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# MTCONNECT-BASED KAIZEN FOR MACHINE TOOL PROCESSES

**B.E. Lee, J. Michaloski, and F. Proctor**
National Institute of Standards and Technology
Gaithersburg, Maryland

**S. Venkatesh**
Boeing Company
Seattle, Washington

**N. Bengtsson**
Production Modeling Corporation
Gothenburg, Sweden

## ABSTRACT

Kaizen is a part of Lean Manufacturing that focuses on the concept of continuous improvement to reduce waste. For implementing Kaizen on the factory floor, comprehensive and efficient tools for data acquisition, process measurement and analysis are required. The MTConnect open specification provides for cost-effective data acquisition on the manufacturing floor for machine tools and related devices. This paper will look at a Kaizen implementation on the shop floor level for continuous improvement using real-time MTConnect data. The Kaizen transformation of machine data into production knowledge was performed in order to understand energy consumption, asset operation and process performance. The paper takes a detailed examination of the machine tool energy management.

## Keywords

MTConnect, device, machine tool, Kaizen, Lean Manufacturing, Computerized Numerical Control, open–architecture

## Nomenclature

| | |
|---|---|
| **CNC** | Computer Numerical Control |
| **DCOM** | Distributed Component Object Model |
| **FIFO** | First In First Out |
| **HTML** | Hypertext Markup Language |
| **HTTP** | Hypertext Transfer Protocol |
| **MTC** | MT Connect |
| **OEM** | Original Equipment Manufacturers |
| **OMAC** | Open Modular Architecture Control |
| **RPC** | Remote Procedure Call |
| **SOAP** | Simple Object Access Protocol |
| **SQL** | Structured Query Language |
| **SDK** | Software Development Kit |
| **XML** | eXtensible Markup Language |
| **XSD** | XML Schema Definition |

## INTRODUCTION

Kaizen is one of the principles within lean manufacturing. Kaizen describes a business environment where companies proactively work to improve manufacturing and is part of a corporate culture of anticipating a changing marketplace and exceeding customer expectations. Traditionally, improving production is most often associated with the start of a new project. However Kaizen places an emphasis on businesses to focus their resources and employees on the continuous improvement of production, not just at large production deltas. To achieve Kaizen, one must maintain an unbiased view of the current manufacturing process. Continual process improvement can be especially difficult when business is going well, as changes can appear to be wasteful or an unnecessary risk. In Kaizen, process changes should be undertaken only through continuous studying and understanding of the current process.

In discrete parts manufacturing, continuous studying and understanding of the processes on the factory floor has been limited. This is primarily due to closed, proprietary CNC architectures that make business-driven Kaizen difficult, if not impossible. Understanding and improving the milling process on the machine tool has traditionally been relegated to research or academia.

Thus, conservative production approaches are adopted, because improvements, if attainable, are too expensive to implement on closed proprietary platforms.

Understanding the need for an open communication standard in manufacturing, the Association for Manufacturing Technology has developed MTConnect. MTConnect is a new standard for data exchange on the manufacturing floor. MTConnect is an open and royalty free standard "built upon the most prevalent standards in the manufacturing and software industry, maximizing the number of tools available for its implementation and providing the highest level of interoperability at a reasonable cost with other standards and tools in these industries [1]." As the MTConnect specification is still evolving, it will further leverage the already highly advanced control features found in machine tools.

After preliminary successes with MTConnect, Boeing worked with NIST and other members of the Open Modular Architecture Controllers (OMAC) User Group, to investigate the feasibility of MTConnect-based Kaizen on the plant floor. 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. The OMAC Machine Tool Group has been working and promoting the challenging issue of "mainstreaming" machine tool and factory floor integration.

This paper looks at the feasibility of MTConnect-based Kaizen as a means to continually study and improve the factory floor machining processes. Section 2 gives a brief overview of MTConnect. Section 3 describes an extended MTConnect-based architecture to implement Kaizen. Section 4 discusses the test deployment of the extended MTConnect-based system to implement Kazan at Boeing. Finally, a summary of the feasibility of MTC-based Kaizen including future directions is given.

## MTCONNECT OVERVIEW

In order to reduce costs, increase interoperability, and maximize enterprise-level integration, the MTConnect specification has been developed for the manufacturing industry. MTConnect is a specification based upon prevalent Web technology including Extensible Markup Language (XML) [2] and Hypertext Transport Protocol (HTTP) [3]. Using prevailing technology and providing free software development kits minimize the technical and economic barriers to MTConnect adoption.

Figure 1 shows the high-level system architecture of the MTConnect specification, and includes the following concepts:

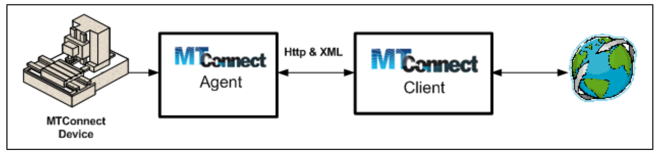



**FIGURE 1**. MTCONNECT OVERVIEW

**MTConnect Device** - is a piece of factory equipment organized as a set of components that provide data.

**MTConnect Agent** - is a process that acts as a "bridge" between a device and a "Client Application". The MTConnect Agent receives and stores single or a time series of data samples or events that are made available to the Client Application.

**MTConnect Client** - is typically a factory application, including applications such as shop floor dashboard visualization, Overall Equipment Effectiveness (OEE), and data mining of asset and process knowledge

The MTConnect specification defines an XML header for message communication and an XML structure to define information models. An MTConnect device is modeled in XML as a set of components, and initially the MTConnect specification is targeted at machine tools and their constituent components axes, spindle, program, and control sequencing. The MTConnect XML structure used to describe MTConnect devices is defined as a tree structure of nested XML tags:

```
Devices/Device/Components/Component/DataItems/DataItem
```

In this Device model structure, one or more devices contain a series of components, of some Component type: controller, linear axis, rotary axis, etc. Each component then has event or sample Data Item definitions. The MTConnect Device model is not hardwired; rather users assemble an XML information model to match their devices as seen in the following Figure 2.

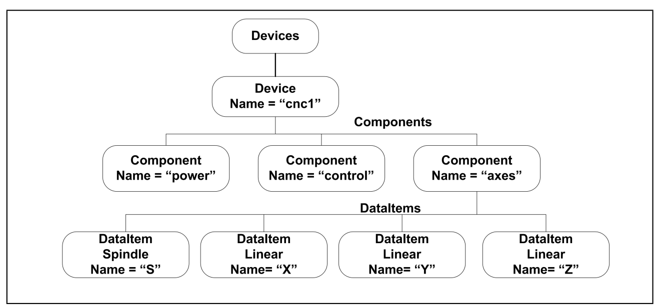



**FIGURE 2**. MTC XML HIERARCHY

MTConnect further provides XML attributes in which to help refine the Device information models. Such XML attributes include Category, Name, Type, Subtype and Units. Below is a partial definition for a single device with just a spindle "S" containing spindle speed (Srpm), and spindle override (Sovr) DataItems.

```
<Devices>
<Device>
...
<Components>
  <Spindle name="S" >
    <DataItems>
      <DataItem category="SAMPLE"
        name="Srpm"
        type="SPINDLE_SPEED"
        units="REVOLUTION/MINUTE"
        subType="ACTUAL" />
      <DataItem category="SAMPLE"
        name="Sovr"
        type="OTHER"
        units="PERCENT"
        subType="ACTUAL" />
    </DataItems>
 </Spindle>
...
</Components>
</Device>
</Devices>
```

The MTConnect Agent uses HTTP to transport data and acts much like a Web Server. The MTConnect Agent handles Device and Applications messages with the same HTTP and XML mechanism. Communication data between an MTConnect Agent and either the device or client can be either MTConnect samples, which are the value of a continuous data item at a point in time, or MTConnect events, which describe an asynchronous change in state.

MTConnect communication relies on the use of URL parameters, which have been included within the specification since the earliest HTTP drafts [3]. URL parameters are described as "name=value" pairs appended to the URL query, with multiple URL parameters separated by a '&'. The "Decorated URL" is sent by either the MTConnect Client Application or the Device to the MTConnect Agent and contains all the command and parameters required for the sample request. Below, a Decorated URL storeSample command with parameters from a MTConnect device is shown:

```
http://cnc1/storeSample?dataItemName=Srpm&value=2000
```

The first part of the Decorated URL indicates what protocol to use (i.e., HTTP). The second part specifies the IP address or the domain name (i.e., cnc1) where the MTConnect agent is located. Next a Decorated name/value pair follows, where the dataItem is the Spindle RPM or Srpm.

Communication from the MTConnect Agent running on the MTConnect website will be shown as an example of the HTTP/XML communication. The following HTTP query retrieves current Device status from the MTConnect agent:

```
http://agent.mtconnect.org/current
```

This HTTP request will retrieve all the current data and events in the MTConnect device. Figure 3 shows most of MTConnect XML response in a web browser with some XML branches collapsed for space considerations.

Compared to other factory standards, MTConnect provides a straightforward integration paradigm. One alternative specification is OPC, which is a prevalent factory floor standard in the batch and process industries but whose scope does not include any device models. OPC has been used in previous OMAC factory-floor integration projects [4, 5]. OPC has also been combined with MTConnect on the factory floor, with OPC acting as an MTConnect Adapter, providing raw data that an MTConnect Agent collects and reformats into XML [6]. Similar to others experience, when OPC implementations rely on DCOM for remote communication, deployment is difficult, beset with configuration, security and firewall issues.

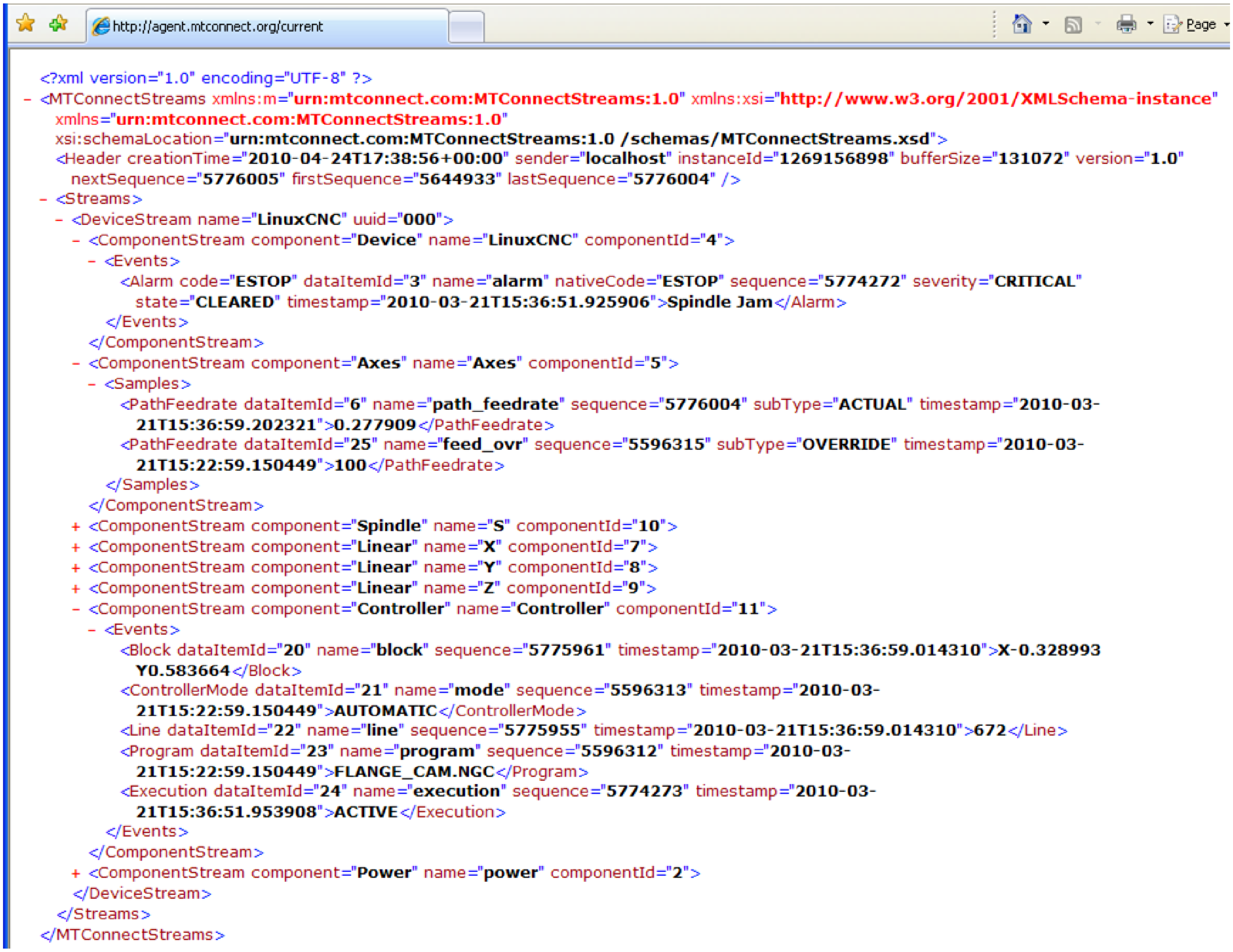
From experience with MTConnect, we found that XML provides a convenient format for transferring the contents of data to and from remote clients. We have implemented other approaches, such as SOAP Web Services, for shop floor data collection. Web Services is ostensibly easy, however, integration of C++ code was extremely limited in its flexibility in dealing with it, limited to RPC SOAP implementations [7]. Mixing SOAP development platforms produced subtle errors, and different SOAP interface versions was problematic.

Overall, MTConnect is version friendly and allows independent development of versions, with new extensions coexisting with legacy functionality. From [1], "MTConnect data items are self-describing and messages carry a protocol version number, and extensions can be added to MTConnect without jeopardizing backwards compatibility; principals that do not understand the extensions can safely ignore them." For example, we were able to add PartCount DataItem, which is not explicitly part of the MTConnect specification, without any trouble.

## MTConnect-based Kaizen

Informative, accurate and timely production knowledge is considered vital to lean CNC-based manufacturing. Due to the previously stated limitations of proprietary machine tools, often production knowledge can only be gathered at a higher level of operation. Workorders enter the shop floor and then overall performance is measured upon completion. Typically, this shop floor knowledge may be augmented by manual signoffs at various stages and visual observation and manual documenting of the process. Intermediary analysis of the process steps and costs involved are then generally estimated. Ideally, all data acquisition should be completely automated at the machine level, and then the derived knowledge will be more precise. Strategically however, due to the cost to instrument machine tools with data acquisition and knowledge automation, it may not warrant such an undertaking.

Lean manufacturing at a reasonable implementation cost using MTConnect-based Kaizen was the focus of the Boeing/NIST MTConnect work. The goal of this research was to see not only if MTConnect could automate the data acquisition cost-effectively, but also to determine the feasibility of automating the Kaizen knowledge generation. Therefore instead of measuring the pro-




```
<?xml version="1.0" encoding="UTF-8" ?>
- <MTConnectStreams xmlns:m="urn:mtconnect.com:MTConnectStreams:1.0" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns="urn:mtconnect.com:MTConnectStreams:1.0"
    xsi:schemaLocation="urn:mtconnect.com:MTConnectStreams:1.0 /schemas/MTConnectStreams.xsd">
    <Header creationTime="2010-04-24T17:38:56+00:00" sender="localhost" instanceId="1269156898" bufferSize="131072" version="1.0"
      nextSequence="5776005" firstSequence="5644933" lastSequence="5776004" />
  - <Streams>
    - <DeviceStream name="LinuxCNC" uuid="000">
      - <ComponentStream component="Device" name="LinuxCNC" componentId="4">
        - <Events>
            <Alarm code="ESTOP" dataItemId="3" name="alarm" nativeCode="ESTOP" sequence="5774272" severity="CRITICAL"
              state="CLEARED" timestamp="2010-03-21T15:36:51.925906">Spindle Jam</Alarm>
          </Events>
        </ComponentStream>
      - <ComponentStream component="Axes" name="Axes" componentId="5">
        - <Samples>
            <PathFeedrate dataItemId="6" name="path_feedrate" sequence="5776004" subType="ACTUAL" timestamp="2010-03-
              21T15:36:59.202321">0.277909</PathFeedrate>
            <PathFeedrate dataItemId="25" name="feed_ovr" sequence="5596315" subType="OVERRIDE" timestamp="2010-03-
              21T15:22:59.150449">100</PathFeedrate>
          </Samples>
        </ComponentStream>
      + <ComponentStream component="Spindle" name="S" componentId="10">
      + <ComponentStream component="Linear" name="X" componentId="7">
      + <ComponentStream component="Linear" name="Y" componentId="8">
      + <ComponentStream component="Linear" name="Z" componentId="9">
      - <ComponentStream component="Controller" name="Controller" componentId="11">
        - <Events>
            <Block dataItemId="20" name="block" sequence="5775961" timestamp="2010-03-21T15:36:59.014310">X-0.328993
              Y0.583664</Block>
            <ControllerMode dataItemId="21" name="mode" sequence="5596313" timestamp="2010-03-
              21T15:22:59.150449">AUTOMATIC</ControllerMode>
            <Line dataItemId="22" name="line" sequence="5775955" timestamp="2010-03-21T15:36:59.014310">672</Line>
            <Program dataItemId="23" name="program" sequence="5596312" timestamp="2010-03-
              21T15:22:59.150449">FLANGE_CAM.NGC</Program>
            <Execution dataItemId="24" name="execution" sequence="5774273" timestamp="2010-03-
              21T15:36:51.953908">ACTIVE</Execution>
          </Events>
        </ComponentStream>
      + <ComponentStream component="Power" name="power" componentId="2">
      </DeviceStream>
    </Streams>
</MTConnectStreams>
```


**FIGURE 3**. MTC XML RESPONSE

ductivity of the factory floor at a higher enterprise level by tracking the gross movement of the workflow, we hoped to push this knowledge acquisition onto the factory floor. Furthermore, if some machines provide additional data for process improvement, knowledge automation could leverage this on an as-needed basis. This distributed approach scales better, offers more flexible deployment options but at a higher level this approach does require more synchronization activity among these systems.

The Boeing shop floor machines provide the following basic MTConnect machine tool data acquisition: position, feeds, speeds, program, control logic, and some tooling. Our goal was to supplement this basic device knowledge, and continuously monitor more complex device knowledge, such as cycle time, setup time, downtime, process anomalies, and energy consumption. From previous work, we have found that the lack of data items can make deriving machine tool process knowledge impossible. For example, in understanding CNC cycle time, part count is imperative for accurate and efficient monitoring of process times. For our work, Boeing requested the machine tool vendor add the data items: 1) part count to understand cycle time and 2) servo and spindle loads to assist in energy management. Unfortunately, given the current state of CNC technology, some immensely valuable process knowledge is precluded from data acquisition. For example, the material of the part being machined would be highly beneficial in understanding the machining loads, specifically when machining titanium as opposed to aluminum. However, the current, and rather archaic, CNC “M&G” [8] programming paradigm does not include this information.

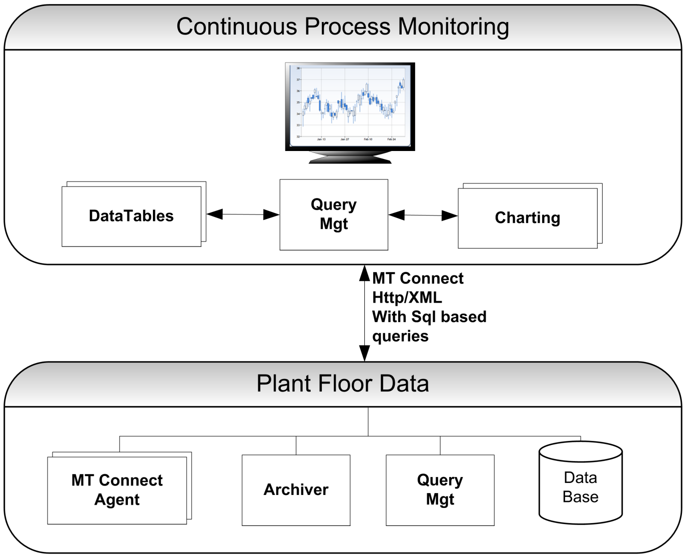



**FIGURE 4**. DEPLOYMENT OVERVIEW

MTConnect provides a Software Development Kit (SDK) that implements a turnkey Microsoft C# .Net implementation of an MTConnect Agent [9]. Having successfully used the SDK, we felt that the MTConnect Agent could easily be expanded to handle more complex device knowledge, especially if we leveraged the powerful C# XML and DataSet technologies. DataSet and DataTable are in-memory representations of a database and its tables. C# provides the ability to export an XML or XSD representation of a DataTable, which can then be transported across HTTP and imported into an MTConnect Client Application DataTable.

Figure 4 shows the architecture we adopted to implement the MTC-based Kaizen Architecture. On the Plant Floor, we extended the MTConnect Agent with new Decorated URLs to handle Cycle times, Failure statistics, and Energy Management. These decorated URLS were modified to allow support of C# DataTable SQL-like Queries. The MTConnect agent already had some historical data retention, but we augmented this with an Archiver, which saved data from one or more machine tools into a Microsoft Jet Database for longer term data retention. A Query Management component handled MTConnect SQL queries on the historical Data Base to retrieve the process knowledge.

At the Continuous Process Monitoring application level, our first goal was to visualize the processes on the plant floor. Due to the ability to import DataTable directly into C# Charting software, this made MTConnect Client Application visualization straightforward. The Continuous Process Monitoring has a similar Query Management module to encode and decode MTConnect XML, XSD and SQL queries into a corresponding DataTable representation.

C# provides SQL relational functionality for DataSet and DataTables. SQL is the longstanding database computer language designed for managing data in relational database management systems [10]. SQL includes data query and update, schema creation and modification, and data access control. SQL defines a set of general purpose query operators that allow traversal, filter, and projection operations on a database.

The simplicity of the transformation sequence of the data is important in understanding the benefit of this XML DataTable-driven approach. The negotiation between the MTConnect Agent and Client follows this procedure. First, query MTConnect agent for DataTable XSD to create Client DataTable. The MTConnect Agent calls WriteXmlSchema which generates the XSD in Figure 5 for an “archive” Energy Management response containing the DataTable column names and column types.


```
<?xml version="1.0" encoding="utf-8" ?>
- <xs:schema id="NewDataSet" xmlns="" xmlns:xs="http://www.w3.org/2001/XMLScher
  - <xs:element name="NewDataSet" msdata:IsDataSet="true" msdata:MainDataTable="Arc
    - <xs:complexType>
      - <xs:choice minOccurs="0" maxOccurs="unbounded">
        - <xs:element name="Archive">
          - <xs:complexType>
            - <xs:sequence>
                <xs:element name="TimeEntry" type="xs:dateTime" minOccurs="0" />
                <xs:element name="MachineId" type="xs:string" minOccurs="0" />
                <xs:element name="Shift" type="xs:short" minOccurs="0" />
                <xs:element name="TotalPower" type="xs:double" minOccurs="0" />
                <xs:element name="TotalMachining" type="xs:double" minOccurs="0" />
                <xs:element name="TotalOff" type="xs:double" minOccurs="0" />
                <xs:element name="TotalAlarm" type="xs:double" minOccurs="0" />
              </xs:sequence>
            </xs:complexType>
          </xs:element>
        </xs:choice>
      </xs:complexType>
    </xs:element>
  </xs:schema>
```


**FIGURE 5**. ARCHIVE XSD SCHEMA RESPONSE

It is necessary to create the DataTable using an XSD schema so that there are explicitly-typed Data Columns in order to do SQL queries, such as those based on date and time, or numerical comparison. If not, all the DataColumns are strings, which makes many SQL comparisons impractical. Next, Query MTConnect Agent for DataTable contents and load into Client DataTable. Figure 6 gives the XML response for “archive”.


```
- <DocumentElement>
  - <Archive>
      <TimeEntry>2009-12-10T20:00:00-05:00</TimeEntry>
      <MachineId>M25730</MachineId>
      <Shift>1</Shift>
      <TotalPower>0.072</TotalPower>
      <TotalMachining>185.328</TotalMachining>
      <TotalOff>0</TotalOff>
      <TotalAlarm>0</TotalAlarm>
    </Archive>
  </DocumentElement>
```


**FIGURE 6**. ARCHIVE XML RESPONSE

Passing SQL queries using HTTP is relatively straightforward, but some ASII characters are not URL friendly and have been transliterated. An MTConnect Agent SQL query to retrieve energy readings before 9/30/2009 for shift zero is seen in the following Decorated URL:

```
http://cnc1/archive?query=TimeEntry<'9/30/2009' And Shift=0
```

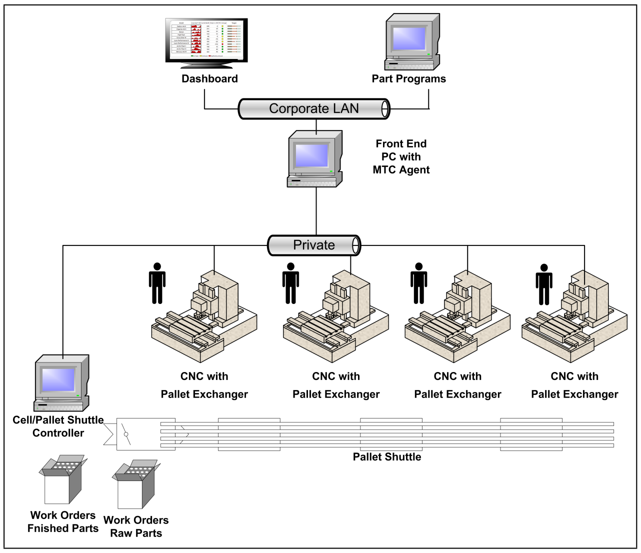



**FIGURE 7**. MTC DEPLOYMENT IN WORKCELL

## FACTORY DEPLOYMENT AND ANALYSIS

The preferred Kaizen methodology is to employ a "hands-on" assessment at the shop floor using specific, interactive feedback, as opposed to a remote meeting-room analytical approach [11]. In this vein, we decided to investigate the feasibility of an MTConnect-based "hard-data" approach to Kaizen on the Boeing shop floor.

The Boeing Auburn plant has been an early adopter of MTConnect and has extensive MTConnect connectivity throughout the factory. Existing MTConnect factory integration provides data to a Dashboard that includes real-time and historical tracking of equipment status and job progress. For our initial analysis, we concentrated on understanding the process within an integrated Workcell that is primarily dedicated to making aluminum plane shims, brackets and body joints. Cycle times for these parts vary from twenty minutes for a bracket, to five hours for a body joint.

Figure 7 shows the Workcell layout, which consists of four five-axis CNCs connected by a linear pallet shuttle and four operators to oversee operation. Each CNC features a high-speed spindle and other options for high-speed machining. The Workcell operates on batch lots of aluminum parts with part runs ranging from one shim to hundreds of brackets with assorted milling, drilling, facing and probing operations.

The manufacturing workflow consists of Workorders assigned First-In First-Out to machine tools based on machining match of part characteristics to machine capability. Workflow is scheduled by Industrial Engineers, with each Workorder consisting of a "lot" of parts and the required raw material. Workorders are delivered to the Workcell staging area, and parts are loaded onto the pallet shuttle to be processed by the next free machine tool. If necessary, part programs are downloaded to the Workcell. Production volume varies, generally a little under 24/7 capacity, with most machines running 3 shifts a day.

The MTConnect Agent runs on the Front End PC (FEPC) as constrained by the security configuration of the factory network. The networking scheme uses a dual Ethernet solution to provide a safety and security buffer for every CNC by isolating it from the main corporate intranet but still allowing TCP/IP [12] connectivity through a FEPC. MTConnect C# Agent runs as a Windows Service on the FEPC, and on each CNC runs an MTConnect Adapter provided by the machine tool vendor that outputs data messages on a TCP/IP socket. The MTConnect Agent connects to this TCP/IP socket on each CNC machine and archives the data output from each CNC.

Because of the increased worldwide focus on the environmental aspects of manufacturing, we studied the energy consumption of the Workcell as a means to attain lean as well as sustainable manufacturing. Support for MTConnect energy data was initially not available, but with help from the CNC vendor, integration of servo load values into the MTConnect Device adapter was made possible. Table 1 shows the power for the machine tool electrical components.

As a baseline, it is straightforward to determine the worst-case machine energy consumption, that is, 100 % loading all the time. The equation for energy efficiency is:

$$P_m = P_e \times \eta \qquad (1)$$

where

$P_e$ = electrical input power
$P_m$ = rated continuous mechanical output power in kW
$\eta$ = servo power efficiency

In our case we conservatively estimate an energy loss of approximately 20 %, which gives $\eta$ equal to 80 %. At one hundred percent loading on a machine tool, $P_e$ is equal to 40.2 kW. To compute power cost:

**TABLE 1**. MACHINE TOOL POWER RATINGS

| Mechanism | | Output (kW) |
|---|---|---|
| Spindle | | 15.0 |
| X-axis | | 3.5 |
| Y-axis | | 3.5 |
| Z-axis | | 3.5 |
| A-axis | | 1.0 |
| C-axis | | 1.0 |
| Hydraulic Pump | | 1.5 |
| Coolant Pump | | 0.37 |
| Chiller | | |
| | Spindle | 0.4 |
| | Chiller unit | 1.1 |
| | Fan | 0.15 |
| Chip Conveyor | | 0.2 |
| Magazine Rotational Motor | | 0.6 |
| ATC drive motor | | 0.4 |
| Total power | | 32.22 |

$$E = P_m \times t \times K \quad (2)$$

where

$E$ = total cost of energy

$K$ = cost of electricity per kWh.

$t$ = time measured in hours

The cost of electricity per kWh for industrial customers in the Seattle area is about 5 cents a kWh [13]. This gives an expected cost of about 2.00 dollars per hour at maximum machine loading.

To test the feasibility of our Kaizen concepts, we took snapshots of spindle and servo loads using the MTConnect Agent for several manufacturing shifts over the course of several days. Workorders were processed with no a priori knowledge of lots or scheduling. MTConnect machine tool load data is given in percentages, so that a 50 % spindle load using the Output from Table 1 corresponds to 7.5 kW of instantaneous power. We sampled the data at ten second intervals and summed up the total energy for machining and for idle states.

First, we produced charts of the energy consumption based on various visualizations of energy consumption of the machine tools, shifts and cutting tools. Figure 8 shows the visualization for daily energy consumption of one machine tool, "Machine 25730". Similarly, Figure 9 shows the visualization for total energy consumption of shifts and daily usage of a shift, "shift 0" in this figure.

Analysis of the actual energy consumption reveals that machining costs are around 50 cents per hour given the Seattle area industrial power rates of 5 cent per kWh. Inspecting the data, we found the spindle was generally never highly loaded. The lower loads can be attributed to the use of High-Speed Machining (HSM), where the machine tool takes small depth of cuts using high feeds and speeds and is gaining popularity due to better part finishes, less part warping, and improved accuracy.

It must be noted that this is a small sample of energy data, and only a rough estimation of actual energy use. We did not measure the energy use of the machine tool at the power source, but have confirmed that the cost of actual machine tool energy correlates will with related NIST work [14].

Kaizen for alarm monitoring is crucial to process improvement because of the potential adverse impact of alarms on safety and productivity. An alarm is a signal to an operator requiring attention to a problem and indicates some undesirable or potentially unsafe system state. MTConnect alarms provide some flexibility and multiple alarm types (ERROR, CRICITAL, INFO) but can become ineffective due to the lack of specificity. Upon initial inspection, we monitored alarms and uncovered a process anomaly, where we found a periodic "CRITICAL" alarm that lasted for only about 11 seconds and was actually more of a warning. We are investigating a better mechanism for cataloging of alarms to enable detailed analysis.

MTConnect provides a method to collect machine statistics over time. Combining the data for cycle time, part count, alarms, downtime gives a detailed picture over machines efficiency and brings attention to machines that need more maintenance or replacement to increase overall performance on the factory floor that enables Kaizen.

## DISCUSSION

Lean manufacturing is the relentless pursuit of eliminating waste and inefficiencies. For Kaizen, manufacturers need to continuously measure and analyze the shop floor operation in order to improve processes. With our work, we felt that the MTConnect specification makes Kaizen feasible by lowering the cost of manufacturing data acquisition, and by increasing the productivity and usability of such services. By lowering the barriers and maintaining the proper commitment toward continuous process improvement, manufacturers can ultimately achieve Kaizen.

Summarizing, MTConnect was easily able to provide real-time Boeing shop floor data to help understand energy consumption during actual production. The MTConnect data acquisition was not intrusive and we were able to quickly ascertain that machine tools with modern servo motors may only be able to attain

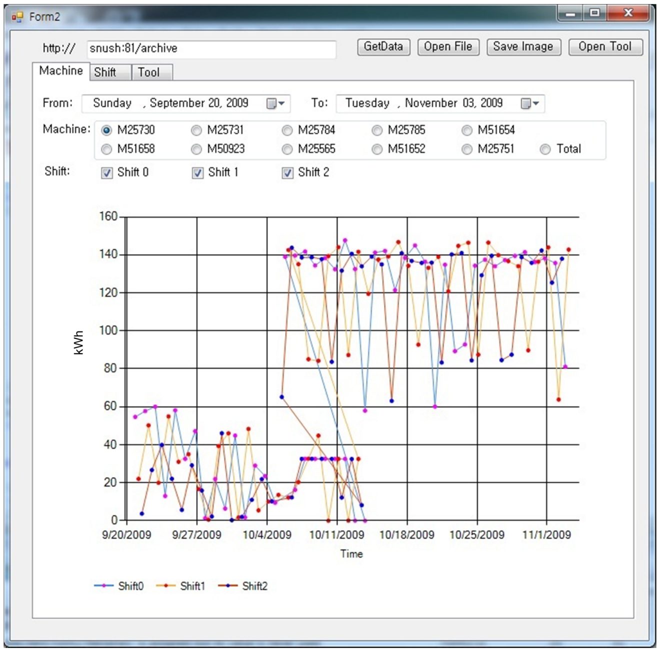



**FIGURE 8**. DAILY SHIFT ENERGY MACHINE 25730 IN kWh

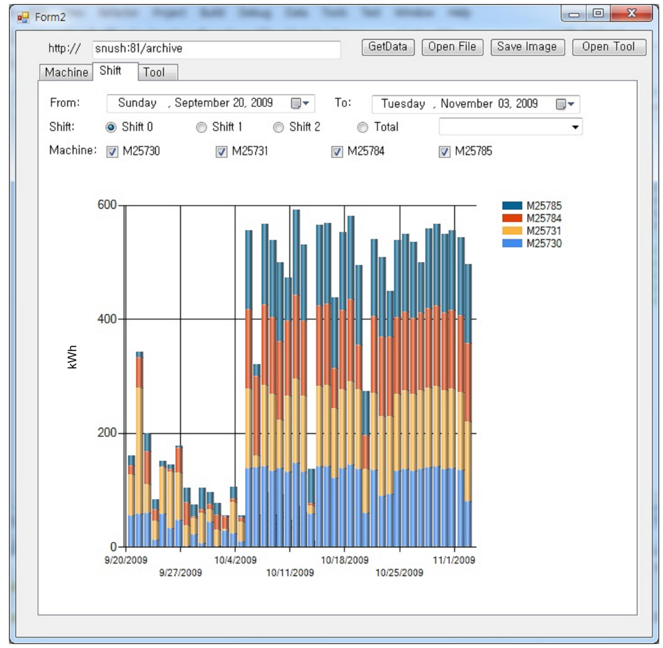



**FIGURE 9**. SHIFT CONSUMPTION BY MACHINE IN kWh

limited energy savings. In the near future, we plan to integrate long term energy and process data to see if there is any correlation to quality and process reliability.

## 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.

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