Integration of Manufacturing Applications: Overcoming Heterogeneity to Preserve Investment

Adriano Carvalho[1,3], Eduardo Tovar[2], José Oliveira[2], Mário Alves[2], Mário Sousa[1,3],

Paulo Portugal[1,3]

[1] FEUP-DEEC, Rua dos Bragas, 4099 PORTO Codex, Portugal; Tel: +351.2.2007505; Fax: +351.2.319280

[2] ISEP-IPP, Rua de S. Tomé, 4200 Porto, Portugal; Tel: +351.2.8300922; Fax: +351.2.821159

[3] Institute for Robotics and Systems, Praça Coronel Pacheco, 4000 Porto, Portugal; Tel: +351.2.2041619

e-Mail: emt@garfield.fe.up.pt

Abstract

The work presented in this paper consisted on the integration of several areas within a factory by using different communication standards. The implementation described satisfies several types of requirements, which include not only the functional requirements, but also the preservation of previous investments. The fulfilment of the latter imposed the use of heterogeneous technologies, both in terms of vendors and generations. This resulted in additional difficulties for the integration that were overcome. The use of OSI based technologies, such as those developed in the aim of CCE-CNMA, contributed to the success of this work.

1. Introduction

1.1. Background

Efforts are being done towards making applications independent from the hardware and software environments, such as computers, operating systems, communication networks, industrial devices, and databases. The technologies based on the OSI (Open Systems Interconnection) model appear as a result of that convergence effort, both providing and allowing for the development of important integration tools.

1.2. Motivation and Contribution

This paper describes one work item within the European initiative ESPRIT Project 7096 CCE-CNMA (CIME Computer Environment by integrating a Communication Network for Manufacturing Applications) [1]. This project covered three main work areas: CIME computing environment, OSI usability and CNMA communication profiles.

In order to demonstrate the applicability and usability of the CCE-CNMA technologies, these were implemented in a variety of industrial environments: EFACEC (Portugal), Mercedes-Benz (Germany), Aerospaciale (France) and Magnetti Marelli (Italy) factory plants.

The EFACEC pilot [2] site is located in the EFACEC Distribution Transformers factory, 2 Km north of Porto, Portugal. Being part of the EFACEC Group, this factory produces distribution transformers for the world wide market.

The CCE-CNMA technologies were used to improve shop-floor production efficiency by integrating several different areas using a multivendor, heterogeneous computing environment.

New equipment, applications and functionality's were introduced in symbiosis with some of the already existent in order to preserve previous investments.

2. Plant Overview

2.1. Process Description

The transformers manufacturing process consists of several production phases in the following sequence: low voltage windings assembling; high voltage windings assembling; assembly of windings and core into the transformer's container; drying and filling; and laboratorial quality control tests.

These activities are supported by two automatic warehouses for raw and semi-manufactured materials. The transport system, based on 4 AGVs, transfer tables and rolling bridges, feed 45 working stations used in the first three phases.

2.2. Production Characterisation

The production at the factory is characterised, in general terms, by the low volumes produced of each transformer model, and the large diversity of the model characteristics, such as electric power, voltages or even dimensions.

The production activity is based on automatic and semi-automatic operations performed by different computer and control equipment. Each product involves a significant group of engineering and manufacturing operations, whose execution is based on a large range of control and manufacturing applications and different equipment.

3. What Could be Enhanced?

It was considered that the drying and filling process operation, the production planning application and the shop-floor database could be significantly improved, and their functionality's enhanced.

3.1. Drying and Filling Operation

The transformers arrive completely assembled at the drying and filling area. At this location, the transformers may be simply dried or both dried and filled with oil. Two vacuum chambers are used for that purpose, each one with a maximum capacity of 5 transformers, along with 5 drying devices shared by both chambers.

The system demanded that the operator manually introduce the manufacturing data at the 5 drying devices and filling control system front panels. These manual procedures may cause frequent human errors since the process can last up to 7-8 hours.

During the process the output data was visually collected by the operator every 20 minutes. This data was not processed, constituting a serious handicap as the results of this analysis may be used to optimise the drying process.

3.2. Production Planning

It is essential to gather a large amount of information in order to perform the production planning in this factory. That information was spread over different systems, which resulted in extra effort to search and collect the data. Moreover, there was a need to manually consult paper files, with all the inherent disadvantages.

The need to compile commercial and design information, which are stored both at the factory's IBM mainframe (in a different building) and at the shop-floor databases managed by a proprietary management and monitoring system (SSGI), lead to the introduction of CCE-CNMA technologies also within this area. In this way, all the needed information may be efficiently gathered by a new production planning application.

3.3. Shop-floor Database

Several different databases were used on the shop-floor site. As these databases were implemented either in different moments in time and with different scopes, they were not specially suited to the fulfilment of the emerging requirements. In particular, they did not offer practical mechanisms for the implementation of historical data storage, and presented unnecessary data redundancy that can result in data inconsistency.

Moreover, the multitude of database environments reduces the capability of applications to evolve.

4. Topics on Implemented Technologies

4.1. Overview

This section describes the tools and services used to integrate the different items described above. Likewise, some aspects of the developed applications are explained.

As it was previously highlighted, the preservation of previous investments incurred in the use of already existing equipment along with the newly acquired, resulting in a more heterogeneous environment to integrate.

As a consequence, different hardware equipment from several vendors such as Bull, Siemens, Siemens-Nixdorf, Digital or IBM was used. The environment also reflects heterogeneity regarding the operating systems used: SNI Sinix-Z, MS-DOS, MS-Windows (3.11 and NT), IBM OS/2, Digital VMS.

This equipment is interconnected by IEEE 802.3 CSMA/CD and IEEE 802.5 Token Ring networks that support several communication protocols, most of which based on industrial communication standards. Examples of those protocols are: MAP/MMS (Manufacturing Automation Protocol / Manufacturing Message Specification), MAP/SQL/RDA (Structured Query Language / Remote Database Access), SNA (Systems Network Architecture), TCP/IP (Transport Control Protocol / Internetwork Protocol) and RPC (Remote Procedure Call) over TCP/IP.

Figure 1 illustrates the computing environment described.

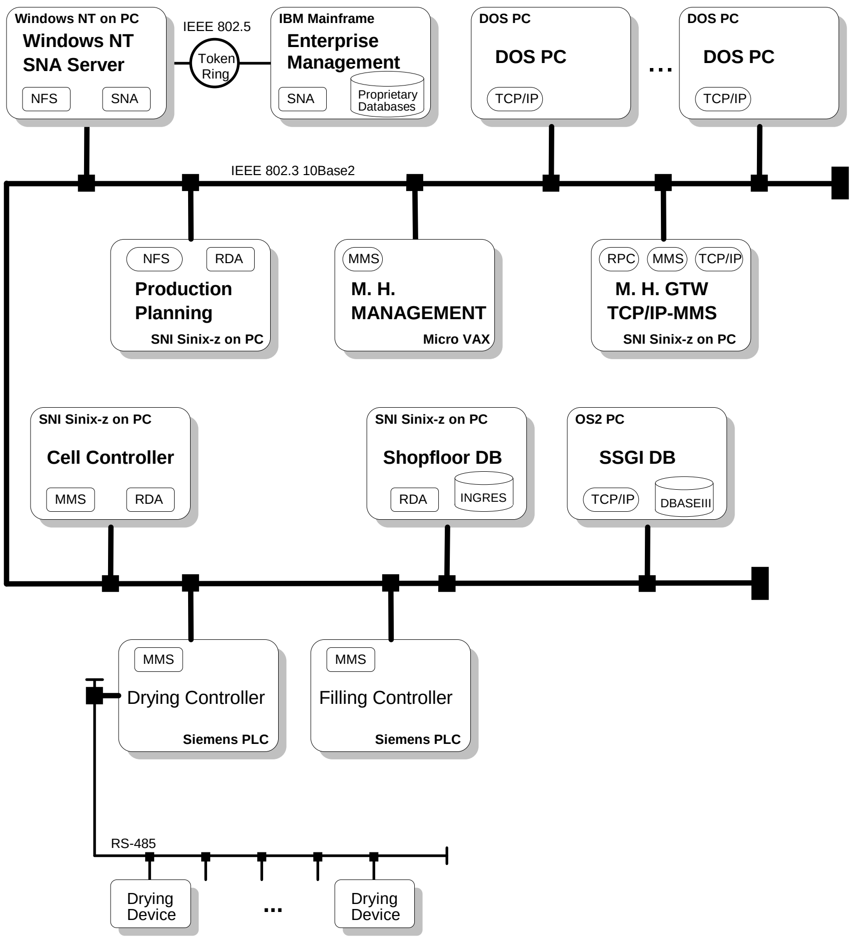

Figure 1 - *Computing Environment*

4.2. Drying and Filling Area

Figure 2 illustrates the computing equipment, applications and communication protocols involved in this system.

The drying subsystem consists mainly of five independent drying devices, which use Joule's effect to dry up to five different transformers. These microprocessor based drying devices were developed by University of Porto and EFACEC, and were designed to communicate with a PLC through a multi-point RS-485 industrial communication network with a proprietary protocol.

The vacuum and filling subsystem was supplied from an external vendor and all the functions supported by this subsystem are controlled by another PLC.

The two subsystems are now integrated using CCE-CNMA technologies. The result of this integration can be fully used on a PC, that permits the operation of both systems together, supplying the processes with the necessary information and collecting the processes variables.

The man-machine interface (MMI) provides details of the most important variables in the drying and filling process, namely the voltage, current, power, temperature and chamber pressure, as well as the possibility to monitor all operation parameters of the drying devices. This is a key aspect when, for example, a specialised operator wants to check, after an alarm, if there is any problem in resuming the drying process of the device.

Before starting a cycle in a particular chamber, the operator has to pick up the manufacturing orders from a list of queued transformers sorted by priority, due date or kind of oil. The operator can access this data using the MMI at the cell controller. It uses RDA to access the shop-floor database, automatically assigning the accessed information to various procedures both in the cell controller application itself, and in the drying and filling controller PLCs.

A complete drying and filling cycle currently takes approximately eight hours, resulting in a very large amount of data exchanged between the different computing devices. Each of these computing devices has it's own execution state machine, that must be synchronised with the rest. Various abnormal situations are taken into account in these state machines, some of which demand human intervention for security purposes.

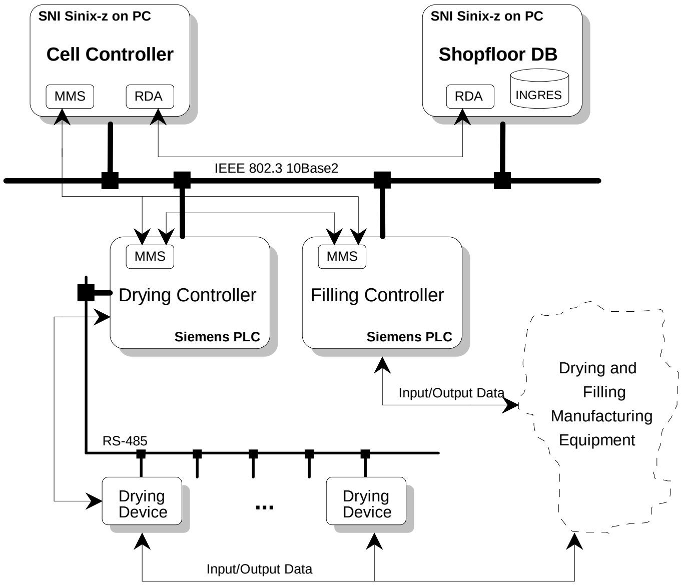

Figure 2 *- Drying and Filling Application*

Figure 2 shows how the cell controller application inter-operates with lower level controllers (drying and filling) and the shop-floor database. It also shows the major data flows as well as the corresponding communication protocols.

Different MMS services are used between the cell controller and both PLCs [3]. Those services perform, for instance, the downloading of manufacturing data, the issuing of job commands or the reading of process variables. The PLCs may also provide the cell controller with event driven data, by using specific MMS services, in order to synchronise state machines or to report alarms. This is an important achievement since it allows the optimisation of traffic flow, avoiding time consuming polling mechanisms. A similar synchronisation mechanism is used between the two PLCs.

The need for data exchange between the cell controller and the shop-floor database is fulfilled using SQL queries through standard remote database access communication protocol (RDA), permitting updating and retrieving of manufacturing data.

Several software packages were used in this implementation. As an example, and reporting only to the cell controller, the following were used: Sinix-Z Operating System [4]; C compiler; Motif for SINIX-Z [5]; SNI OSI-Communication Stack; DBA.X for RDA [6]; SNI Vargen and SNI MMSI [7]; RPC. Additional information on these packages can be found in the corresponding referenced documents.

4.3. Production Planning

A production planning application was developed taking advantage of the inter-operation between the different database management systems.

Figure 3 shows the resources used by the production planning application. The main information flows and the required protocol for each are also shown.

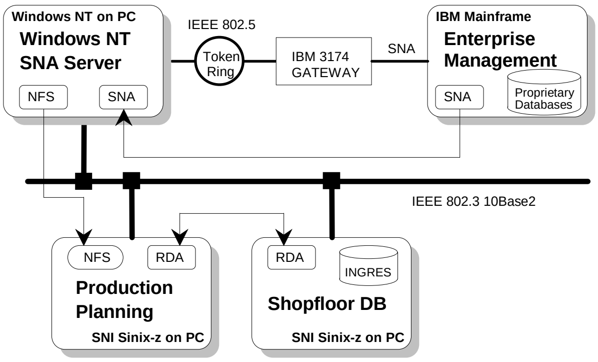

Figure 3 - *Production Planning Application*

Database tables with information originally available at the IBM 4318 mainframe are handled by this application.

A proprietary database management system at the mainframe manages such information as: description and quantity in inventory of raw materials; descriptions and behaviour according to the items supplied and historical records about all the supply orders of suppliers; description and behaviour according to the demands requested of customers; technological data that completely defines a type of transformer.

The IBM databases are accessed through Windows NT SNA Server using the factory IEEE 802.5 Token Ring network. An IBM 3174 gateway inter-networks the IBM mainframe SNA communication infrastructure with the Token Ring LAN.

Essential information updated at the IBM mainframe is now made available to the Windows NT server. A notification mechanism is used to provide that information to the production planning application.

The production planning application is responsible for generating a Master Production Planning (MPP) for the distribution transformers factory. To achieve this goal it is necessary to be aware of the current factory load, received firm customer orders, forecast demands and planned inventory levels for standard transformers.

This application has to issue a MPP plan every week, which states what is to be produced, how many and when orders are to be completed as well as the load, for each factory area, for the following week.

The production plan is divided in two planning horizons, the firm plan and the indicative plan. The former states all the production requirements for satisfying the clients orders and the stocks orders of transformers and semi-manufactured items. Any modification introduced within this planning horizon results in considerable perturbations to the manufacturing process, with all the inherent costs. The indicative plan states the production requirements based on sales forecasts for a long planning horizon, allowing the anticipation of production and modifications to be made without incurring in excessive costs.

Data is presented to the planner in a user-friendly way. It includes: process or scheduling diagrams; load diagrams; records diagrams; charts including statistics concerning manufacturing orders, teams, operators and workstations (delays, rejected manufacturing orders, timings, deviations, efficiency); charts including factory historical information on several items (manufacturing orders, teams, operators, workstations, suppliers, clients).

The possibility to perform simulations on a "what-if" basis also helps the planner to define the better solution to a particular problem, by viewing the results as described above.

4.4. Shop-floor Database

A new relational shop-floor database system was implemented using an INGRES [8] database management system.

For that purpose, a replication mechanism was developed in order to provide the new shop-floor database with specific data managed in the existing DBASE III SSGI database system. This mechanism is composed by two different applications. One runs on the OS/2 machine which supports the SSGI database, while the other runs on the Sinix_Z machine supporting the new shop-floor database.

This capability is built with the help of a gateway application providing a messaging facility between two remote applications using TCP/IP or MMS. This gateway receives messages in a local mailbox on the Sinix_Z or OS/2 system environment and forwards them to a remote mailbox on the other operating system. Structured messages can be sent from one node to the other, synchronously or asynchronously.

The replication can be triggered by any side of the database link through a mailbox interface with the help of a start message. Alternatively, the replication mechanism can run periodically as a background process. Therefore, tables, or parts of them, can be replicated from DBASE III under OS/2 to INGRES under Sinix_Z and vice-versa.

Figure 4 shows the implemented replication mechanism.

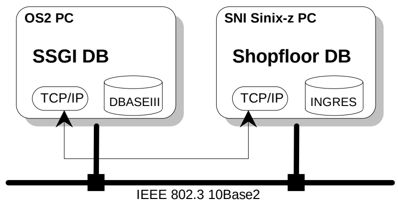

***Figure 4** - Shop-floor Database Replication Application*

The application is distributed over two different PC computers, one running an OS/2 system and a Dbase III database, and another running a SINIX Z system and an INGRES relational database.

4.5. Materials Handling Application

Besides the three previous manufacturing applications, an additional application was developed for different purposes.

The materials handling system, installed at the distribution transformers factory, is a wholly EFACEC implemented product.. The system, based on a μVAX VMS platform, performs the management of two automatic warehouses and four automated guided vehicles. This materials handling system feeds 45 load/unload workstation locations. In these workstations a PC is available to inter-operate with the materials handling management system. These PCs communicate with the μVAX by using a proprietary application protocol over TCP/IP.

A new MMS interface was developed on the µVAX, using DECOMNI MMS [9] and DECNET-OSI, with the intention of providing the materials handling system with an open system standard compliant protocol.

Figure 5 presents the overall architecture, including data flows and communication protocols.

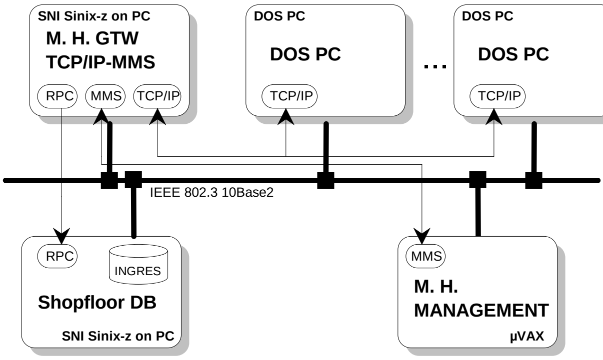

Figure 5 *- Materials Handling Application*

5. Conclusions

The CCE-CNMA technologies were applied in the EFACEC transformers factory in order to support the implementation of manufacturing applications using a multi-vendor, heterogeneous computing environment.

New equipment, applications and functionality’s were introduced in symbiosis with some of the already installed equipment and software base. This fulfilled one of the most important objectives, that is, the preservation of previous investments .

Furthermore, another important issue was achieved: integration work in a labouring factory without disturbing it's production activity.

Concerning the improvements in the manufacturing applications, the following are the most relevant:

Drying and Filling Operation

The drying and filling subsystems are now integrated using CCE-CNMA technologies. The result of this integration can be fully used on a PC, allowing to operate both systems together, supplying the processes with the necessary information and collecting the processes variables.

One of the main advantages of this integration is the reduction of drying time in about 25%. This is possible due to the analysis of collected process data, which is important to tune vital parameters in the various controllers. Moreover, these enhancements in data processing together with the elimination of human errors, increased the process quality in about 33%.

Production Planning

The new Production Planning Application allowed for a reduction of 50% in manpower effort associated with the planning tasks, from 8 to 7 weeks in the lead times and the inactivity in the teams and workstations. These allowed for a reduction in the overall cost of a manufacturing order and also in its delivery time.

Another important achievement was the elimination of recovery weeks.

Shop-floor Database

Several manufacturing areas were improved due to new shop-floor database.

Besides, the usage of standard remote database access services confers the applications with increased flexibility and capability to evolve.

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