Computers in Industry 81 (2016) 26–35

Contents lists available at ScienceDirect

Computers in Industry

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

Redundancy and scalability for virtualized MES systems with programmable infrastructure

Octavian Morariu, Theodor Borangiu, Silviu Raileanu, Cristina Morariu *

University Politehnica of Bucharest, Department of Automation and Industrial Informatics, Bucharest 060042, Romania

ARTICLE INFO

Article history:
Received 19 February 2015
Received in revised form 26 July 2015
Accepted 25 August 2015
Available online 9 October 2015

Keywords:
Private cloud
Virtualization
Smart manufacturing
Redundancy
Programmable infrastructure
COBASA
Event driven

ABSTRACT

Virtualization of manufacturing execution system (vMES) workloads offers a set of design and operational advantages to enterprises, the most visible being improved resource utilization and flexibility of the overall solution. This paper explores redundancy and scalability, as other important operational advantages introduced by the use of private clouds for MES virtualization in the context of the programmable infrastructure (PI) concept. PI is a new architectural approach in which the computing infrastructure, represented by resources, networks, storage, becomes dynamic and is controlled by the application, in contrast with traditional architectures where the application has to adapt to a static infrastructure. For MES applications, the adoption of PI has the potential to add a new layer of flexibility and optimization by allowing quick configuration and re-configuration based on environmental changes, especially in the context of virtualization in private cloud where workloads can be provisioned and de-provisioned in real time. In this context, this paper presents the main redundancy and scalability requirements for the workloads identified in ISA-95.03 based solutions and discusses in detail the strategies to assure the redundancy and scalability requirements of these workloads both individually and at the system level. The main contributions of this paper are therefore the introduction of PI combined with private cloud virtualization at the MES layer in order to achieve redundancy and scalability of the control solution. The pilot implementation presented is based on PI concepts and is realized in practice using SOA BPEL and IBM CloudBurst REST APIs. The MES system considered for the pilot implementation adopts a multi-agent vMES architecture having COBASA-type functionality. The experimental results presented in this paper show the system response in a set of failure scenarios, with focus on the reconfiguration time of workloads, and the dynamic response to perturbations in the system.

1. Introduction

The migration from physical systems towards virtualization of software platforms gains more and more traction in modern enterprises across all business lines. There are a series of direct benefits offered by virtualization for almost any kind of software system: improved resource utilization, higher flexibility and availability, which help reduce operational costs for the enterprise. At the same time, virtualization is the main enabling technology for cloud computing in all delivery methods considered [1]. Enterprises can take advantage of public cloud offerings to provision virtual workloads (IaaS), applications built for specific platforms (PaaS) or directly access in multi-tenant applications (SaaS) with convenient chargeback models, with no or minimal initial investment required. At the manufacturing execution system level, cloud computing adoption refers mainly to virtualization of MES workloads [2]. While MES implementations are different and usually depend directly on the actual physical shop floor layout, the general MES functions are aligned with the set of functions defined by ISA-95.03 specification. ISA-95 defines five levels for the hierarchical organization of a manufacturing enterprise [3], as follows:

- Levels 0, 1 and 2 represent the process control levels and their main objective is to directly control the physical shop floor equipment in order to execute the actual production operations that result in one or more (batch of) finished products.

* Corresponding author at: CloudTroopers Intl., Cluj-Napoca, Romania.
E-mail addresses: octavian.morariu@cimr.pub.ro (O. Morariu), silviu.raileanu@cimr.pub.ro (T. Borangiu), theodor.borangiu@cimr.pub.ro (S. Raileanu), cristina@cloudtroopers.ro (C. Morariu).

http://dx.doi.org/10.1016/j.compind.2015.08.011
0166-3615/

- Level 3 is the manufacturing execution system (MES) level and consists of several activities that have to be executed in order to prepare, monitor and complete the production process executed at levels 0, 1 and 2. The main activities at MES layer are: production tracking, quality management, maintenance, scheduling, and others depending on the specifics of each shop floor and manufacturing process. Several formal specifications and reference architectures for MES have been attempted [4].
- Level 4 is the enterprise resource planning (ERP) level that executes the financial and logistic activities. These activities are usually not integrated in real time with the MES and the shop floor activities due to their runtime nature. These include: marketing and sales, procurement, long term planning and so on. The dataflow at this layer is asynchronous in regards to MES execution and is routed through an enterprise service bus (ESB) [5].

A section view through the IT software architecture of an ISA-95 type manufacturing enterprise would show a layered architecture, as illustrated in Fig. 1. The strategy for cloud adoption must result in a robust architecture which is able to assure that the information flow is in sync with the material flow at all times, and flexible enough to allow dynamic reconfiguration through APIs exposed and SOA governance [6]. Standards alignment is also an important factor to consider in this context: (STEP, 2013), (OAG BOD, 2013), (ebXML, 2013). One commercial initiative in this direction, focusing on SOA and standards adoption is the IBM manufacturing integration framework [7], implemented successfully in automotive and electronics industries. Similar solutions, based on SOA design patterns for manufacturing enterprises, are available from software vendors and integrators.

The lower layer consists in the so-called shop floor or physical layer and maps to ISA-95 levels 2, 1 and 0. This layer contains the actual shop floor actors like: resources, transportation devices and intelligent products involved in the manufacturing process [8]. The physical software workloads at shop-floor layer are most of the times proprietary (custom hardware and custom software) or in some cases semi-proprietary (standard hardware and operating system and custom software) and are responsible for real time, direct control of the physical resources and of the material flow in the shop floor [9–11]. The manufacturing execution system (MES) layer is tightly coupled with the physical layer. MES maps with level 3 of ISA-95 specification. The communication pattern between MES and the physical workloads in the shop floor is service choreography with point to point message exchange in real time, considered from an SOA perspective. When considering adoption of cloud environments, these characteristics of MES workloads can be best implemented in private cloud environments with workload virtualization [28].

In this context, the other emerging concept that promises to have an important impact in virtualized MES design is programmable infrastructure (PI). PI provides a series of application programme interfaces (APIs) to the installed software stack, including hypervisor, operating system and application layers, for accurate identification, monitoring, real time configuration and reconfiguration and control [12,13]. This evolution of the infrastructure, in contrast with legacy fixed infrastructure, allows the application logic, in this case the MES system, to pre-programme the infrastructure according to the estimated operations that would be required [14,15]. In practice, these estimations can be directly derived from the customer orders. The PI works in conjunction with private cloud virtualization, as it deals primarily with network configuration (and reconfiguration), while private clouds deals with computing and storage aspects. In this context, the PI can offer for the MES implementations features like ad hoc virtual private networks for intelligent product batch isolation, dynamic reconfiguration of WIFI routers in various areas of the shop floor based on product locations and mapping between network infrastructure and virtualized workloads at MES layer for real time distributed execution [16,17]. As illustrated in Fig. 1, the PI adoption allows moving the decision point on infrastructure layout towards the intelligent products that are using it, thus making the allocations and de-allocations more efficient and in sync with the actual execution needs. At the same time, private cloud workload virtualization and programmable infrastructure offer a new perspective on the implementation of redundancy mechanisms of MES implementations. The main goal of the redundancy mechanisms proposed here is to achieve the larger objective of a fault tolerant MES system, that can provide repayable control flow for the manufacturing operations.

This paper focuses on defining the *redundancy requirements* and *programmable infrastructure impact* for each individual workload identified at level 3 of ISA-95 specification and the *redundancy mechanisms* and *PI strategies* for the entire vMES solution. The study is done in the context of a virtualized MES (vMES) architecture with private cloud support and considers several

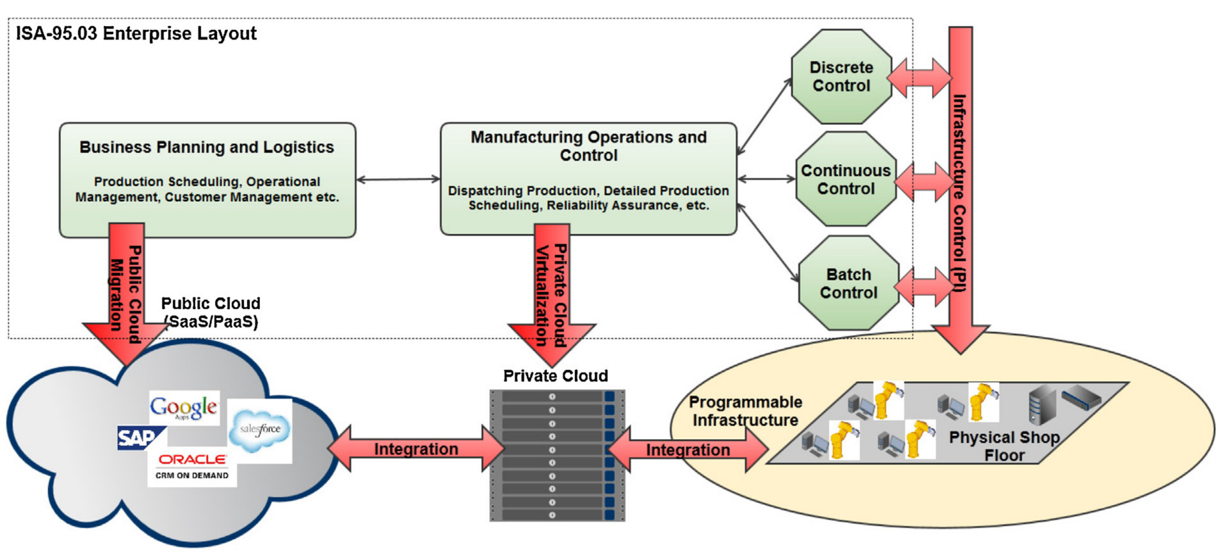

Fig. 1. Adoption strategy of virtualization and programmable infrastructure for manufacturing enterprises.