PMC Consulting.
Bradford, ON
V6Z 2H3

Phone+1 289.231.8660

WWW.PMCCL.COM

mailto:davewr@pmccl.com
(DAVEWR@PMCCL.COM)

Intelligent Manufacturing Systems

Holonic Manufacturing Systems

HTTP://WWW.PMCCL.COM

Copyright Notice

PMC Consulting.
Bradford, ON
V6Z 2H3

Phone +1 289.231.8660

WEB Site:

HTTP://WWW.PMCCL.COM

mailto:davewr@pmccl.com

Contents

Introduction

Many groups and individuals are researching the problem of how to organize the systems in a manufacturing plant and they all seem to have a common goal: Higher Profits through reduced manufacturing costs. The common thread is one of improved system architectures. What does this mean to the manufacturer? What are the hoped for benefits? How will they be realized?

Proposed Benefits

- Higher profits
- Increased Market Share
- New Markets
- Faster development of New Products

Means to Achieving the Benefits

- Lower Costs
- Higher Quality
- Faster Retooling for product change
- Faster Start-up times for product changeovers
- Better Coordination of efforts because of improved information flow
- Faster Plan to Product time
- Lower Manufacturing Cycle times

Traditionally these benefits have been achieved through process improvements. However recent experience (see the MESA white papers at http://www.mesa.org/) is beginning to show that the changes needed to improve the current manufacturing practises are more subtle, and fundamental. The changes needed are system architecture changes - not process changes, and not changes in cost accounting methodologies.

The publications of the IMS Consortium, MESA and the AMR (American Manufacturing Research Group) clearly point to a need for the rethinking of how we design and implement manufacturing systems, and the need for the amalgamation of a significant body of the technology into a Manufacturing Execution System.

From what we can see, all of these proposals for a next generation manufacturing framework propose a modular approach to the problem, and an architecture that is forgiving to companies that already have a large investment in older generation systems. According to MESA, AMR and the HMS, these new systems must be modular, object oriented systems that promote agile manufacturing techniques. But is this possible - and if so, how?

Our belief is that these new agile manufacturing systems are possible if you address certain key elements, of which the information sharing or communications ability of the component systems is the most important. Since the systems are by necessity diverse, and bridge technology generations, we are going to treat this as a fundamental premise, and state that any solution which will be widely adopted must successfully address this point.

In summary, we will assume that the previously stated benefits are the goals of the R&D efforts. Second, we will also assume the following points:

- A messaging and data communications technology will be the heart of the improvement.
- MES technology will become an important part of the entire Enterprise Resource planning system.
- Modular (Holonic) systems will play an ever increasing role (No matter

what they are called.)

- Robotic systems will play an ever increasing role
- The various proposed systems architectures will converge to similar - if not identical - structures through necessity and because of technological constraints.

The modular architecture has been arrived at by a number of groups, and we now believe it is a foregone conclusion that all next generation manufacturing systems will adopt this philosophy because of the inherent benefits of these types of systems. The analogy in Information Technology and Computer Science is the Intelligent Agent or Object Oriented Programming technology (OOP) of which so much is heard these days. And, now that the technology is better understood, we are starting to reap the benefits of reduced programming time, and lower maintenance costs on large systems.

If we accept that the modular (Holonic) technology will win the day, then the major issue to be decided is one of the communication methodology to be used by the various system components. In a practical vein you could ask a question like: If we buy your scheduler, how can we be assured that it will talk to our ERP system? How do we know that the planning and logistics systems can access and use the data in a meaningful way. How do we know that your system will communicate effectively and in a timely fashion with our other systems? An interesting exercise is to ask the following question(s) of current and potential vedndors or ERP and MES systems.. *Since I am ready to begin the process of upgrading my current manufacturing system can I choose the components of my system at will? - or - Do I have to establish an integration project to combine the programs I choose into a single working entity? Will the ERP talk to the MES and will both talk to my planning software, and can I plug the SCADA system into the Shop Floor data collection system?* We will simply say no, and leave it to you to test the conclusions.

However, we will make one last point for those who say that ABC Co. can provide one stop shopping for the complete Enterprise manufacturing system. The question you should ask your system vendor is not: *Do you have one stop shopping?* - but rather as the AMR puts it: *Do you have one stop shopping through alliances and service organizations?* So, even the companies that claim to have the total package are putting together custom solutions through vendor alliances. While the integration is tight, it is likely “final” (and custom), and replacing an unsatisfactory piece of the overall package may be difficult at best, and impossible at worst. So, the best solution in the long run will be to choose systems that share a common architecture for data and message interchange. The problem is that these systems do not yet exist.

A significant effort by the European and Japanese groups at the HMS, and by our company, has been to develop such a data interchange and synchronization system which will accept “pluggable” intelligent agents into the manufacturing system.

The next technological advance will be in communications and messaging - because it must be so to advance the state of the art.

Holonic System Architecture

A Holonic Manufacturing System (HMS) integrates the entire range of production activities in a manner that provides a dynamic, agile manufacturing system. (See figs. 1. & 2.) An HMS is built on autonomous, intelligent cooperative building blocks (Holons). An HMS is capable of reorganizing itself and rescheduling the resources of the system to deal dynamically with external or internal change. Because the HMS adapts quickly to change the promise is one of agile manufacturing at a low cost.

Because these goals are consistent with that of a good Manufacturing Execution System (MES), ACSI has chosen to combine the architectural philosophy of Holonic systems and the MESA vision. To this end, we have developed our scheduler's and data collection agents so that each part of our system is modular, and can operate when other parts of the systems are not functional, and can re-synchronize and reestablish cooperation as the system is restored to full functionality. This behavior is very critical in shop floor data collection where accidents due to the nature of the industrial environment are relatively common place. Cable breakages, power outages, and damaged files due to inopportune or improper shutdown of equipment is common place. For example, the data collection modules in ASAP-RTS diagnose the network state upon start up or restart and examine and repair damaged data files. In the case of a malfunctioning network, the system uses its last good copy of the plant schedule and resumes operation. When the network restarts, the system reestablishes data synchronicity. The scheduling and data collection is designed so that the system can deal with dynamic rescheduling (perhaps due to breakdown), communication failure, or parts shortages. Modern distributed data base systems were a necessary precursor to this model. Thus the system can operate, self diagnose and cooperate as is possible without constant human intervention.

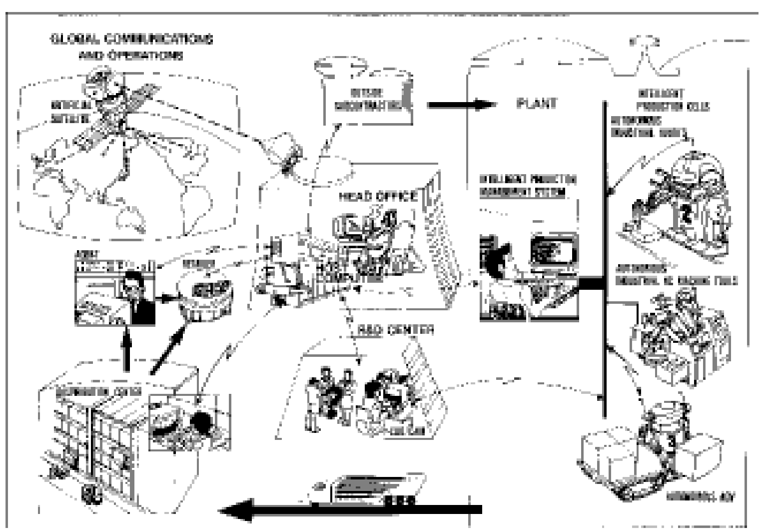


Figure 1. The HMS Vision

Background

Many people have come to recognize that incremental improvements in industrial automation and production technology are not sufficient in order to cope with steadily increasing requirements from the market place. Global competition and socioeconomic trends are forcing change on the manufacturing companies, and the work force they employ.

The Issues

- Highly educated workers prefer to be employed in tertiary industries leaving a shortage of skilled workers to deal with the ever more sophisticated manufacturing work place.
- Internationalization of markets and manufacturing sites creates a need for product and process standardization.
- Consumers demand higher quality, lower prices and customized products with a shorter design and delivery time.

Barriers

- Islands of automation have been installed ad-hoc with out standardized interfaces.
- Manufacturing systems and technologies are not reusable, and the cost of technology transfer is too high.
- The operational systems are inflexible and factories can not quickly change production volume, product design or the current products being built without a major systems redesign.

Holonic Manufacturing Systems

In January of 1990 the Intelligent Manufacturing Systems Program was initiated to: “Develop manufacturing systems which are flexible, adaptable and reusable in different environments.”

The Holonic Manufacturing Systems Consortium was formed within the IMS with the aim of providing a systems architecture to meet the demands of modern decentralized manufacturing systems built from a modular mix of (semi-) standardized, autonomous, cooperative and intelligent elements that allow for:

Faster and more reliable design and implementation of new and/or adapted manufacturing systems where designs are characterized by a large degree of scalability and extensibility.

Scalable automation means;

- The efficient reuse of manufacturing systems, including recycling;
- Quicker, self organized adaptation to changes in the product design and required production volume;
- Shorter lead times (faster change over);
- More stable operation because of built in capabilities for monitoring, diagnosis and quality assurance;
- Graceful, incremental transition from current manufacturing systems to fully Holonic Systems. (Multi-tier systems architecture)

Functional and structural concepts of HMS are derived from general concepts of other areas as biology, psychology and social sciences. This paradigm combines the natural concepts of hierarchical systems and the integration of autonomous, cooperative intelligent elements in distributed systems. HMS concepts are based on the pioneering work of Arthur Koestler in the late 1960’s on the modelling of biological and social systems as systems which consist of self-contained units, capable of functioning independently but nevertheless being dependent on other units. The structure of these systems was characterized by a hierarchy of these units, and these units were called

Holons. The word **Holon** is a fusion of the Greek word ‘holos’ meaning whole and the suffix ‘on’ denoting a particle, as in neutron, proton, etc. These concepts were first extended to manufacturing systems in Japan in the late 1980s, and were further refined and systematized in Test Case 5 of the IMS-Feasibility Study.

The Holonic Model

Whereas conventional manufacturing system architectures are modelled along hierarchical lines with command-obey relationships, Holonic architectures are modelled using whole-part relationships. It differs in the following aspects:

- An HMS is composed of Holons. Each Holon is a system building block which is autonomous and cooperative. A manufacturing Holon may perform a manufacturing step, transport, store and/or validate information and physical objects. The Holon consists of an information processing part and often a physical processing part, and can be part of another Holon (i.e. Hierarchical).
- An HMS is organized as a Holarchy, which defines the basic rules for cooperation of the Holons and thereby limits their autonomy, and which is inherently a lean organization without hierarchies
- An HMS is, however, not organized in a fixed way, but organizes itself dynamically to meet its goals, and adapts itself to changes in its environment or itself. Thus it can also organize itself in temporary hierarchies.
- An HMS integrates the entire range of production activities from order booking through design, manufacturing, and marketing to realize the agile manufacturing enterprise (fig. 1. and fig. 2.).

<u>HMS’s have the potential to provide the following operational benefits:</u>

- HMS’s are capable of rapid self-reconfiguration in response to the change and uncertainty in the manufacturing environment.

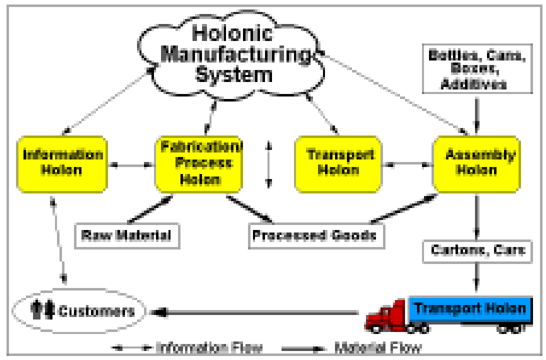


Figure 2: *The general concept of HMS*

- The role of the human is explicitly taken into account in HMS architecture, thereby enabling enterprises to maximize the use of human intellectual skills and flexibility.
- The incorporation of human and machine intelligence into Holons, and their inherent cooperative behaviors, will enable the formation of “virtual companies” both within and across enterprise boundaries.
- Holons can be introduced in an incremental manner into the current manufacturing environment

<u>But moreover, *Holonic* means and implies:</u>

- **Integration and Decentralization** of the diverse resources of the enterprise into the System. This is already the traditional focus in the CIM approach; but in HMS it is the Holonic philosophy which generates the rules for this integration.

Graphical Representations of Holonic Models

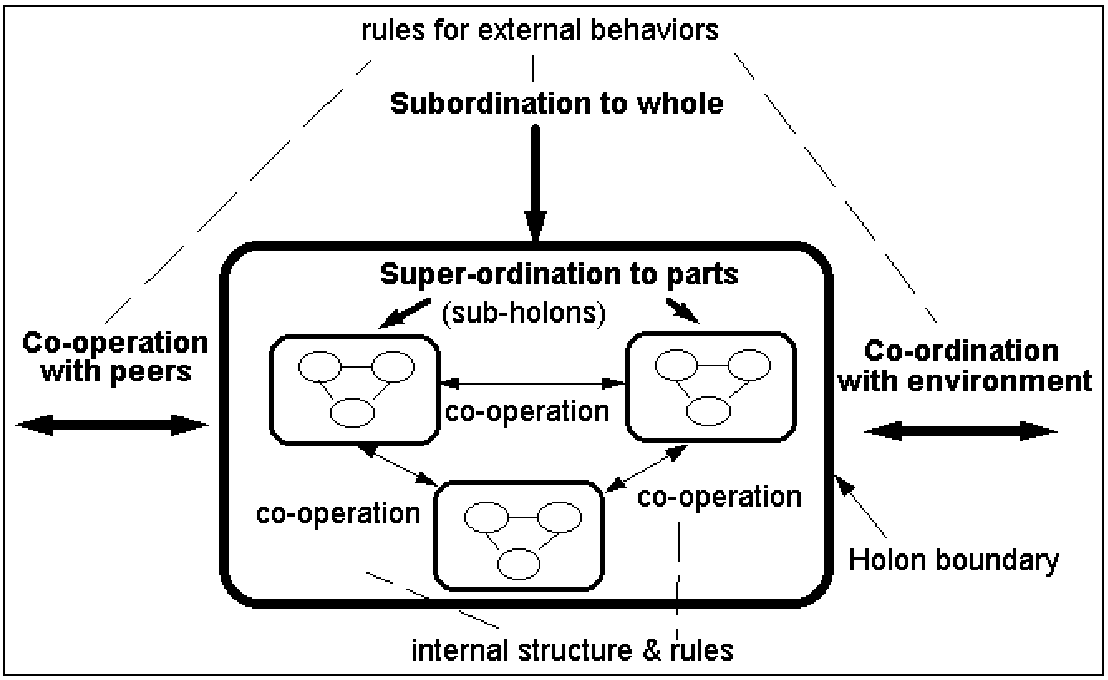


Figure 3. The "Social Contract" in a Holarchy

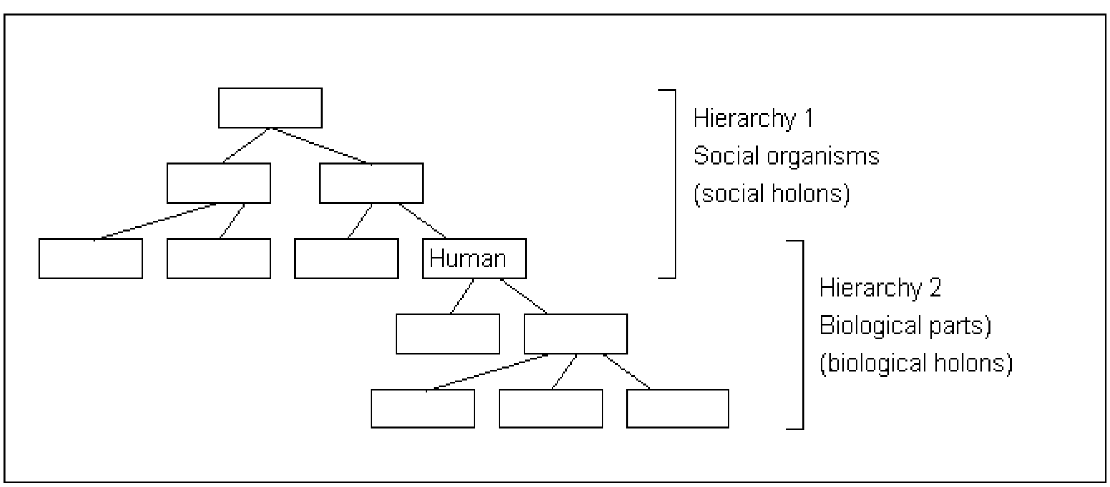


Figure 4. Different Holonic Hierarchies

- **Human Integration**. In CIM systems the human operator was often considered a disturbance in automation (a necessary evil), whose influence needed to be restricted to narrowly defined inputs and mechanical functions. In general there is little doubt that the ultimate objective of CIM is to dispense with the human operators; the fully automated *lights out* plant. HMS on the other hand is also strongly influenced by the idea of Human Integrated Manufacturing and takes the view that the human operator has unique skills and that these skills must be exploited and enhanced by the technical system. By being more responsive to the needs of the work force, their human (and unique) intelligence can be optimally utilized and both productivity and job satisfaction can be increased. HMSs allow the flexible reaction of a production system to socioeconomic requirements by allowing a *suitable degree of automation*. The decision *automation or not* is now a permanent optimization process where the structures and elements of a manufacturing line are continuously changed.
- **Synergy**. Holons must preferably cooperate with other Holons to exploit fully all their capabilities.
- **Modularity**. Each Holon has interfaces for interacting with a range of other Holons, not just one or two dedicated interfaces, and to permit a simple upgrading of the HMS by replacement of Holons. This is in effect the driving force behind the move to object or agent technology in the Information Technology field.
- **Improvement**. A HMS is not only improved from external sources, i.e. by engineering teams which develop and install new methods, software, equipment, etc., but also from the Holons built-in capabilities such as self-learning and adaptation without external support.
- **Fault Tolerance.** Since an HMS has the ability for each of its modules to work independently or within the web of systems, it provides a highly reliable and fault tolerant architecture. When implemented with messaging and transaction protocols the ability to provide string fault tolerance is inherent in the architecture.

Characteristics of a Holon or Subsystem

Autonomy

According to Koestler's concepts, applied to the domain of manufacturing, the manufacturing Holons are members of a hierarchy in which each member is a semi-autonomous closely integrated subsystem. In order to function as semi-autonomous subsystem, it must be equipped with self regulatory and control components [4, p.97], and enjoys a form of self-government [4, p.64]. "Its operations must be guided by its own fixed canon of rules and by pointers to a variable environment" [4, p.97], i.e. by its own pre-defined and self-adapting control. The activity of a holon can be triggered and switched on or off; "but once triggered into action, it will follow its own course. No higher echelon in the hierarchy can interfere with the order of its operations, laid down by its own canon of rules". E.g. "The organelle is a law unto itself, an autonomous holon with its characteristic pattern of structure and function, which it tends to assert, even if the cell around it is dying" [4, p.64]. More complex holons have different types of coordinating centres and self-regulatory devices.

The JEIDA study [2, p.56] expresses thus the autonomy of a manufacturing holon as its feature to control its behaviour by itself independently of external control or to behave on a rule established by itself. This may include:

- Capacity as slave to behave correctly during a range of time, under a command given by its master. Under ordinary conditions a Holon functions under its own initiatives - i.e. it follows its own internal set of fixed rules and/or deals with flexible strategies.
- Basic functions necessary to accomplish its manufacturing functions/goals, may be: processing, assembling, testing, conveyance, calculation, data storage, communication.
- Capacity to control its conditions continuously. So it can detect extraordinary conditions immediately, diagnosing details and extent of any trouble, and separating the sub-holon in trouble without affecting any other holons.
- Self-monitoring, autonomous self-diagnosis, self-repair and self-restoration for unmanned operation or fault tolerance.
- Capacity to metamorphose, changing components or internal organisation to change or improve its capabilities.
- A preparation function independent of the total system, and an off-line learning function and a self-organisation function.
- Capacity to support a job other than its original (in alarm condition) or to replace an other machine, when the behaviour of the master is wrong or the neighbouring machine is behaving incorrectly.
- The ability to change the order of jobs and steps to accomodate new priorities, or current problems.
- Capacity to understand targets or goals of the total system and principally of the holon of which it is part of.

Cooperation

According to Koestler cooperation of holons is expressed in their capability of subordination to the whole and their integration tendency. The holon acquires by integration all or a subset of the goals of the whole as its own, shared goals. The cooperation capabilities permit the composed holon/holonic system to be autonomous on its higher level and to be integratable into an even higher holon. Holons may have thus inherent goals as part of its nature, i.e. inherited from its class, as manufacturing holon or as a more specialised holon, as well as acquired goals by the 'is-part-of' relation. Its cooperativeness within a greater holon is measured by the alignment of its goals and capabilities to the goals (properly decomposed) of the particular greater holon. We consider the goals of a holon as attributes.

In the process of the hierarchical composition of a Holonic system the self-organising capability of holons may make it unnecessary to define all the sub-goals of the system in advance. How the holons acquires the goals of the super-holon is not defined by the Holonic theory. It is part of its self-organising capability (of the super-holon). It may be by allocation/assignation by an other controlling entity/holon within the super-holon or by negotiation of cooperative arrangements with their peers, if holons can understand the higher level goals and decompose them into lower-level goals, instrumental goals, which they can accomplish with their capabilities.

The JEIDA study expresses the cooperativeness of the holons by following possible features [4, p.56]:

- Capacity to recognise the conditions of neighbouring holons and the total system, and conceptual targets at any time.
- Support of neighbouring holons of the same level.
- Capacity to support a neighbouring holon in trouble according to given criteria under its own initiative.
- Capacity to report its condition to the total system and to neighbouring holons.
- Bidirectional communication with the total system, with holons of one rank above, with neighbouring holons.
- Easy entry and separation from the total system. Which gives the characteristics of fault tolerance and ease of system reconfiguration.

Intelligence

Holons can accomplish their goals in a mechanised way, i.e. following their fixed rules. In this case a forecast for the reaction of the system is possible, if we know its actual state and the incoming events and triggers. Thus, the autonomy of the system and its capability of cooperation can be just a mechanised/determined reaction to the incoming signals.

The possibility to deal with flexible strategies, i.e. to behave problem solving to decide between different alternatives, and to react by a changing environment gives the autonomous holon the freedom, which requires a degree of intelligence. Examples are highly autonomous manufacturing holons which select path, route, speed and the picking up of materials and products independently [2, p.55].

The intelligence as the capability to deal with flexible strategies shouldn't be set equal to the human intelligence in usual sense. This capability can be found also in the biological or crystal holons in the generation process [4, pp.63, 342]. In Holonic manufacturing system the realisation of intelligent holons in the proper sense is still given by using the intelligence of its human components to decide between the flexible strategies.

At the actual stage of the HMS research the concept of intelligence is thus applied to holons as the

- capability to acquire and use knowledge (Historical Data), to develop or refine goals, and to develop strategies and make decisions how these system goals may be achieved.

In this sense intelligence includes the powerful searching for and integration of knowledge and the planning, direction and control of activities in the achieving of goals.

Developmental Modelling for HMS

Incremental development

Incremental development means a strategy to develop the system step by step, beginning with its core and its most important functions. As the right path becomes clear, by a better understanding of how the system should function, new steps are added. In this way the system is incrementally enlarged until the desired level is reached. Such an incremental strategy also provides faster feedback in the development process.
The greatest advantage of incremental development strategy is the accelerated feedback to the development process.

This means especially:

- more "learning cycles" in a defined period;
- quicker response to committed errors and wrong assessments, and;
- better control of investments.

Potential disadvantages of the incremental process may be reduced by careful analysis and therefore minimize the potential problems of not having a detailed long term strategy. However, the ability to adapt the system continuously and quickly may be more important that understanding the exact methodology to achieve the long term goals.

Indeed, the incremental development model seems the most suitable for HMS technology because a step by step optimization fits well to complex, interconnected system, in which complex interaction of very different system elements/holons is required, and it is probably not even possible to understand all the ways that interconnection will occur as the system develops. Furthermore the incremental model fits well to the future challenges of always faster changes referring to market demands, technological standards, quality demands. Figure 5. shows the incremental model based on the incremental delivery process described of Gilbs [20].

Continuous improvement (Kaizen)

Kaizen means continuous *stepwise improvement.* Improvement may be done stepwise as a sequence of small steps, i.e. as Kaizen, or as *innovation*, i.e. as the drastic improvement by investment for a new technology. The improvement starts with the problem identification and ends with the solution of the problem, as shown in figure 5. On this way, Kaizen may be considered as a method for problem solution. The improvement increases by each problem solution.

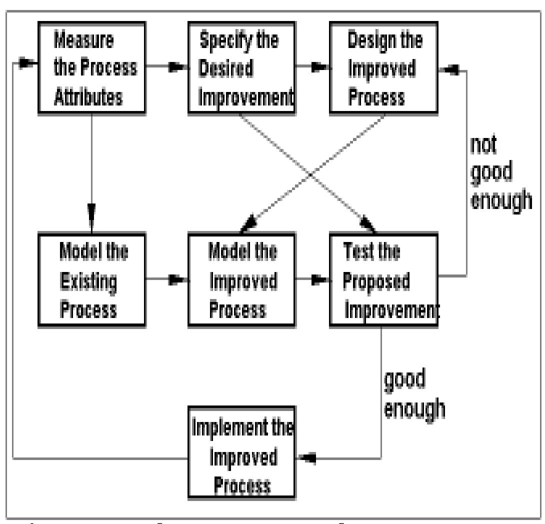


Figure 5: *The incremental HMS engineering process*

Kaizen focuses on a process oriented quality control, in contrast to a result oriented control, and requires the continuous effort to improve the processes. Kaizen uses a set of methods and tools as QC (quality control), SQC (statistical quality control), QC-circle and TQC (total quality control). The success of an innovation step is guaranteed with the application of Kaizen after each innovation step.

The incremental development strategy is characterised by the effort for continuous improvement. Also maintenance may be considered itself as a specialisation of system development. A system normally develops through changes. New development is a special case. It constitutes a change from nothing into something. Thus, system development and maintenance is a process of progressive change as shown in figure 6. Also the status quo of a system can be maintained only with continuous effort, i.e. with Kaizen. Therefore, Kaizen can be considered as an engineering process for system development as well as for maintenance. As explained below in this chapter the Kaizen model seems suitable as essential element of the HMS engineering process model.

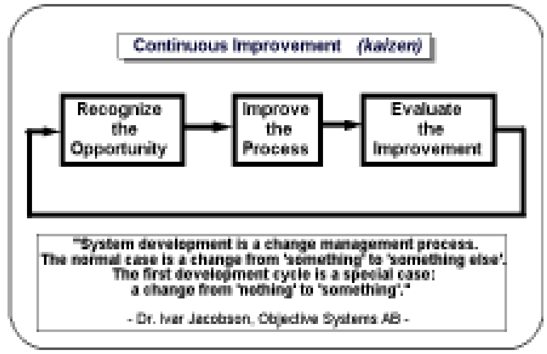
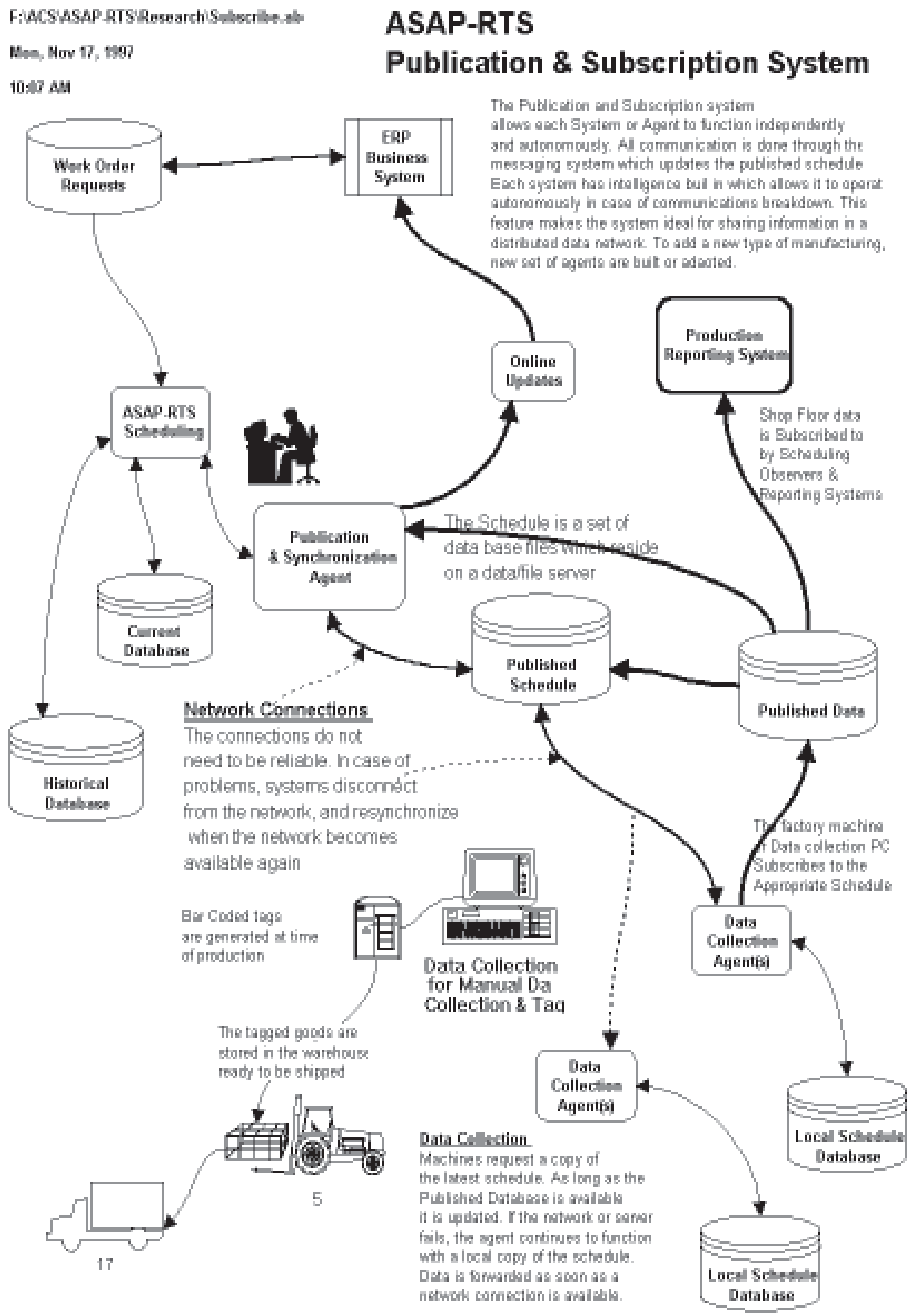


Figure 6: *Continuous improvement model*

Publish/Subscribe

Distributing Schedule information in a distributed computing (database) environment can be a significant challenge. The Publish/ Subscription method offers tremendous freedom from the necessity to maintain reliable links on a wideflung corporate network, or even a local area network where the plant operations have been know to experience reliability problems due to the industrial environment. This architecture also fits well with the HMS distributed architectural model.
In the ASAP-RTS system, data is published, by updating the "published" schedule data file. This data file is in a known location in the system, and can be accessed by running an install program and "pointing" the data collection reporting system at the data. Each station then updates the data in the published schedule as production data is recorded. Each station also logs, or "publishes" transaction data to the central data logging system whenever it is available. In this manner, data synchronization is maintained throughout the entire system.
Data synchronization is maintained whenever ASAP-RTS can determine that a network is present. Whenever the network is not present, data is stored locally until the network is available again. Then, the synchronization is performed, and data is updated at the central data storage location.
All ASAP-RTS data is published to the network including the Quality Control schedule, and the current Bill of Materials for the Work in Progress (WIP). This methodology ensure that data remains consistent throughout the manufacturing process. Documents, drawings and any other required material can be published and maintained through the synchronization process as well.
The messaging system that ASAP-RTS employs is based on communication through a data file installed on a file server. Modest changes would permit the use of a data server on a UNIX or Windows NT system.

After three years of working with and refining the Publish/Subscribe system that was built into the original ASAP-RTS system, we are able to say that this methodology is reliable, and lends itself well to fault tolerance enhancements. The fault tolerance and file repair mechanisms were installed to deal with the issues of power outages and occasional computer system failures at the shop floor level. The fault tolerance mechanism is progressive, and supports rebuilding of individual transactions, or will progress to complete rebuilding of the local data and schedule files from the most recent published data. The fault tolerance mechanism based on the Publish/ Subscribe mechanism has totally eliminated the need for emergency file repair, and has totally eliminated the need for night-time service calls. Problems with data still occur, but these problems are dealt with during normal working hours, and have not resulted in any significant downtime over the period since the fault tolerance was installed.



F:\ACS\ASAP-RTS\Research\Subscribe.ab
Mon, Nov 17, 1997
10:07 AM
ASAP-RTS
Publication & Subscription System
The Publication and Subscription system allows each System or Agent to function independently and autonomously. All communication is done through the messaging system which updates the published schedule Each system has intelligence buil in which allows it to operat autonomously in case of communications breakdown. This feature makes the system ideal for sharing information in a distributed data network. To add a new type of manufacturing, new set of agents are built or adapted.
Work Order Requests
ERP Business System
Online Updates
Production Reporting System
ASAP-RTS Scheduling
Shop Floor data is Subscribed to by Scheduling Observers & Reporting Systems
Publication & Synchronization Agent
The Schedule is a set of data base files which reside on a data/file server
Current Database
Published Schedule
Published Data
Historical Database
Network Connections
The connections do not need to be reliable. In case of problems, systems disconnect from the network, and resynchronize when the network becomes available again
The factory machine of Data collection PC Subscribes to the Appropriate Schedule
Bar Coded tags are generated at time of production
Data Collection for Manual Da Collection & Tag
Data Collection Agent(s)
The tagged goods are stored in the warehouse ready to be shipped
Data Collection Agent(s)
Local Schedule Database
Data Collection
Machines request a copy of the latest schedule. As long as the Published Database is available it is updated. If the network or server fails, the agent continues to function with a local copy of the schedule. Data is forwarded as soon as a network connection is available.
5
17
Local Schedule Database

Appendices

Acknowledgment

Some of this material was taken from publications of the HMS and the IMS group and modified for the purpose of this information paper.References 7-16 are proprietary information available only to the HMS Consortium.

Contacting PMC Consulring

Any changes are the responsibility of PMC Conulting and do not reflect on the policy or the directions of the IMS or the HMS consortium.

This paper was assembled by Dave Robinson. He can be reached at:

PMC Consulting
Bradford, Ont.
V6Z 2H3
CANADA

HTTP://WWW.PMCCL.COM

Phone: +1 289.231.8660
mailto:davewr@pmccl.com

Contacting The IMS

For more information about the HMS and the IMS you can contact the IMS or Alan Martel through the IMS Canada Web Site.

http://www.imscanada.ca/introduction.htm

IMS Canada Secretariat
135 Dunbarton Court, Ottawa ON
K1K 4L6,
Canada

Telephone: +1-613-744-1938
Fax: +1-613-749-2001

Email: amartel@imscanada.ca

Annex B - Key References

[1] Suda, H. ”Future Factory System Formulated in Japan (1)”; Techno Japan, Vol.22, (1989), No.10, pp.15-25

[2] Suda, H. ”Future Factory System Formulated in Japan (2)”; Techno Japan, Vol.23, (1990), No.3, pp.51-61

[3] N.N.: ”Joint International Research Programs into an Intelligent Manufacturing System”; IROFA, January 1990

[4] Koestler, A.: ”The Ghost in the machine”; Arcana books, London (1989)

[5] Deen, S.M.: ”From Agent to Holons”; England, Keele University (1993)

[6] Warnecke, H.J.: ”The Fractal Enterprise”, Springer-Verlag, New York (1993), ISBN 0-387-56537-X

[7] Christensen, J.H.: ”System Components of autonomous Modules and their distributed control”; IMS-Test Case 5: Holonic Manufacturing Systems, Allen-Bradley,

[8] Christensen, J.H.: ”Design Support Requirements”; IMS-Test Case 5: Holonic Manufacturing Systems, Kingston, Allen-Bradley, June 24, 1993.

[9] Christensen, J.H.: ”Engineering Support requirements” IMS-Test Case 5: Holonic Manufacturing Systems, Kingston, Allen-Bradley, June 24, 1993.

[10] Ohnishi: ”Holonic Properties based in Input-Output Relations”; IMS-Test Case 5: Holonic Manufacturing Systems, Yokohama, June 7, 1993.

[11] Sugimoto: Holonic manufacturing system, HMS/ CWP4SC(Sugimoto)1. Yokohama, June 7, 1993.

[12] Hara: Holonic manufacturing system, HMS/ CWP4SC(Sugimoto)1. Yokohama, June 7, 1993.

[13] Sugimura: Keywords describing HMS, HMS/ CWP4SC(Sugimura)1.

[14] Rawden, A.:
"Definition of Needs and Evaluation Criteria"; IMS-Test Case 5: Holonic Manufacturing Systems,

[15] N.N.:
"Sample classification and evaluation criteria"; IMS-Test Case 5: Holonic Manufacturing Systems, WP4-North American Region, Ohio, April, 1993.

[16] N.N:
"WP3 Australian region"; IMS-Test Case 5: Holonic Manufacturing Systems, , Melbourne, 17/6/93.

[17] Akao, Y.:
"Quality Function Deployment. Integrating customer requirements into product design"; Productivity Press.

[18] Zultner, R.E.:
"Software Quality deployment. Adapting QFD to Software"; Zultner&Company, 1989.

[19] N.N.:
"Computer integrated Manufacturing. Open System architecture."; PrENV 40 003. 1990

[20] Gilb, T.:
"Principles of Software Engineering Management"; Addison Wesley (1988).

[21] ISO TR 10314, part 1:
"Reference model for Shop Floor Production Standards";

[22] N.N.:
"MAP/TOP Directory for Manufacturing Enterprises"; Emug European MAP/TOP User Group (1992)

Glossary of Terms

ALAP As Late As Possible. (Backward Scheduling) - Allocate the production so that the job finishes on the due date.

Algorithm - A method of solving a problem — a step-wise solution.

ASAP (Forward Scheduling) - Allocate the job in the first available time slot.

ASAP-RTS - The PMC scheduling system. (ASAP Scheduling and Production – Real Time Systems)

Bottleneck - The machine that sets the production pace.

Constraint - A constraint is a restriction – as in - it must be on a certain machine, or in a certain sequence, or done by a given date.

Constraints, Theory of - See the series of books by Goldratt about how production can be improved by always finding and improving the slowest or most restricting process.

Data Highway - An Allen-Bradley term for the Ethernet system used on their PLC's.

ERP (Enterprise Resource Planning - System) - A software system used for manufacturing. Many companies who used to produce an MRP II package are now claiming that they are a wider more encompassing ERP system.

Ethernet (See Data Highway and TCP/IP) - A data communications protocol and hardware description for communicating on LANS – closely linked to TCP/IP and the Internet.

Finite Capacity Scheduling - A scheduling methodology that takes into account the rates of the machines and the time and resources actually available.

Genetic Algorithm or Genetic Search Algorithm (GA or GSA) - New programming technique used in systems that learn.

Heuristic - A rule of thumb – or assumption about how an algorithm should proceed to solve a problem.

HMS (Holonic Manufacturing Systems) - A holon is an intelligent, independent, autonomous, co-operative unit – for example a human. Holonic systems exhibit these characteristics.

Holon see above.

Holarchy - A hierarchy of Holons. The Holonic philosophy states that machines should be able to organise themselves into systems and behave like humans in an organisation. (There are scientists who believe that this is not necessarily a good thing.)

IMS - The Intelligent Manufacturing Systems Association of which the HMS is a member organisation/project.

Infinite Capacity Scheduling - Most MRP systems do not take into account the actual capacity, but will simply accept new orders, and tell you what you have to order to build these new orders.

Makespan - The total time that a set of orders takes to processed on a (set of) machine(s).

MES (Manufacturing Execution System) - See the MESA WEB page at for a series of White Papers that describe the ideal MES system. They have an 11 point rating system.

MESA or MESA International (Manufacturing Execution Systems Association) See above

MRP and MRP II (Material Requirements Planning) - Originally developed in the late 1960's and 70's as a way of organising manufacturing accounting and planning systems.

Objective Function - This is a mathematical function that defines the goal or objective of the scheduling system.

Optimisation - You minimise time or use of material when you optimise a schedule.

Penalty Function - Certain actions are acceptable but still undesirable when you schedule or build a product. A penalty function attempts to persuade the algorithm - by assigning a bad score to an action - not to do things in certain ways - unless the alternative is even worse.

PLC Programmable Logic Controller - A low level machine controller. Programmed by ladder diagrams.

Process Industry - Any industry that uses measurement as opposed to discrete units when assembling goods. E.g. Board Plants, Food Processing etc. As opposed to building carburettors – for example – where you can count the parts precisely.

Resource - A machine or worker used in building a good.

Resource Calendar - The availability list for machines and workers.

SCADA (Supervisory Control and Data Acquisition) The supervisor system in a network of data acquisition systems.

Search Space – A mathematical expression for degree of the equation(s) used to solve the schedule.

Tardiness - A term for lateness or earliness of the individual item in the schedule.

TCP/IP Transmission Control Protocol / Internet Protocol - The communication protocol for the Internet and some LANS.