of LOVIS EOS.

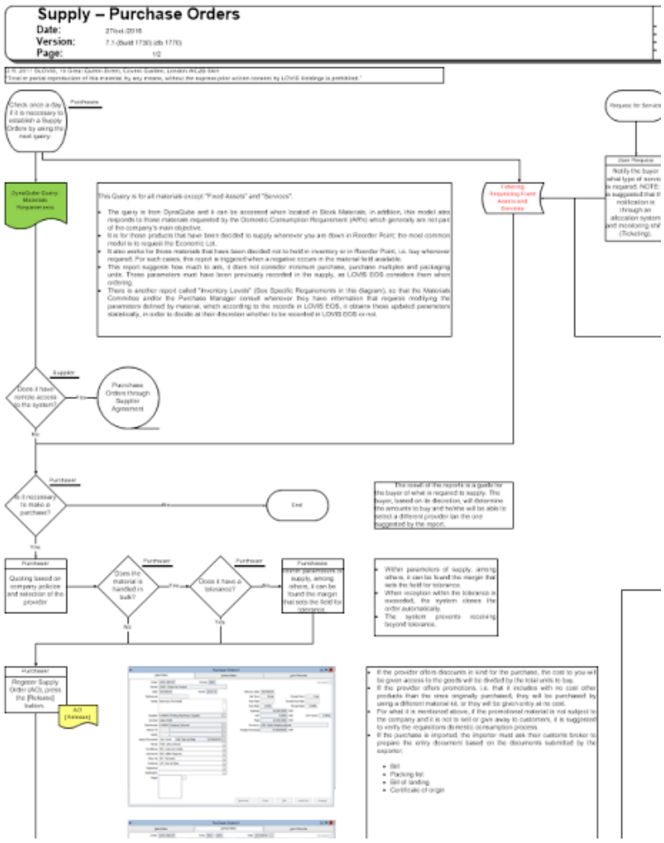

Fig. 3. Computation viewpoint, partial model used for modeling business processes.

Partial models have been already defined by the LOVIS company containing all possible ways in which a process can be executed. For example, the LOVIS company recognizes only fourteen different ways for executing a purchasing process. Each partial model represents one type of process, when the process is configured to the business necessities, it represents a *chromosome* of the enterprise, and the chain of configured processes represent the *genome* of an enterprise. In other words, multiple individual enterprise behaviors can be represented using a finite set of partial models.

In the engineering viewpoint, the required e-services needed to deploy business processes are identified. The e-services are supported by e-applications. Inside the EOS these e-services are related to: production, production planning, engineering, purchases & supply, inventory, sales & distribution, accounting, treasury, accounts receivable, accounts payable. These services are supported by a set of integrated applications (Fig. 4). Additional applications may be configured to interact with the EOS using standardized Application Provider Interfaces (APIs). In contrast with the computation viewpoint, where business managers have active participation in the process design, the engineering viewpoint is realized by the LOVIS company. The LOVIS company believes that business processes need to be flexible (user defined) while their operation must be guided by business principles (fixed rules). Once having the process descriptions and the applications supporting them, the EOS is configured to satisfy the deployment of such processes.

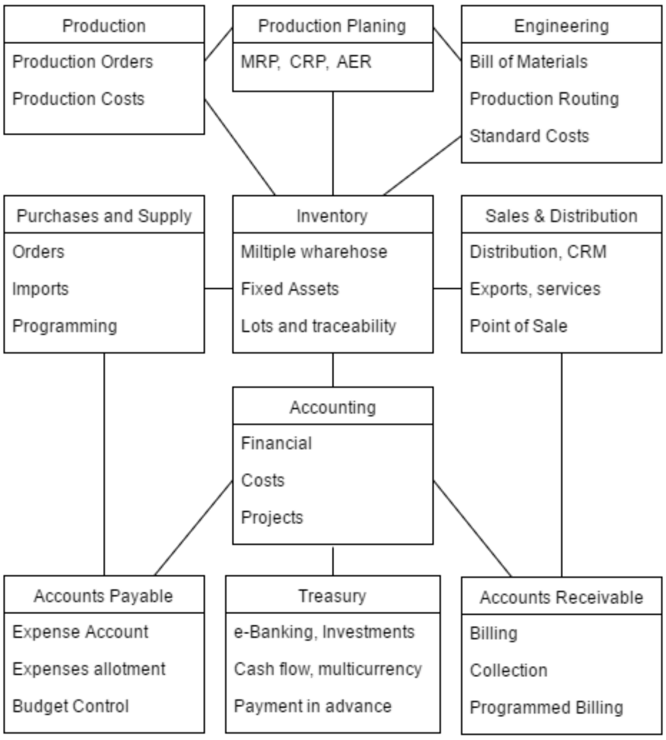

Fig. 4. e-services and e-applications incorporated in the EOS.

Finally, the technology viewpoint is about the technologies that enable the business operations. These technologies include smart and sensing components. In a manufacturing enterprise, the plant design is specified in this viewpoint. The technologies that enable the EOS operations are: cloud computing, relational databases, virtual private server (VPS), Network Attached Storage (NAS), high-availability load balancer, Remote Desktop Services (RDS), Distributed File System (DFS), etc.

4. EVALUATION OF THE EOS

The concept of EOS has evolved. The conceptual architecture provided by Youssef et al. (2016) shows the most recent conceptualization of EOS. Therefore, it used as a rubric to evaluate the LOVIS EOS. Such architecture involves the five components described in section 2 (i.e. ERM, EPM, EIM, PM, IM) and an EOS interface that allows the interaction with business managers.

The LOVIS EOS interface connects business managers to the EOS in order to control the business processes. According to real-time analytics and customer needs, the manager decides to execute a set of business processes. This interaction is provided by the EOS based on user profiles. In addition, because it is cloud-based, it can be accessed anytime from multiple devices and locations.

Then, the EPM coordinates the processes according to a set of business principles and business rules. The business principles are the result of research done by the LOVIS company in order to help its clients improve their value through better operations. On the other hand, business rules allow the tailoring of such practices allowing the adoption of business processes that leverage client's competitive advantages. These tailored processes are denominated *next practices*. The scheduling is not defined in time, but as a sequence of tasks in a workflow with the elements in order to establish the proper priority. The authorization of the process is managed by this component. In addition, because the operation sequence is known, when a process gets stuck, the managers know exactly where an action is needed.

The IM is present in the core code of LOVIS EOS. This component allows the interaction of users and applications. It can be configured to fulfill the needs of any industry sector. Therefore, LOVIS EOS is able to provide a universal application to all its clients. This interoperability also provides interconnection capabilities to other vendor applications. The interconnectivity is achieved through standardized APIs and intermediary tables that allow the communication. The exchange of information has the purpose of populating the universal database present in the EOS. So, specialized (vertical) functionalities are performed by the external applications, while management (horizontal) functionalities are preformed inside the EOS.

The EIM is present in the form of a universal database. The access to the database is controlled by predefined rules that guarantee the integrity of all information. Thereafter, the EIM provides reliable information to any application that needs it.

The ERM is present to manage the resources of the company. The system allows the management of human resources by assigning roles. Tasks are dynamically assigned to the person that has the required role in the workflow. In addition, there is a workflow supervisor component that allows managers to handle exceptions and reassign resources. The applications are constantly monitored, validating its inputs and outputs. A business intelligence component guarantees the alignment of applications to business objectives. Machines are monitored in terms of its capacities, functions, and its level of utilization. The demands are dynamically allocated to different facilities. The EOS can alert users in case the demand exceeds current capacities. Thereafter, managers can take actions to accomplish such demands.

The PM is the component that allows the connection of resources (human, applications, and machines) to the EOS. Human resources are connected through interfaces that are personalized according to a user profile. These interfaces guarantee security because information does not travel through the Web. External application resources are connected with standardized APIs and tables. Additionally, machine resources can be connected using specialized Manufacturing Execution Systems (MES) that can be connected as an external application.

All components are reflected in the LOVIS EOS. In addition, the goal of configuring the application for specific enterprise goals without developing code is achieved. The use of partial models that contain specific features of the EOS allows a straightforward configuration.

The LOVIS EOS has provided several benefits when it is compared to traditional enterprise applications. The EOS has been implemented in more than 27 industry sectors, always in less than six months and providing a Return on Investment (ROI) of at least 100% during the first year. Furthermore, it has been always implemented within budget having zero operational disruption at *Go-live*.

5. CONCLUSIONS

The paper has presented an EOS approach to implement reference models that allow the creation of the S^3 enterprise. The characteristics that define and distinguish the EOS are presented. As a result of following such characteristics, some benefits has been founded which include, on time and on budget implementations, payback within the first year of implementation, no operational disruption, and successful implementation in six months or less.

The S^3E-RM has been proposed to guide the enterprise engineering process that is needed to establish the EOS as the application of a system. The enterprise viewpoint helps in identifying the business objectives. The information viewpoint allows the classification of information needed to take smart decisions. The computation viewpoint establishes the business processes design. Finally, the technology and information viewpoints show how the LOVIS company has used technologies to develop applications and services that support the business operation.

When evaluating the LOVIS EOS against the components defined in the literature, it could be seen that it reflects the main components of an EOS.

AKNOWLEDGEMENTS

This research has been done in collaboration with the LOVIS company, which has provided information about its enterprise application.

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