Journal of Loss Prevention in the Process Industries 26 (2013) 104–116

Contents lists available at SciVerse ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

An ontology-based framework for process monitoring and maintenance in petroleum plant

Rabee Elhdad*, Naveen Chilamkurti*, Torab Torabi

Dept. of Computer Science & Computer Engineering, La Trobe University, Melbourne, Victoria 3086, Australia

ARTICLE INFO

Article history:
Received 22 May 2012
Received in revised form 25 September 2012
Accepted 4 October 2012

Keywords:
Ontology
Preventive maintenance
Corrective maintenance
Process monitoring
Plant process optimization
Process business rules

ABSTRACT

In production plants, monitoring and maintaining industrial processes and emergency shutdowns are not straightforward tasks due to the large number of events and alarms which are triggered during the plant shutdown process. It is also vitally important to provide decision support to stakeholders for efficient and effective monitoring and maintenance of production process. This paper presents a novel framework and design to enhance maintenance decisions based on the knowledge gathered through the process of monitoring. This monitoring process is based on signals which are triggered during the plant safety shutdown process. We have designed and implemented a framework using an ontology and business rules to define the logical structure and operation of the petroleum plant with the objective of monitoring the cause and effect of the petroleum plant shutdown process. To enhance maintenance decisions, we have extended the ontology and the framework to ensure that decision makers have sufficient information to make the right decision at the right time. The proposed extended framework is designed, implemented and evaluated using an example petroleum production plant as a case study.

1. Introduction

Monitoring and maintenance are the most important activities in production plants. The objective of plant monitoring is to maintain the production process and minimize plant failure time. In addition, maintenance activities can assist the production plant by reducing maintenance costs and downtime in the production process. Most production plants have implemented automated safety shutdown systems to protect the production plant of and avoid hazards. These shutdown safety systems are mainly implemented as part of the Supervisory Control and Data Acquisition system (Chan, 2005). Identifying and monitoring the cause and effect of the plant shutdown process is not a flexible task, due to the large number of events which occur and alarms which are triggered during the plant shutdown process. Furthermore, monitoring and maintaining safety shutdown devices is a major concern in most production plants. Although these systems are efficient, they have several limitations which have not yet been addressed in many automated systems. These limitations become apparent when there is a need to make certain modifications to the plant structure. Various physical modifications are regularly needed in production plants. Such physical modifications to a plant also necessitate respective modifications to the logical plant structure. However, one of these limitations is that the majority of existing systems (ABB Technology, 2010; Rockwell Automation, 2010; Siemens Industry, 2010) cannot be modified by the domain expert when the company requirements change or physical modifications to the plant are conducted. Also, the flexibility of creating one's own business process rules is not always an option in many existing systems (Chan, 2005; Klose, 2002; Uraikul, Chan, & Tontiwachwuthikul, 2007). Another limitation is a lack of data for maintenance decision support and/or structured approach for historical data storage.

We propose a novel design for the monitoring and maintenance of a production process using an ontology and business process rules to overcome the existing limitations. The framework consists of two layers: the structural layer and the operational layer. In our previous work, we designed and presented the application of the structural layer (Elhdad, Chilamkurti, & Torabi, 2011). In this paper, we present the application of the operational layer to support maintenance.

1.1. Organization of paper

This paper is organized as follows: section two provides an overview of the related work; section three outlines the proposed

Abbreviations: ESD, Emergency Shutdown; PSD, Process Shutdown; UCL, Unit Control Logic; PM, Preventive Maintenance; CM, Corrective Maintenance; GOSP, Gas and Oil Separation Plant; NC, National Concession.

* Corresponding authors.
E-mail addresses: rselhdad@students.latrobe.edu.au (R. Elhdad), n.chlamkurti@latrobe.edu.au (N. Chilamkurti), t.torabi@latrobe.edu.au (T. Torabi).

0950-4230/$ – see front matter © 2012 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.jlp.2012.10.001

framework using the plant ontology, section four describes the framework architecture; section five gives an overview of the implementation; section six presents the case study of the proposed framework and finally, we conclude the paper in section seven with a description of future work.

2. Related work

In this section, we highlight various issues related to industrial automation. Many researchers have attempted to address these issues by incorporating various methodologies. In this section, we evaluate some of these methodologies including: ontology, decision support, and business rule methodologies.

2.1. Ontology development

The ontology approach has been adopted in various information technology areas such as knowledge engineering, artificial intelligent and expert systems, (Noy & McGuinness, 2001; Rayo, 2007). An ontology can provide common knowledge on the domain structure to stakeholders and can provide a common understanding between domain experts (Noy & McGuinness, 2001). The ontology approach has been adopted in a chemical process plant (Morbach, Yang, & Marquardt, 2007), and in the medical science domain to provide solutions to a range of problems (Bratsas et al., 2007). Moreover, it has been developed in various biological areas (Villanueva-Rosales & Dumontier, 2008). However, research on devolving an ontology in the monitoring of a petroleum production process is limited (Uraikul et al., 2007).

2.2. Monitoring and maintenance of production process using decision support systems

Nowadays, most production companies are fully automated and utilize the latest technology to control and monitor the plant to avoid high costs and to achieve high production performance. The safety shutdown systems are responsible for protecting the various plant assets, such as oil tanks or pumps, during the shutdown process. Therefore, it is essential for production companies to monitor and maintain plant shutdown safety systems to avoid plant malfunction. The majority of these companies have implemented different decision support systems to supervise and maintain their safety systems. Although these systems are efficient, they contain several limitations which have not yet been addressed in many production company systems (Jardine, Lin, & Banjevic, 2006; Muller, Crespo Marquez, & Iung, 2008).

Many petroleum companies have implemented expert systems in different departments, including the petroleum engineering department, the exploration department, the drilling department and the operation department. The majority of these systems focus on decision support systems (Chan, 2005). For instance, these systems are implemented in seismic data analysis or in petroleum refineries. Some examples include a fuzzy rule-based expert system for seismic range predication, and an agent-based decision support system for supply chain management at a refinery (Klose, 2002). An attempt has been made using expert decision support system for the monitoring and diagnosis of petroleum production and separation processes for an oil company in Canada, which lacks flexibility for modification by domain expert (Chan, 2005).

In the last few decades, different maintenance techniques have been successfully applied to a variety of industrial areas such as, manufacturing, construction, chemical and power plants. According to the current literature (Gulledge, Hiroshige, & Iyer, 2010; Hao, Xue, Shen, Jones, & Zhu, 2010; Jardine et al., 2006; Muller et al., 2008), there has been improvements in the development of Condition Based Maintenance (CBM) technology in a range of the industrial areas (Utne, Brurok, & Rødseth, 2012). Different approaches have been adopted and implemented in CBM including web technology (Glasgow, Burkholder, Reed, Lewitus, & Kleinman, 2004; Livshitz, Chudnovsky, & Bukengolts, 2004), multi-agent systems (Chunhua, Xinze, Zongqi, & Xinping, 2006; Jing-Gao, Xin-Bin, & Dao, 2002), and mobile agents (Buse, Feng, & Wu, 2003; Buse & Wu, 2004).

2.3. Limitations in existing maintenance decision support systems

In the last decade, many maintenance decision support systems have been introduced in the industrial sector. These systems have been implemented using different approaches to satisfy industrial requirements. Although these systems are efficient, they contain several limitations which have not yet been addressed in many production systems (Jardine et al., 2006; Muller et al., 2008). One of these limitations is a lack of collected data, as a result of an incorrect data collection approach. There are also difficulties in implementation, due to frequent changes in the physical design structure, and business process. Another difficulty is the large volume of data generated from the plant elements, which are require to implement an effective maintenance approach. Therefore, we propose a novel framework for the monitoring and maintenance of a petroleum production plant using ontology and business rules to overcome the limitations in the existing systems.

2.4. Business process rules specifications

Traditionally, business rules are hard coded in programs in the form of if-else statements or designed in the database structure such as procedures or triggers (Rabova, 2009). These techniques for implementing business rules might result in the system being unreachable for any modifications or changes which might occur. Business rules can be found in business policy documents or in operation manuals, which give valuable background on the nature of business rules. From this background, business rules can be divided into two categories: structural business rules and operational business rules (Rabova, 2006, 2007, 2009).

Structural business rules enable the organization to structure its own systems based on the organization's knowledge. In addition, this capability gives the domain expert the ability to restructure their system according to the changes or new requirements. Operational business rules are mainly responsible for the organization's operation and activities. This enables the organization to perform their operations or activities in a suitable and optimized manner. In addition, operational business rules enable process changes to be made easily without affecting the operations. In our previous work (Elhdad et al., 2011), we applied structural business rules to our framework, whereas in this proposed design, we incorporate operational business rules, based on a specified ontology for industrial automation.

3. Problem domain overview

3.1. Domain overview

In petroleum production plants, the monitoring and maintenance of the emergency shutdown signals is not a straightforward task in most production plant automation systems (ABB Technology, 2010; Rockwell Automation, 2010; Siemens Industry, 2010) due to the large number of events which occur and alarms which are triggered during the plant operation and shutdown process. There is a need to monitor and track the cause and effect of the plant shutdown process in a more reliable way as a failure in one of these shutdown devices may result in production plant