Proceedings of IDETC/CIE
2007 ASME International Computers and Information in Engineering Conference
Las Vegas, NV, USA, September 4–7, 2007

DETC2007-35760

CLOSED LOOP CNC MANUFACTURING – CONNECTING THE CNC TO THE ENTERPRISE

S. Venkatesh and R. Morihara
Boeing Company
Seattle, WA

J. Michaloski and F. Proctor
National Institute of Standards and Technology
Gaithersburg, MD

ABSTRACT

Closed Loop manufacturing describes the use of feedback from a Computer Numerical Control (CNC) to the Enterprise Resource Planning (ERP) to help in business operations. Although conceptually simple, many obstacles make CNC-ERP connectivity difficult - incompatibilities of various generations of systems supplied by multiple vendors, differing personnel mindsets and objectives, and outright complexity of ERP. A long journey starts with a single step, and this paper describes a successful pilot project that detected scrap on a CNC during production of the Boeing 737 Leading Edge panels and then automatically entered a scrap reorder into the ERP Supply Chain Management (SCM) Reorder System. The pilot leveraged three major technologies, including open-architecture CNC, OLE for Process Control (OPC) integration technology, and supply chain Web Services. Overall, the pilot project successfully established that integration of CNC into SCM can be straightforward as we automated 90% of one manual step within the scrap Supply Chain Reorder process to impart a leaner manufacturing operation.

Keywords

Enterprise Resource Planning, Supply Chain Management, machine tool, milling, Computerized Numerical Control, openarchitecture

Nomenclature

CNC	Computer Numerical Control
ERP	Enterprise Resource Planning
HTTP	Hypertext Transfer Protocol
IT	Information Technology
LE	Leading Edge
OLE	Object Linking and Embedding
OMAC	Open Modular Architecture Control
OPC	OLE for Process Control
ROI	Return on Investment
SCM	Supply Chain Management

1 INTRODUCTION

In the discrete parts industry, the concept “Closed loop manufacturing” has come to epitomize the tightening of the relationship between the top floor and the shop floor. The top floor is the domain of Enterprise Resource Planning (ERP), which is the broad term for the set of activities that help a manufacturer, including Marketing and Sales, Field Service, Production Planning, Inventory Control, Procurement, Logistics and Distribution, Human Resources, Finance and Accounting. On the shop floor, production involves Computer Numerical Control (CNC) machines and machinists manufacturing parts. The continuing pressure on manufacturers to reduce costs and improve time to mar-

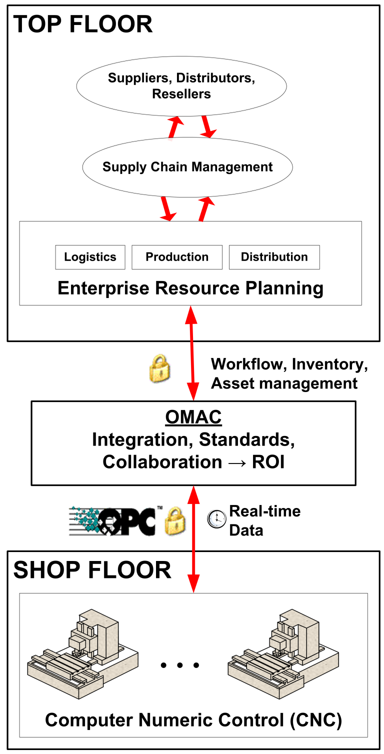

Figure 1. OMAC Perspective on CNC-ERP Integration

ket places a premium on closed loop manufacturing and intensifies the need to integrate feedback from the shop floor into the enterprise business systems.

For our discussion, closed loop manufacturing will be defined as the ability to integrate feedback from a CNC machine tool into the ERP to improve manufacturing and business control. Closed loop manufacturing broadens the capability of the CNC to perform – not just machining – but business functions. Assuming closed loop manufacturing, the CNC can now incorporate business analytics to better contribute to the enterprise day-to-day operation. Until recently, closed loop manufacturing with a shop floor CNC has been difficult if not impossible, but is now easier due to two factors.

First, CNCs are now open-architecture, which is a CNC whose specification is made available to the public by the developers [1]. With an open architecture, factory automation no longer simply controls machines; it now provides access to real-time data and information that can be used to optimize manufacturing and enterprise processes. For example, using real-time monitoring of CNC production, it is possible to do part accounting based on actual machining costs to determine parts produced, cycle times, machine and machinists performance.

Second, CNCs can more easily and cost effectively be integrated into the enterprise due to the OLE for Process Control (OPC) manufacturing integration standard. OPC is an integration technology developed by the OPC Foundation that defines a standard interface to process control devices [2]. Before OPC, data access applications were required to develop completely different integration software for each control device. With the OPC standard, only one driver is needed to access data from any OPC-compliant process control device. OPC has emerged as the leading worldwide standard across most batch, process and discrete industries in enabling manufacturing connectivity. Because OPC is based on commercial off the shelf technology, it provides a cost-effective as well as widely-supported integration technology.

At Boeing, a simple yet compelling application of Closed Loop CNC manufacturing would be to automatically issue a scrap reorder into the Supply Chain from a

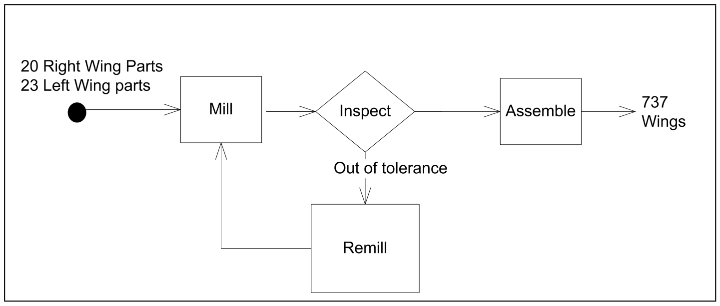

Figure 2. Boeing 737 Leading Edge Process

CNC during manufacturing. The current method of scrap reordering is based on human involvement, referred to on the factory floor as a "touch" operation. A more lean manufacturing environment would demand "non-touch" operations, where the CNC would automatically generate scrap reorders. "Non-touch" operations would benefit the enterprise through more timely scrap reorder and removal of costly and error-prone scrap data entry. To determine if the "Non-touch" scrap reorder was practical – deployable with a reasonable amount of effort – a pilot project was undertakend by the authors of this paper, who are members of the Open Modular Architecture Controllers (OMAC) Machine Tool Working Group.

OMAC is an affiliate organization of the Instrumentation, Systems and Automation Society (ISA) working to derive common solutions for technical and non-technical issues in the development, implementation and commercialization of open, modular architecture control [3]. The OMAC Machine Tool Working Group is a group of end-users, control vendors and machine tool builders who as part of their effort collaborate in the development of best practices and standards for smarter CNCs. A recent thrust has been on CNC-ERP connectivity, which places an emphasis on real-time CNC data collection using OPC to maximize the Return on Investment (ROI) of discrete part machinery within the enterprise, for inventory, asset management and workflow processes. Figure 1 shows the OMAC closed loop manufacturing vision of top floor to shop floor in this scenario.

Major challenges to CNC-ERP integration exist. ERP systems and IT personnel working together with control systems and manufacturing engineers can be difficult. ERP systems are complex and expensive, based on database technology incorporating tables, fields, and records that can easily number in the thousands for a complex enterprise version. Further difficulty integrating into an ERP can arise due to incompatibility issues between systems within the organization. Access to the database can be difficult requiring database credentials, table descriptions and software interfaces. Often resistance to sharing data between departments can make integration into an ERP downright impossible.

This paper looks at the integration of the reorder of scrap within the production and assembly of Boeing 737 Leading Edge (LE) Panels. The validation goal was to prove that with a reasonable amount of effort we could automatically initiate a scrap reorder from a CNC into the Boeing Supply Chain Management system. The remainder of this paper looks at the integration issues and results. The paper is organized as follows. In Section 2 we summarize the Boeing 737 Leading Edge process and how scrap is handled. In Section 3 we present the system architecture and the necessary technology that was the foundation of the pilot project. Finally, in the last section we discuss the results of our pilot.

2 TECHNICAL BACKGROUND

As the leading aerospace manufacturer in the world, Boeing produces the twin-engine 737, a short to medium range airliner. The front of each 737 wing is called the leading edge and contains over 20 leading edge panels per wing. Figure 2 shows the LE process within a production line, where the LE panels are machined and then joined together in making the left and right aircraft wings. The leading edge panels are milled, inspected and assembled on the wing, but occasionally after inspection out-of-tolerance panels are scrapped and new panels are remilled.

When a Leading Edge Panel is scrapped, an order is

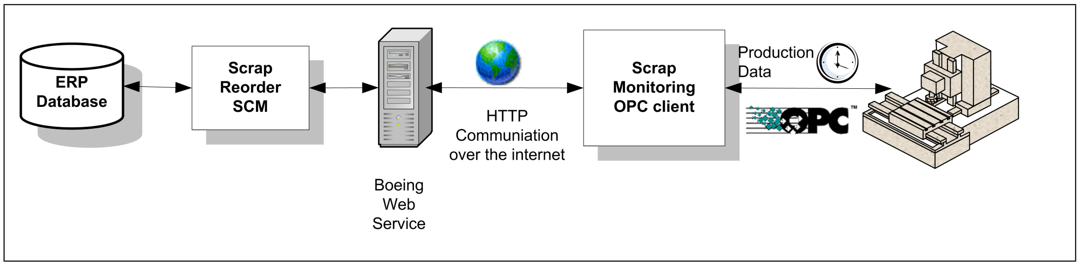

Figure 3. Scrap Reorder CNC-ERP System Architecture

placed into the scrap Supply Chain Management System (SCM) to adjust the raw material inventory. The scrap reorder entry is not done immediately in real-time, but later multiple scraps accumulated over time are bundled together for data entry. Overall, the complete scrap SCM handling requires approximately 10 steps and involves manual entry and tracking from various people in different functional areas to maintain appropriate stock inventory levels.

In general, SCM deals with the corporate handling of inventory, including raw materials, work-in-process, and finished goods. For optimized shop floor SCM, the manufacturing flow operates on a just-in-time (JIT) basis with minimum lot sizes and parts moving through the system with maximum efficiency. To achieve the most accurate JIT operation, distribution channels should be based on real-time data not historical forecasts. Our goal was to change a portion of the existing manual, batched operation into a real-time operation to automatically enter a scrap reorder into the production SCM system.

The existing scrap reorder method was based on a Web-form based entry system. The Web front–end is completely manual which was linked through the internet to a back-end database server, that was linked again into the corporate ERP. At given intervals, someone would type in all the scrap reorders for a given production line. Since the scrap reorder Web–entry was a manual operation, no automated technique had been developed as there was no need for this. To automate the scrap order, we would need machine to machine interaction over the internet or company intranet, which is generally described as a Web Service.

A Web Service is software designed to support communication of services over the Internet, through the compliance with open standards such as Hypertext Transfer Protocol(HTTP) [4], eXtensible Markup Language (XML) [5], or Simple Object Access Protocol (SOAP) [6]. The motivation behind Web Services is to facilitate interaction with other clients, without having to go through lengthy integration design and/or to unnecessarily expose internal application details.

Software tools exist today to support multifaceted Web services, such as XML and SOAP, but were not available as a part of the scrap reorder SCM system. Adding such functionality to the scrap reorder system would take time and be an expensive development solution. Instead, we were able to work out a compromise that used a simple automated Web entry mechanism, decorated Uniform Resource Locator (URL) queries (described later), which allowed us to automatically issue a scrap reorder by computer.

Given automated access to the scrap reorder SCM system, we developed a lean manufacturing scenario that automated 90% of one manual step within the scrap SCM process. In this scenario, we would generate a scrap reorder into the SCM directly from the CNC, based on business intelligence of daily machining operation, in order to determine when scrap has been generated.

3 SYSTEM ARCHITECTURE

The construction of a plane is a major undertaking – over 14 millions parts make up a 737 plane. For each plane, Boeing has a unique identification system. Boeing runs a single "production line" for each plane and a part is one of the elements of the production line. For the LE wing components, the part programs `L01-L23` and `R01-R20` LE panels are required. The program name follows the following convention: `productionline#-part#.extension`. For example, `1857-R1.min` indicates that the `R1` LE panel is being milled for production line number `1857` on an Okuma machine tool.

Scrap can be determined by monitoring all the part programs run on the CNC and if a repeated production line

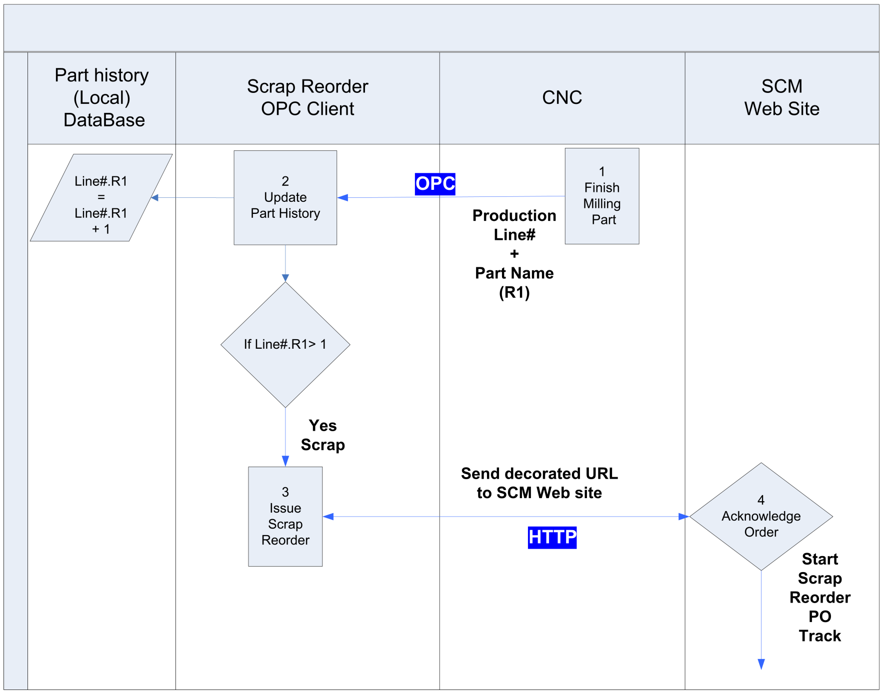

Figure 4. CNC–ERP Web–based Supply Chain Management Scrap Demo Data Flow

part is machined, we have scrapped a part and are making a new one. For example, within production line `1857`, if two `R01.MIN` parts are machined, we knew that first part has been scrapped.

Figure 3 shows the scrap reorder pilot project System Architecture. The LE panels' production took place on an Okuma THiNC OSP-P100 CNC simulator, an open architecture controller. The Okuma THiNC CNC provides an OPC server that allows the collection of machine event data in a data tagged format. We felt confident that the simulation was sufficient proof of feasibility because of previous success at implementing a part accounting OPC Client using the Okuma CNC with OPC Server in actual production at Boeing [7].

Next, NIST developed a Scrap Monitoring OPC client application written in Visual C++ that ran on the Okuma CNC. We used OPC data access to automatically monitor the machining of parts. To determine scrap, we only needed a few OPC tags, which the Okuma OPC server provided. First, to determine what part is being milled, we monitored the OPC Item `Program.ProgramName`. Next we monitored `Program.PartCount` to determine when a part had completed as a finished part would bump the part counter.

We leveraged the concept of the "URL parameter", which has been included in the URL syntax defined within the HTTP specification since the earliest drafts. The URL parameters (i.e., `name=value` pairs) are appended to the URL query, separated from the path by a '&'. The decorated URL is sent by a client back to the Web Service containing all the parameters that the user would have manually filled into the input fields that are appended to the URL for the HTTP POST query protocol.

The scrap reorder decorated URL looks something like

```
http://scm.acme.com/reorder.asp?PartNo=
123&PartName=R1&
```

The first part of the URL indicates what protocol to use (i.e., HTTP). The second part specifies the IP address or the domain name (i.e., scm.acme.com) where the Supply Chain Management Web Service is located. The decorated parameter begins with a question mark and takes the form `name=value`. If more than one URL parameter exists, each parameter is separated by an ampersand &. We had almost twenty name/value pairs of the form:

`?PartNo=123&PartName=R1&`

URL parameters let you easily pass user-supplied information without worrying about firewalls, as the HTTP communicates over socket port 80, usually open to allow internet communication. When an internet server, such as Apache, receives the decorated URL request, the server parses the parameters for the requested page before serving that page to the designated URL web page.

Given this background, the following steps were involved in a CNC scrap reorder for the 1st Right LE panel.

1. Finish Milling Part. When the CNC finishes milling a Leading Edge panel, the part count is incremented. The OPC Server monitoring activity on the Okuma CNC controller communicates to the Scrap Monitoring OPC Client with an event notification of this part completion. As part of OPC, the OPC client can register for event notification for data changes. Both OPC tags "PartCount" and "ProgramName" were monitored. This OPC communication was locally performed on the Okuma, but in practice, could have been local or distributed.
2. Update Part History. In our scenario, a history of each production line is maintained by the Scrap Monitoring OPC Client. To determine if the Leading Edge panel has been milled before, the part history for a production line is queried and if the part count is greater than one, a part has been scrapped.
3. Reorder. When a scrap is detected, a decorated URL query was sent to the SCM reorder system. For our pilot we used the test SCM reorder system so as not to disrupt actual SCM. There are number of software possibilities in which to communicate the decorated URL to the SCM web service. We initially used the Microsoft Win32 Internet Functions to send the request over Hypertext Transport Protocol (HTTP). We easily demonstrated automated communication this way, but unfortunately one piece of data was required to be manually entered by the operator. Because we could not completely automate the scrap reorder, the CNC Scrap Monitoring OPC Client instead generated and displayed a Web page for the operator to fill in the missing piece of data, and when the operator hit send, the Web page containing Javascript [8], built and then sent the decorated URL query to the scrap reorder SCM system.
4. Acknowledge Reorder. The corresponding Boeing SCM URL parses the decorated URL query, and sends back an URL POST acknowledgement that a scrap reorder had been entered into the reorder supply chain.

4 DISCUSSION

This paper describes a pilot project to automate 737 Leading Edge scrap reorder within a Supply Chain Management system. The CNC-ERP connectivity pilot leveraged open-architecture CNC control, OPC integration technology, and Web services in order to validate the feasibility of automated shop floor SCM. The pilot relied on the use of a decorated URL query to communicate between the CNC and the SCM system. Decorated URL query, such as `http://scm.acme.com/reorder.asp?PartNo=123&PartName=R1&`, offer a simple yet quite effective means transitioning manual Web-based operations to automated computer–to–computer operations. In all, we successfully realized most of our goal of a "Touch" to "Non-touch" operation in replacing the tedious data entry required of the machine operators with a more automated approach.

Once the details of interaction between the shop floor and the scrap reorder SCM system had been established, the actual demonstration was straightforward. The proof that integration was easy was a critical aspect of our pilot. For CNC-ERP SCM to realize any ROI, we needed to establish that not only was CNC-ERP connectivity possible, but simple and cost-effective.

DISCLAIMER

Commercial equipment and software, many of which are either registered or trademarked, are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology or Boeing Aerospace, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

REFERENCES

[1] Proctor, F., and Albus, J., 1997. "Open Architecture Controllers". IEEE Spectrum, **34** (6) June , pp. 60–64.

[2] OPC Foundation. http://www.opcfoundation.org.

[3] OMAC Users Group. http://www.omac.org.

[4] THE INTERNET SOCIETY, 1999. *Hypertext Transfer Protocol – HTTP/1.1*. http://www.isoc.org.

[5] Bray, T., Paoli, J., Sperberg-McQueen, C. M., Maler, E., and Yergeau, F., Eds., 2006. *Extensible Markup Language (XML) 1.0 (Fourth Edition)*. http://www.w3.org/XML.

[6] Gudgin, M., Hadley, M., Mendelsohn, N., Moreau, J.-J., and Nielsen, H., Eds., 2003. *SOAP Version 1.2 Part 1: Messaging Framework*. http://www.w3.org/TR/soap.

[7] Venkatesh, S., Ramayya, V., Michaloski, J., Proctor, F., Huynh, L., and Sides, B., 2007. "Case Study in the Challenges of Integrating CNC Production and Enterprise Systems". International Conference on Smart Machining Systems.

[8] ECMA INTERNATIONAL, 1999. *Standard ECMA-262 ECMA Script Language Specification 3rd edition (December 1999)*. http://www.ecma-international.org.