Ontological Modeling of ERP for Industry 4.0*

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Abstract

Data is a pillar of Industry 4.0 (I4.0), centralized in Enterprise Resource Planning (ERP) for easy access and collaboration. ERP is the standardized process of collecting and organizing business data via an integrated suite of ERP software, a collection of applications that automate business functions. Industry 4.0 is a new paradigm for technology-based system automation based on integrating information and communication technologies and those comprising the concept of intelligent manufacturing. The latter has provided tremendous opportunities for manufacturing systems, particularly in planning and control, from resource to supply chain levels. Hence, enterprise resource planning (ERP) based on I4.0 elements is being researched and developed. Otherwise, ERPs are recognized for autonomy, distribution, and heterogeneity. As a result, an ERP system's requirement to deliver requested data in short response times, exchange data, and process data from multiple systems cannot be met. This limitation is primarily due to a lack of interoperability and the heterogeneity of data representation formats, which are critical concerns in such a context. Indeed, interoperability issues arise at various levels, such as the semantic level. This paper presents a review of the use of ERP in Industry 4.0 and how ontologies offer a relevant complementary solution to semantic interoperability problems. In addition, an ontological model for ERPs is developed.

Keywords

Ontology, Semantic Interoperability, ERP, Industry 4.0

1. Introduction

Manufacturers have long relied on a network, machines, and devices. However, these technologies are insufficient in today's competitive landscape and rising customer demands. The recent wave of industry trends is centered on integrating enterprise technologies such as collaboration and communication technology, business analysis tools, and accounting software that automates workflows, enhances communication and gives data access to increase productivity. Industry 4.0 (I4.0), or the Fourth Industrial Revolution, is the industrial wave using Artificial Intelligence

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(AI), the Internet of Things (IoT), big data, and cloud computing. Through information and communication technology, Industry 4.0 concepts have been used to increase horizontal and vertical integration in manufacturing systems [1]. Thanks to advancements in industry technologies, employees can always stay connected to the shop floor and their data. Enterprise Resource Planning is the glue that connects industry solutions and allows for immediate access from top to bottom.

ERP (Enterprise Resource Planning) is a business management system that combines all aspects of a business. ERP solutions, designed to integrate into an organization's environment over time seamlessly, are increasingly being used by larger businesses and governments [2]. ERPs are defined as computerized management systems that aid in effectively administrating administrative operations by facilitating data storage and processing [3]. Digital format and networked technology systems, according to the Industry 4.0 concept, can assign production planning and control tasks to "intelligent" objects such as machines, products, and parts [4]. Although Industry 4.0 can help streamline processes across a manufacturing organization, the full benefits of these advancements can only be realized through an integrated platform, such as a manufacturing ERP system. This is the point at which Industry 4.0 and ERP meet. Hence, without ERP, IoT devices may create more data silos, limiting visibility for the industry. ERP centralizes IoT metrics and others produced by the industry for easy access and collaboration. ERP interprets the massive amounts of data collected by Industry 4.0 technologies to provide actionable insights. ERP users benefit from real-time data processing because it provides prompt insights from the manufacturing plant. Thus, semantic interoperability was discovered to be an essential aspect of ERP.

Smart manufacturing is powered by the combined strength of ERP software and Industry 4.0 technology. The requirement for diverse modules for various vocabulary businesses causes numerous problems in the ERP system [5]. ERPs perform in a fast-paced environment; to thrive in this context, ERP must share information and collaborate effectively. Furthermore, ERPs are generally characterized by autonomy, dispersion, and heterogeneity. This may cause semantic interoperability issues. Interoperability is a critical problem in this context for ensuring that different ERP systems function together toward a mutually beneficial outcome. Indeed, the semantic web and ontologies offer a complementary answer to semantic interoperability issues. Ontology can be considered an essential step toward more efficient management of heterogeneous data[6]. In this work, we will offer an ontological model of ERP in the context of Industry 4.0, built on semantic web technologies to ensure ERP semantic interoperability.

The remainder of this article is organized as follows: In Section 2, we explore similar works. In Section 3, we demonstrate the function of ERP in Industry 4.0. Section 4 discusses the importance of semantic interoperability in ERP systems. In Section 5, we present our suggested ontological model for ERP. Finally, in Section 6, we conclude and outline future work.

2. Related Work

This section provides an overview of existing knowledge relevant to the current research. Semantic Web technology can be applied in the context of an ERP system to enable the lack of automation and overcome deficiencies caused by the heterogeneity of information contents and semantics provided by multiple sources [5]. The Semantic Web represents a pledge for the next generation of the Web [7].

Pereira. et al. in [8] suggests an ontological approach to support horizontal and vertical information integration in smart manufacturing systems to overcome the challenge of semantic interoperability and horizontal and vertical integration. This research supports the information and knowledge exchange across various manufacturing systems, assisting the manufacturing industry's transition to a semantically interoperable digital environment.

Chuangtao Ma in [9] tackles the problem of inefficiently integrating heterogeneous data from different legacy ERP systems by suggesting a data integration framework for legacy ERP systems based on ontology learning from structured query language (SQL) scripts (RDB).

In [10] Badr NM et al. introduce a framework for incorporating semantic process modeling into existing enterprise applications like ERP. These embedded semantic process models capture the essential concepts of the process modeling languages through their core reference ontology.

Ma Chuangtao and Bálint Molnár in [11] used an ontology learning technology to solve integration issues with legacy ERP systems. A general integration framework based on ontology learning is presented to effectively and efficiently integrate various legacy ERP systems. Data integration was chosen to demonstrate the legacy ERP system integration process based on ontology learning, and the critical steps of legacy ERP system integration based on ontology learning were provided.

The authors in [12] propose the integration of semantics at the level of ERPs using the techniques proposed by the Multi-Agent System and the use of new technologies to resolve most semantic conflicts.

3. ERP and Industry 4.0

There can be no Industry 4.0 without an effective ERP that serves as the central core of the Industry 4.0 global information system (Figure 1). This fundamental repository for the company's strategic data is at the center of information flows.

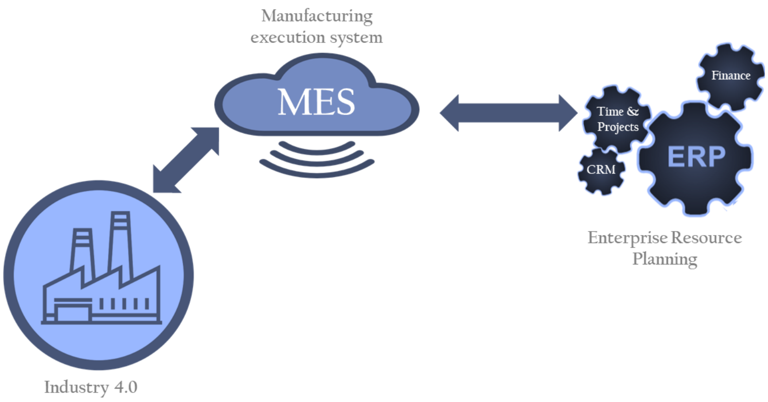

Figure 1: ERP in Industry 4.0.

There are numerous concepts and words associated with IIoT and Industry 4.0, and ERP is one of the fundamental concepts representing a tool for business process management that can be used to manage information within a company. One of the primary benefits of an ERP in a modern industry is the ability to manage multiple critical business areas with a single system and enable them to communicate with one another. The ERP model allows for greater flexibility and adaptability of the manufacturing system itself [13].

ERP centralizes IoT metrics and other enterprise data for easy access and collaboration, and it interprets the massive amounts of data collected by Industry 4.0 technologies to deliver actionable insights. Furthermore, real-time data processing ensures that ERP users receive instant insights. Furthermore, cloud ERP provides the convenience and reach to assist in the transformation and tracking of processes across the globe, and scalable ERP solutions enable companies to implement new technology to build a digital enterprise.

4. Semantic Interoperability for ERP

Interoperability refers to the capacity of systems to provide services to and embrace services from other systems and to use the services exchanged to operate more efficiently together [14]. Semantic interoperability is a subset of the general definition concerned with comprehending and interpreting data exchanged between system actors. Semantic interoperability provides a common understanding of the data using standard nomenclatures and formats. If two systems are operationally interoperable and share the same semantic reference on the object of the interaction, they are said to be semantically interoperable. Interoperability is strengthened by a shared and unambiguous interpretation of the information exchanged between the various stakeholders. It must be accomplished by enabling applications to share information and view the meaning and values of transmitted data, allowing it to be reused without errors or data loss [15].

Semantic Web technology has the potential to significantly contribute to overcoming the shortcomings caused by the heterogeneity of information contents and semantics generated from various sources [5]. The detailed capture of activities and process information is challenging in enterprise information systems. The semantic integration of personal information management systems is a first step towards modernizing ERP applications. Such management information systems should be Semantic Web powered to provide quick access to the resources required for enhanced and effective decision making [16].

Ontologies are the most important way to represent and manage knowledge in the Semantic Web, allowing for information sharing and shared understanding. They are regarded as an essential paradigm in human-machine semantic interoperability, data integration, and knowledge exchange [17] to facilitate the search for required configuration objects for a specific data management configuration task more efficiently. Also, define the configuration required to create a specific instance of master datasets. Furthermore, compare the structure of enterprise systems or business processes to user requirements.

5. Approach Ontology Design

Ontologies are essential for the growth of the Semantic Web [18]. Understanding the information exchanged between systems cooperating in the performance of a global task is a problem with semantic interoperability. To address this issue, the information exchanged must be structured in a way that makes it easy to understand. This structuring uses ontologies, which describe domain knowledge in a formal framework.

The ontology was created in the Web Ontology Language (OWL)[1] using the Protege ontology editor, version 5.5.0 [2] ontology editor to represent the knowledge in a formal, structured, and reusable format. The above ontology (ERPI4.0-Onto) was created to represent an ontology for ERP systems in Industry 4.0.

5.1. Ontology Modeling and Implementation

Ontology is designed to be flexible in order to solve real-world modeling and knowledge representation problems. Individuals/objects, classes, attributes, relationships, and axioms are essential elements of a formal model of a specific domain.

5.1.1. Ontology Domain

In the context of Industry 4.0, the representation of ERP systems was identified as a domain that can define the following scopes: Supply Chain Management (SCM), inventory, persons, Customer Relationship Management (CRM), Business Intelligence (BI), etc.

5.1.2. Ontology Terminology Glossary

The main terms of the ontologies In the application domain were mentioned and used in the class file. This domain model necessitates using specific class terms such as SCM, inventory, persons, CRM, Business Intelligence, product, stock, purchases, sales, supply chain, etc. Classes and sub-classes hierarchies are represented in figure 2.

We present a description of some classes and sub-classes in the specific ontology below:

- CRM: Customer relationship management is a technology that enables both large and small businesses to organize, automate, and synchronize every aspect of customer interaction.
- Business Intelligence: BI is a real-time monitoring of business performance from the top to the bottom of the organization
- Finance: Within a centralized accounting system, record, track, and consolidate business and operational information. This is made possible by financial ERP software's centralized systems, which include general ledger, accounts payable, accounts receivable, and payroll management.
- Human Resources: manage the various social benefits, staff and talent development, and track employee working time and company-wide performance reviews.

[1]https://www.w3.org/TR/owl-features/
[2]https://protege.stanford.edu

Figure 2: Classes and Sub classes hierarchies for ERPI4.0-Onto

- CSM: Supply Chain Management, activities are planned, executed, controlled, and monitored. An ERP solution handles the physical aspects of supply, such as storage and transportation, and the market aspect of effectively managing demand and supply to meet customer demands.

5.1.3. Classes object/data properties

OWL was used to define relationships between previously presented classes by defining object properties of classes. Data properties link individuals and literals to specify the type of data value. For example, the value of a property has_name is of data type string, and the value of a property has_value is of data type reel. Figure 3 depicts some of the object/data properties of the developed ontology model.

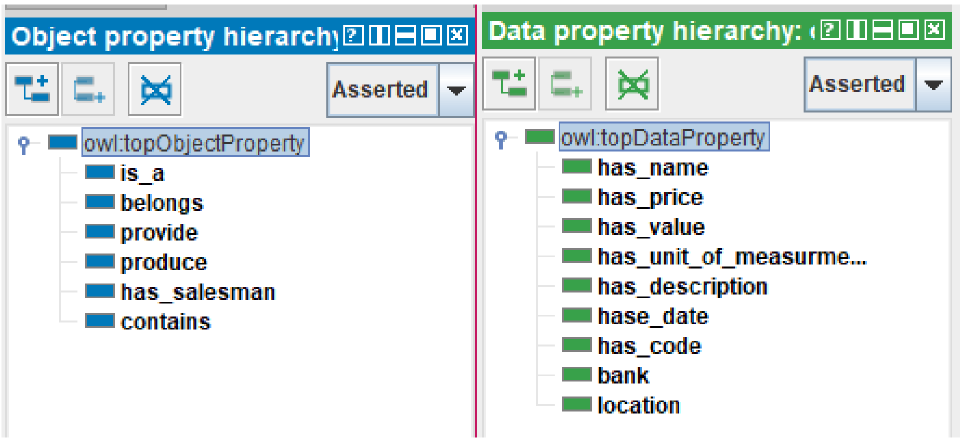

Figure 3: The developed ontology's (ERPI4.0-Onto) object/data properties

5.2. Results and Ontology Evaluation

Ontology verification is the comparison of ontology against the requirements. To test an ontology and check whether it satisfies its functional requirements, which are ambiguous and difficult to formalize. Themis[3] is a tool that automates the implementation execution of requirements tests and includes some inference. In addition to the defined test expressions, an ontology for test requirements is provided. Four outcomes are possible for each test and ontology: undefined terms, passed, absent relation, and conflict[19].
Figure 4 shows some of the test cases that have been run throughout this tool, along with all possible outcomes in the results section.

Tests results

Test	Result	Problem
produce type Property	Passed	None
stock subclassOf inventory	Passed	None
accounts subclassOf finance	Passed	None
category subclassOf products	Passed	None
customers has_salesman sales_persons	Passed	None

Figure 4: Tests and results of the verification of ERPI4.0-Onto ontology

[3]https://themis.linkeddata.es

6. Conclusion

Enterprise Resource Planning (ERP) has a unique role in the Industry 4.0 (I4.0) concept. Thousands of various types of data must be exchanged throughout the process to ensure effective communication. ERP integration in Industry 4.0 is regarded as a complex problem. The leading cause of this problem is semantic heterogeneity among various information sources. Real-time data processing benefits ERP users by providing them with timely insights from the manufacturer. As a result, semantic interoperability was discovered to be a critical aspect of ERP, and it can be addressed by utilizing semantic web technology to achieve software system interoperability.

In this paper, we have presented the role of ERP for Industry 4.0 and the necessity of semantic interoperability in this context. Then, we developed an ontological model of the ERP system built on semantic web technologies to ensure ERP semantic interoperability in the context of Industry 4.0. In the future, we intend to enrich the business domain ontology by providing an intuitive approach to suggest new concepts that are missing from the existing ontology.

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