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# INTERNET–ENABLED TOTAL AUTOMATION
## - Integration of Distributed Tasks in Manufacturing Enterprises

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Abstract: Internet-based total automation is proposed as a solution for manufacturing enterprises, which face constant changes in their markets, customer demands and business practices. When major changes occur, such enterprises require re-engineering of their information systems. This involves handling large numbers of functional objects and regulating many enterprise activities over three application levels: the device level for production control, the plant level for production execution and the enterprise level for production planning. This paper suggests an Internet-enabled automation solution based upon a simple enterprise model developed by the authors. The model, solution architecture and methodology are presented together with case studies.


Keywords: *automation, Manufacturing process, enterprise model, Internet*

## 1 INTRODUCTION

Today, manufacturing enterprises are facing three main challenges:

*The business challenge:* The market is constantly changing and customers demand larger varieties of high quality products at competitive prices.

*The IT challenge:* Accessing and managing information efficiently throughout the extended enterprise and balancing the benefits of the IT revolution with the cost of exploitation.

*The engineering challenge*: Multi-disciplinary teams interact frequently from the earliest stages of the product development lifecycle, using an increasing variety of modelling, mathematical analyses, imaging and information-sharing technologies. Development cycles shortened while the creativity and innovation must be increased.

Solutions to these challenges come from a wide variety of suppliers often with proprietary systems. Historically these solutions are isolated and have poor interfaces with external systems. The IT and automation infrastructures in many manufacturing enterprises are actually a group of isolated technology islands. Re-engineering of enterprise resources is therefore either difficult, costly or both.

Some critical issues facing today's industry are [1]:

- Integration with legacy systems.
- Visualising and managing integration and development.
- Managing the infrastructure for future applications.

A total solution for enterprise automation is proposed based on the Internet. It should be component based with good architecture and interfacing facilities.

The Internet-enabled automation (IEA) system will enable all enterprise activities in manufacturing to be integrated including operational and engineering environments and logistics. Based on a simple enterprise model, the main system coverage can be generalized as a numerical code, 1-2-3: *one* infrastructure backbone, *two* interfaces and *three* applications levels.

## 2 ENTERPRISE MODEL

All the enterprise activities and enterprise components involve elements of material flow, information flow and capital (cost) flow [2]. The three flows and their descriptors comprise the state of the enterprise. The production process becomes a value-added process by converting the cost of production into the product value. The integrated manufacturing process can also be visualised as a material flow system incorporating material handling and material processing functions, controlled by an integrated information flow system.

A real manufacturing system consists of interconnected components, or *subsystems*. It may involve a large number of variables in order to describe the system for a specific requirement. Based on the concept of component-based analysis, a manufacturing enterprise can be seen as a network of components. With Internet servers embedded in these components, production unit becomes a node in a closely connected network; each of the nodes can be further broken down into another network. The mode will be the natural representation of totally integrated manufacturing enterprises.

Eriksson and Penker used the UML (Unified Modelling Language) notation to capture and refine business process models [3]. Based on the UML notation, a simplified model is proposed in the paper to represent the material flow process and information flow in the enterprise environment.

*2.1 The node, a basic generalised unit*

A system is regarded as a network of individual components including subsystems and parts. A component can be taken as an instance of an abstract model, or class, as used in object-oriented modelling methodology.

The class models may be collected into packages related to their behaviour and state. A class encapsulates states (attributes) and offers services to manipulate these states (behaviours).

The basic unit in the enterprise class hierarchy is termed a *node* and can be represented using the notation shown in Figure 1.

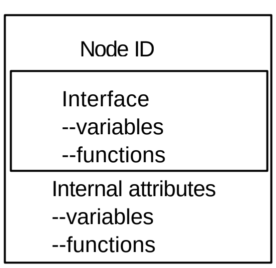


Figure 1. Node notation

The main features are:

1) A node is a model of a real-world entity. It is associated with a unique identifier.
2) A node consists of two groups of elements: a defined set of attributes (states) and a group of methods, commonly implemented procedures or functions, allowing the node to perform various tasks.
3) All the node descriptive state variables are grouped as internal variables and interface variables. Interface variables being used for interaction with external components.
4) A node can be broken down into a collection of several nodes.
5) Nodes can be connected by coupling functions of interface variables to form another node, whose internal variables are only those interface variables of the sub-nodes.

In this way a hierarchical structured model representing a complex system can be established step by step and part by part. The different subsystems can be analysed separately to meet varying requirements in terms of speed or precision.

Using the network of nodes model, all the descriptive state variables are grouped as internal variables inside the nodes with interface variables being used for interaction between the objects.

In practice, not all the components can be mathematically modelled and alternative methods have to be used, such as neural networks, fuzzy modelling and statistical methods. These can be used to deal with the uncertainty and incompatibility associated with individual components.

2.2 *t-Node -- a material flow unit*

Material flow involves conversion of raw materials into product [4]. A production process is a collection of activities and a specific ordering of work activities across time and space. The primary material flow in manufacturing constitutes a serial chain of functions.

Through this process raw materials are procured from suppliers, processed and assembled in workshops and stored in warehouses as inventories, or delivered to consumers as finished products.

To model the processing components, a new type of node can be defined. The basic node can be represented as a flow unit, or a t-Node as in Fig. 2. A section of water pipe can help to illustrate the meaning of the notation. The flux Q denotes how much water flows through the pipe and the potential P denotes the water pressure. For the pipe, the higher the potential difference between the two ends of the pipe, the more water flows through it.

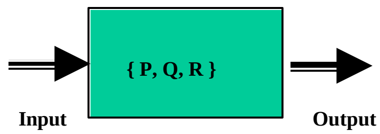


Figure 2 A t-Node

The process notation implies a flow from left to right. Using a single variable R to describe the structural property related to flow impedance, the basic equation for quantitative determination of the flow is:

$$Q=P/R.$$

After defining the generalised parameters Q, P and R of a processing unit, the material flow in a manufacturing process can be quantitatively modelled.

By this network of nodes model, a manufacturing system can be studied part by part, with different subsystems studied at different levels, to meet varying requirements in terms of speed or precision. Manufacturing cell behaviour can be predicted by an input-output map, which may be a result of several years of manufacturing process analysis or a large simulation process.

Based on this model, the application systems can be built to analyse the performance of the system and the performance of individual components by:

- effectively distributing the manufacturing resources for overall performance;
- quantitatively analysing any bottleneck in the production process.

This paper does not include a detailed description of the operations of the model, nor a representation of a dynamic version of the model.

*2.3 n-Node -- an information flow unit*

The modelling of the most complicated information flow process and software applications in a business enterprise requires more interactions among the nodes and a new type of node should be used. Using an n-Nodes, to stand for a neuron type of node, for information processing, the information flow system in an enterprise is studied as a network of these neurons. The n-Node can be represented by means of the general notation shown in Fig 1.

The network of nodes model provides an overview of where the information system being considered will fit into the enterprise structure and its daily activities. It may also provide the justification for building the system by capturing the current manual and automated procedures that will be rolled up into a new system and the associated cost benefits. It also allows the analyst to map clearly the scope of the proposed system and what will be implemented.

Compared with the material flow process, which is a horizontally distributed system [5], the information flow in a manufacturing enterprise forms a vertical network of the nodes dealing with data. Detailed description of the interactions among these nodes is beyond the capacity of the network of nodes model covered here.

*2.4 System modelling with the model*

The production process may be considered to be several closely interconnected flows in the collection of manufacturing resources. The manufacturing resources can be anything that is required for production, whether it is a machine, a warehouse or a piece of software. An integrated manufacturing process is basically a material flow system incorporating material handling and processing functions. The generalised flux parameter Q can be defined as the amount of the materials, raw or finished. The driving force of material flow is value added during the process. If V is used to denote the value of materials, then the generalised pressure $P=V_{out}-V_{in}$, or $P=\Delta V$. In a manufacturing process, materials flow from low value to high value. The equipment capacity (plus operator effort) consists of the resistance to the flow. The node impedance R is used to generalise the effects.

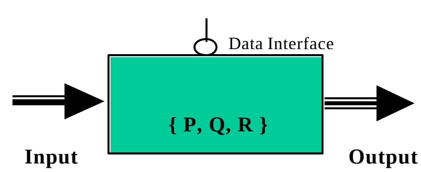


Figure 3. Flow unit(with a t-Node and an n-Node)

In practice, a t-Node does not exist independently. The basic node in an enterprise is either an n-Node or a combination of a t-Node and an n-Node. Thus a node in material flow can be denoted as shown in Fig. 3. The unit attribute R can then be varied for controlling a flow unit from higher lever controllers.

If the manufacturing enterprise is regarded as a flow field, propagation of the potential is by the information system. In a production process, materials flow in certain paths, or linked processing nodes. There are two basic couplings of the units: serial and parallel. A material flow system is formed by coupling these basic nodes.

In serial coupling, node C consists of Node A and Node B as shown in Fig.4.

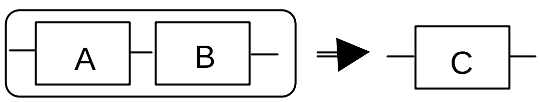


Figure 4. Serial coupling of nodes

In parallel coupling, node C consists of Node A and Node B as shown in Fig 5.

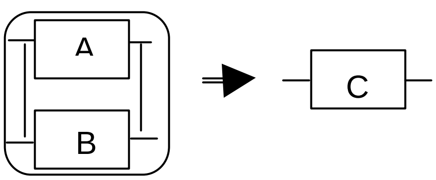


Figure 5. Parallel coupling of nodes

After determining the generalised parameters Q, P and R of Node A and node B, the resulting parameters for Node C can be expressed as:

$Q_c = Q_A = Q_B$
$P_C = P_A + P_B$
$R_C = R_A + R_B$
for serial coupling, and

$Q_c = Q_A + Q_{B;}$
$P_C = P_A = P_B.$
$1/R_C = 1/R_A + 1/R_B$
for parallel coupling

The node could be a lathe with its controller and a web server, or an MRP client station generating production recipes based on customer orders. Functioning units can be combined flexibly in accordance with the modular principle and are easy to reuse. The user continues to configure and program the controller or intelligent field device as usual with the software tool provided by the device manufacturer. A “software node” is then formed from the overall user software for this device. This effectively “encapsulates” the functionality of the intelligent device with application-specific programs. From the outside, only those variables that are required for machine-wide or plant-wide interaction, for visualization and for diagnostics are accessible in the form of a technological interface (component interface). Access to the component interfaces is governed by uniform definitions independent of the internal functionality of the components.

## 3 INTERNET-BASED AUTOMATION

As computer power and communication bandwidth increase and if costs are kept down, Internet-enabled total enterprise automation can become a realistic solution in the near future. Practically every node can have an embedded Web server as an information interface port. Web browsers can be adopted as the standard user interface for applications at all levels as Web interfaces are cross-platform and simple to develop.

IEA solutions can be varied in terms of scale and complexity. They should have at least: *one* infrastructure backbone, *two* interfaces and *three* applications levels. Possible solutions for a reliable, seamlessly integrated automation system may also include:

- Ethernet-enabled data acquisition and control
- Parsing, message manipulation and alarm operation
- Batch control and executions

### *3.1 The Internet backbone*

The backbone of the proposed IEA solution is the Internet. With the Ethernet becoming faster, the communication capacity will meet most enterprise requirements. The IEEE is now preparing new protocol standards to improve the performance of Ethernet applications to give priority to time critical data and to guarantee message segment delivery. The use of switched Ethernet can improve collision detection, which is not very reliable at present, and also provide the necessary system redundancy.

The technology is available for all production and management components to have an embedded Web server connected via the Ethernet. Thus individual machines or a production line can become an Intranet of nodes. A dedicated Intranet loop can meet the requirements for system security, reliability and real-time performance. Future broadband communication can provide extra speed and real time multi-media support.

### *3.2 The two interfaces*

The objectives under the heading of IEA are consistently to modularise plants and machines and to make "distributed intelligence" easy to handle. IEA extends current office automation to the whole production process and provides a view of the overall enterprise.

Two types of Internet interface are of primary importance in an enterprise, that between the Internet and production processes and that between the Internet and databases.

Commercial business management has been working on the latter for many years, making Internet-based database engines a proven technology. However, a great deal of work still needs to be done on the interface to field devices.

There are several established common Internet application services in the commercial field such as FTP (for file transfer), Telnet (for terminal emulation) and SMTP (for email). A similar provision is needed in the industrial world.

Any successful solution must take account of interfacing between existing installed fieldbus systems and the Internet.

### *3.3 Three level applications*

The IEA architecture for the manufacturing enterprise involves the following levels:

Field level. Machine controllers of all types are used. With the advent of "smart" field devices, a wealth of information can be provided concerning devices not previously available.

Process Level**.** The installation of manufacturing execution systems (MES), Distributed Control Systems (DCS) or SCADA systems to monitor and control manufacturing processes has made data available electronically.

Enterprise Level. Enterprise resource planning (ERP) systems are used at the planning level - in the management field. Manufacturers need to access data from the shop floor and integrate it into their existing business systems.

## 4 PROCESS MODELLING--CASE STUDY 1

The business and production processes in a bakery were modelled using the methodology proposed.

There is only one pair of nodes in the business: the customer and the bakery (Fig.6). To a customer, the bakery is a black box with one window: order with payment in and goods out. Customers may only need to know the order status and the goods delivery time and method.

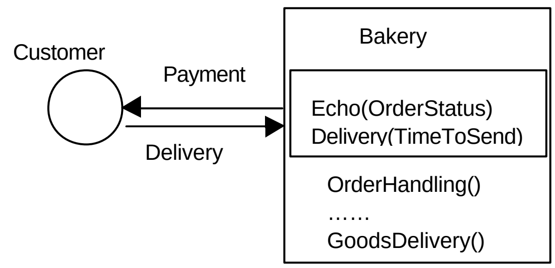


Figure 6. Basic business model

All the main activities triggered by the order within the bakery are shown in Fig. 7.

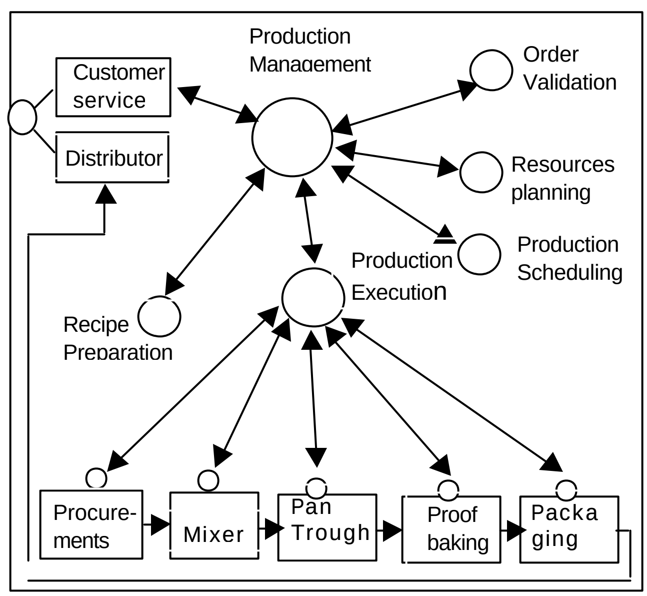


Figure 7. Network of nodes in Bakery

The material flow nodes on the shop floor are five serially linked t-Nodes from which a quantitative model can be built to analyse the process. The process capacity of the plant is denoted by Q, whose value can be given for the actual plant (e.g.300kg/hour). The potential difference over the whole process is denoted by P and can be assigned a value related to cost and value. The plant impedance R can be obtained from the formula Q=P/R.

With the same material flow over every t-Node and if the pressure drop is $P_i$ (the value added within the unit), the unit system impedance $R_i$ can be calculated and linked to the node's structural parameters. By this method, the model framework is built for the process being described in a way that makes further analysis and system modification easier and more efficient.

## 5 INTERNET-ENABLED SCADA SYSTEM--CASE STUDY 2

A project was undertaken by the authors for a major public transportation company, aimed at investigating an Internet based system for remote monitoring and control of temperature and escalator lubrication devices in underground stations.

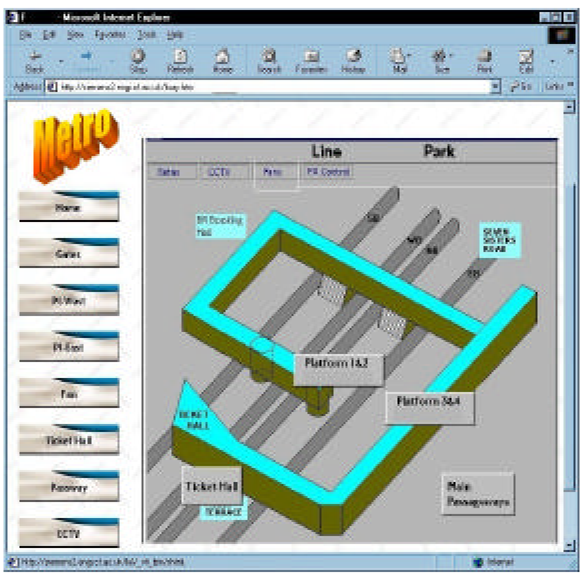


Figure 8. Station page

Fig. 8 shows the page has selected station. From the menu of the pictured page, the fan is selected to run an ActiveX control program (Fig. 9).

There are three system variable indicators for the station temperature, fan speed and escalator lubricant oil level. Several control dialog boxes are provided to enter the parameters such as the setpoint and fan speed etc. A message box is used for reporting the system status and displaying alarm messages.

Multimedia support is provided in the application so those audio and video signals can be exchanged between the station and control centre via the Internet.

## 6 CONCLUSIONS

Internet-enabled automation now shows the potential to become a model for manufacturing enterprises. The distributed Internet server, either as a module in a large computer system or as a unit embedded in field devices, will act as the interface port for a process functioning units. The Internet can integrate distributed objects and every aspect of production activities forming a highly harmonised network of nodes system, which can be modeled and analysed with a simple network of nodes model.

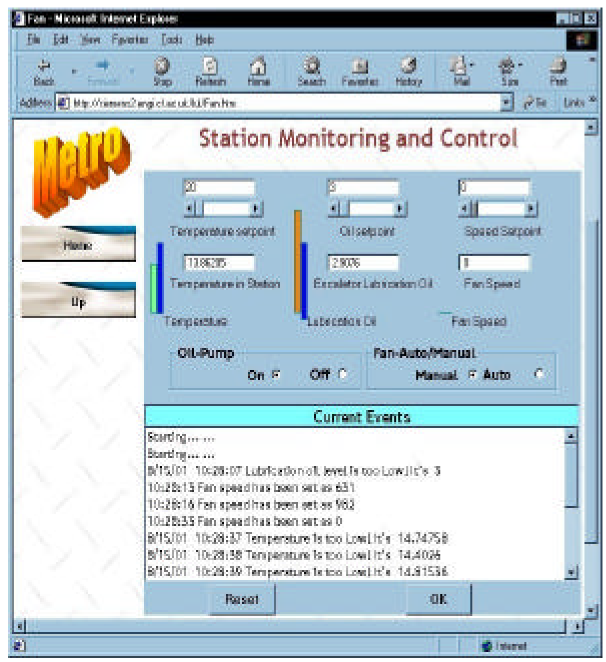


Figure 9. Control interface.

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