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A study on holonic manufacturing systems and its application to real time scheduling problems

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ABSTRACT

The objective of the present research is to develop an holonic architecture of manufacturing systems. A concept of the holonic structure of manufacturing systems are discussed, and an object oriented modeling method is proposed to represent the data and the activities of the holonic components of the manufacturing systems, such as workpieces, workstations, machine tools, AGVs and so on. Object oriented models are developed to represent simulation models of the holonic manufacturing system for the mechanical products and one for the composite parts of the aircrafts. Prototypes of the holonic real time scheduling systems are developed based on the simulation models, and case studies are carried out.

Keywords

Holonic manufacturing system, Real time scheduling, Object-oriented model, Simulation

1. INTRODUCTION

With advances of manufacturing technologies in both software and hardware, automation of manufacturing systems in batch production has been much developed. The control structures of the manufacturing systems, such as FMSs (Flexible Manufacturing Systems) and FMCs (Flexible Manufacturing Cells), are generally hierarchical. The hierarchical control structure is suitable for economical and efficient batch productions in steady state, but not necessarily so for very small batch productions with dynamic changes in the volumes and varieties of the products.

Functions and capabilities of FA (Factory Automation) controllers have made much progress in the last decade, and individual controllers are now able to share information processing and decision making capabilities in the manufacturing systems. New architectures of the manufacturing systems are therefore proposed aiming at realizing more flexible control structures of the manufacturing systems which can cope with the dynamic changes in the volume and the variety of the products and also the unforeseen disruptions such as breakdown of equipment and interruption by high priority jobs (Okino, 1992), (Ueda, 1992), (Moriwaki, 1992), (Warnecke, 1993), (Iwata, 1994), (Wiendahl, 1994), (Sugimura, 1995), (Wyns, 1996), (Gou, 1997), (Bongaerts, 1997), (Arai, 1997).

Some researches have also been carried out for establishing modeling techniques of the manufacturing systems (Patankarm, 1995), (ISO TC 184, 1989), (AMICE, 1992), (Petrie, 1992). The models proposed provide basic framework for the modeling of the manufacturing systems including the holonic manufacturing systems.

The objective of the present research is to develop an holonic architecture of the manufacturing systems. A concept of the holonic structure of the manufacturing systems is discussed, and a holonic real time scheduling method is proposed in the paper. The main topics discussed in the paper are as follows;
(1) basic architecture of the holonic manufacturing system (HMS),
(2) object oriented modeling of HMS, and
(3) holonic real time production scheduling of the manufacturing systems for mechanical assemblies and composite parts.

2. BASIC ARCHITECTURE OF HOLONIC MANUFACTURING SYSTEM

The holonic manufacturing systems are composed of sets of autonomous and cooperative components called holonic components, which include such components as workstations, AGVs, storages and workpieces. The individual holonic components

have functions of infor-
mation processing, deci-
sion making and commu-
nication, and also material
processing for the manu-
facturing.

Figure 1 shows a basic
concept of the holonic
manufacturing systems.
The physical model de-
scribes the holonic com-
ponents of the manufac-
turing systems and the
flows of the materials in
the systems. The logical
model gives the holonic
information processing
and the decision making
structures in the systems.
As shown in the figure, the
production control of the
system is carried out
through the decision
making of the individual
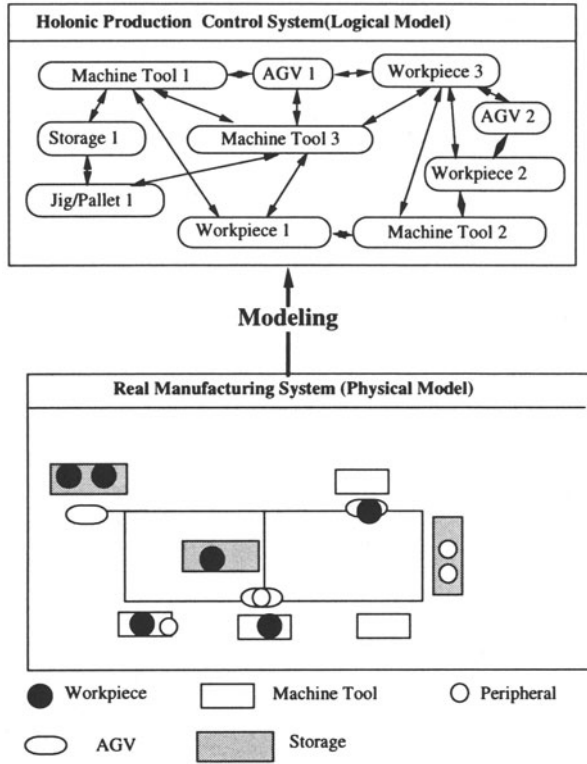holonic components and
their cooperations.

Figure 1 Holonic manufacturing systems

The holonic components of the manufacturing systems are basically divided into
two classes based on their roles in the manufacturing processes; they are,
(a) Manufacturing equipment which transforms the blank materials to the finished
products, and
(b) Workpieces which are transformed by the manufacturing equipment.

The manufacturing equipment includes all the equipment, such as machine tools,
assembly stations, tools, jigs, AGVs, and storages. Blank materials, parts, sub-
assemblies and assemblies are typical examples of the workpieces.

The manufacturing equipment and the workpieces are required to have holonic
decision making functions to determine their own suitable manufacturing processes
in the manufacturing systems on the basis of their status. The followings summa-
rizes the important decision making functions of the manufacturing equipment and
the workpieces;

(a) Manufacturing equipment
1) Design and modification of manufacturing functions.
2) Operation planning and task planning.
3) Production scheduling.
4) Production planning and MRP (Material Requirement Program).
(b) Workpieces
1) Modification of their shapes, dimensions and tolerances.
2) Process planning.
3) Production scheduling.
4) Production planning and MRP.

3. MODELING OF HOLONIC MANUFACTURING SYSTEMS

An object oriented modeling technique is adopted to represent the holonic compo-
nents which carry out the decision making functions for the production control of
the manufacturing systems. The individual objects have both the data representing
the status and the methods describing the decision making procedures.

Object oriented models are proposed to describe and to simulate the decision
making activities and the communication activities of the holonic components of
the manufacturing systems, based on the investigation of the manufacturing proc-
esses of the products. Two types of manufacturing systems are considered here;
they are, a manufacturing system of mechanical assemblies, and a manufacturing
system of composite parts of civil aircrafts. Schematic illustrations of these two
types of manufacturing systems are shown in Figs. 2 and 3, respectively.

The manufacturing system for the mechanical assemblies consists of machining
shops, assembly stations, storages and AGVs, and the manufacturing processes are
carried out by the batch processing. The objects shown in Fig. 4 are needed to
carry out the production control of the manufacturing systems. In the figure, the
nodes show the objects, and the arcs give the is_a relations and the part_of rela-
tions among the objects. The objects are basically classified into four; they are, the
workpieces, the manufacturing equipment, the manufacturing processes of the
workpieces, and the operations.

The Manufacturing system for the composite parts is basically a line type system,
however, parallel line processing and batch processing are included as shown in
Fig. 3. The objects needed to represent the model of the manufacturing system are
slightly different from the ones for the manufacturing system for the mechanical
assemblies, however, the basic components and their relationships are same as ones
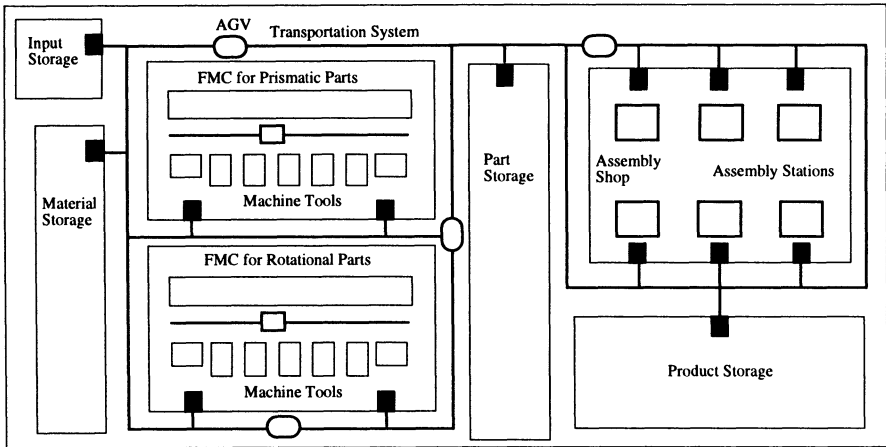in Fig. 4.

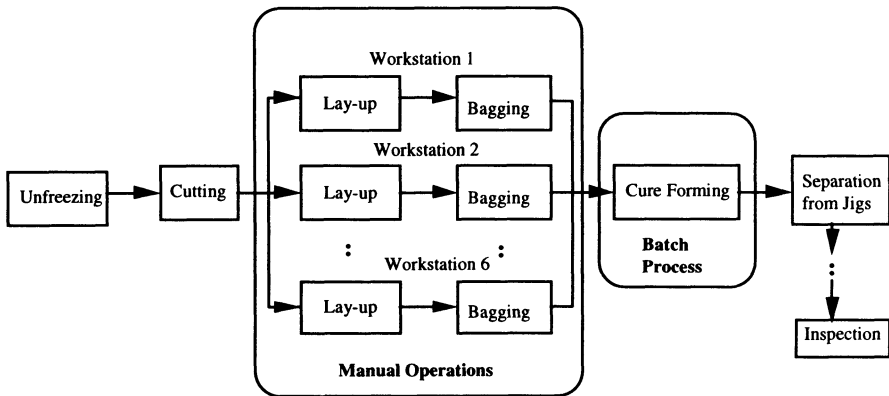**Figure 2** Manufacturing system for mechanical assemblies

Figure 3 Manufacturing system for composite parts

4. HOLONIC SCHEDULING SYSTEM

4.1 Decision Making Structure

The concept of the holonic manufacturing systems is applied to a real time production scheduling systems which is an important problems in the production control. The real time scheduling means that the schedule is determined dynamically only when the status of the manufacturing systems is changed due to the progress of the manufacturing processes and the unforeseen events. Therefore, the scheduling systems only determine the schedules of the manufacturing equipment and the workpieces for very short time period.
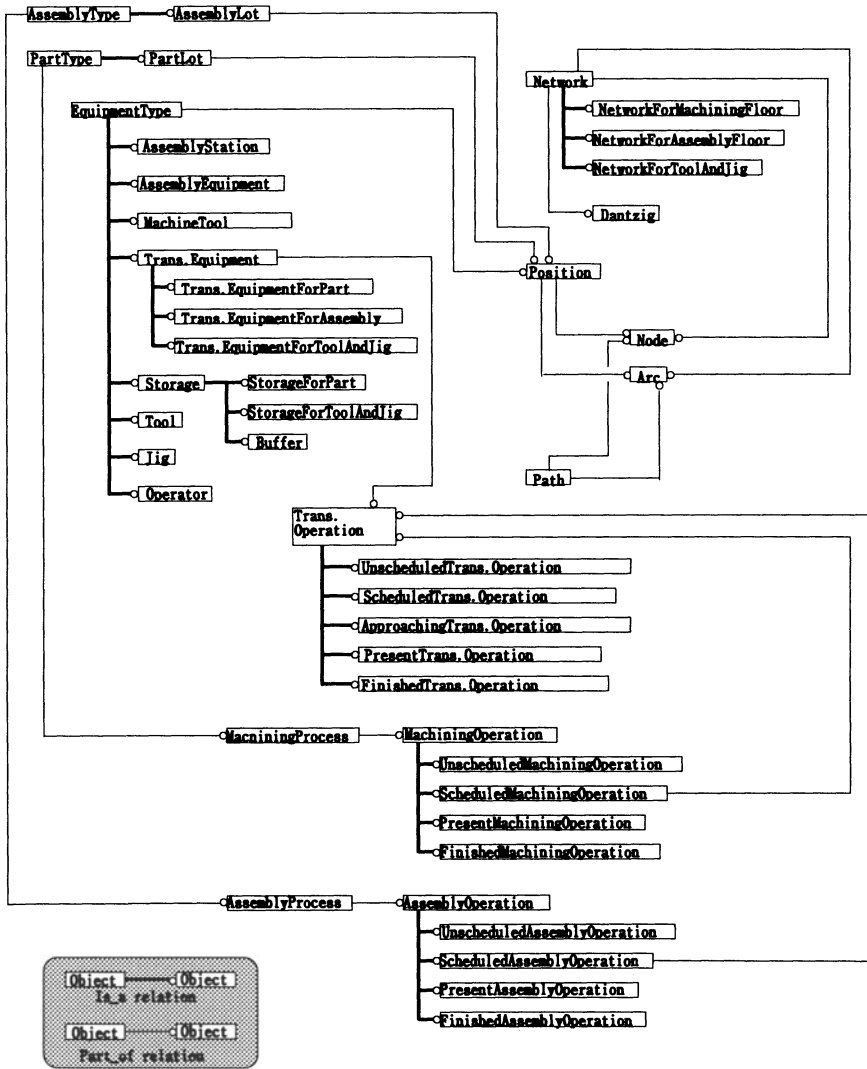
Figure 4 Objects and their relationships needed for production control

The scheduling systems consist of a set of holonic objects representing the work-pieces and the manufacturing equipment, such as the machine tools, the worksta-tions, and the jigs. The production schedule is determined based on the decision makings of the individual holonic objects and their communications. The decisions of the individual objects are made by applying the heuristic rules.

The procedure to determine the schedule is summarized in Fig. 5. The individual objects modify their status, in the first step, if one of the following events occurs;
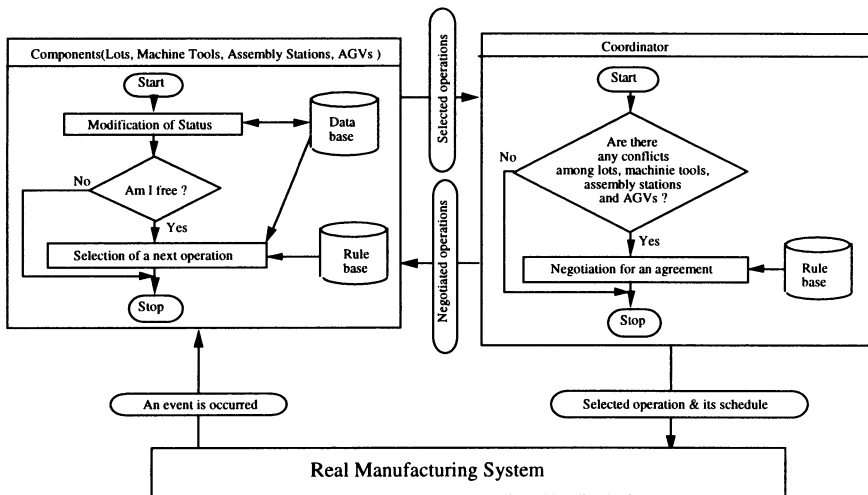
Figure 5 Scheduling processes

(1) an operation of a workpiece/lot is finished,
(2) a workpiece/lot is inputted to the manufacturing system,
(3) a equipment is broken down, or is recovered, and
(4) a status of a workpiece/lot is changed from the normal one to the high priority
    one.

In the second step, all the objects which are free at that time select suitable opera-
tions to be carried out in the next time period of the manufacturing systems based
on their own criteria. The time period means the period between the time when one
event occurs and one when another event occurs. The information about the select-
ed operations are transmitted to the coordinator, and the conflicts among them are
examined. If the conflicts are detected, the decisions of some objects are rejected
and changed by the coordinator. After the coordination, the operations to be carried
out in the next period of the manufacturing systems are scheduled. The procedures
above mentioned are repeated, when the events occur.

4.2 Scheduling Criteria of Components
A rule based approach is applied in the research to describe the decision making
criteria to select the operations to be carried out and to coordinate the conflicts.
The rules of individual objects are described as the methods in the objects. The
contents of the decision criteria of the objects are summarized in the followings.
(1) Lot object
Each lot object has the criteria to select a suitable manufacturing equipment which
carries out the operation of the lot in the next time period of the manufacturing
system. The basic criterion is as follows;

- Select a manufacturing equipment which can finish the next operation of the lot at the earliest time. Where, the finishing time of the next operation is calculated from both the manufacturing time given in the manufacturing operation objects and the estimated transportation time by the AGVs.

The high priority lots must be finished their operations as soon as possible, therefore, the objects of the high priority lots have also the criteria to reserve the manufacturing equipment and the AGVs needed for the future operations of the lots. The criteria to reserve the manufacturing equipment and the AGVs are as follows;

- Select a manufacturing equipment which can finish the operation of the lot in the shortest time, and
- Select an AGV which can transport the lot in the shortest time.

(2) Manufacturing equipment objects
The manufacturing equipment objects have the criteria to select suitable operations to be carried out in the next time period, when they are free at that time. The criteria are summarized as follows;

- Select a operation of the high priority lots, if the high priority lot requires the operations which can be carried out by the manufacturing equipment, and
- Select a operation of the normal lots which can be finished in the shortest time.

(3) AGV objects
The decision criteria of the AGV objects are the rules to select suitable lots which the AGVs transport. The criteria are given as follows;

- Select a high priority lot, if the high priority lot requires the transportation operation, and
- Select a normal lot which requires the transportation operation at the earliest time.

(4) Coordinator object
The coordinator object coordinates the conflicts among the decisions of the lots, the manufacturing equipment and the AGVs. The basic rules of the coordinator object are given in the following;

- High priority is given to the operations of the high priority lots, and
- Select operations which are selected by both the lots and the manufacturing equipment.

4.3 CASE STUDIES
A prototype of holonic real time production scheduling system has been implemented in Smalltalk/Visual Works. Some case studies have been carried out to verify the feasibility of the holonic real time production scheduling method proposed here. In particular, emphasis has been given to clarifying the adaptability of

the holonic system to the scheduling problems of the manufacturing system for the mechanical assemblies and one for the composite parts.

The system for the mechanical assemblies shown in Fig. 2 consists of an FMC composed of four vertical type machining centers and six turning centers, an assembly shop composed of two assembly stations, and a transportation & storage system composed of two AGVs and four storages. One lot of an assembly and the part lots related to the assembly lot are inputted to the manufacturing systems for the case study. Figure 6 shows an example of schedule determined by the prototype system. In the figure, the vertical axis indicate the manufacturing equipment and the lots to be manufactured, and the horizontal axis shows the time. The individual line segments indicates the operations of the individual lots and their schedules. It can be found that the system can generate feasible schedules for the FMC, the assembly shop, and the transportation and storage system.

The other case studies have been carried out for the scheduling of the line production for the composite parts shown in Fig. 3. The manufacturing processes scheduled by the real time scheduling method are shown in Fig. 7. In the figure, the vertical axis indicate the lots to be manufactured, and the horizontal axis shows the time. The individual line segments indicates the operations of the individual lots and their schedules.
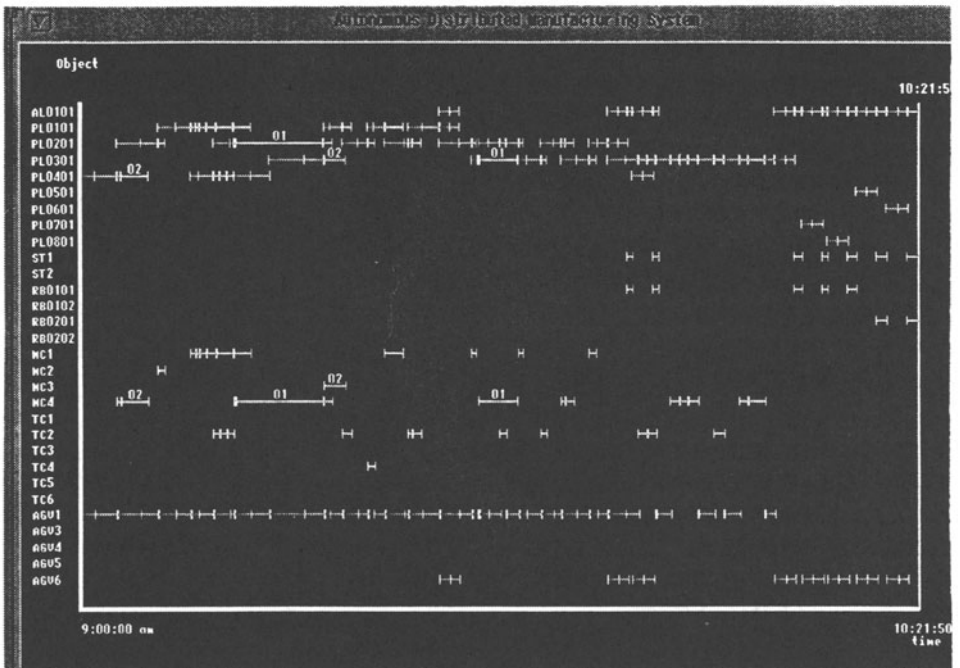

Figure 6 Example of schedule of manufacturing system for mechanical assemblies
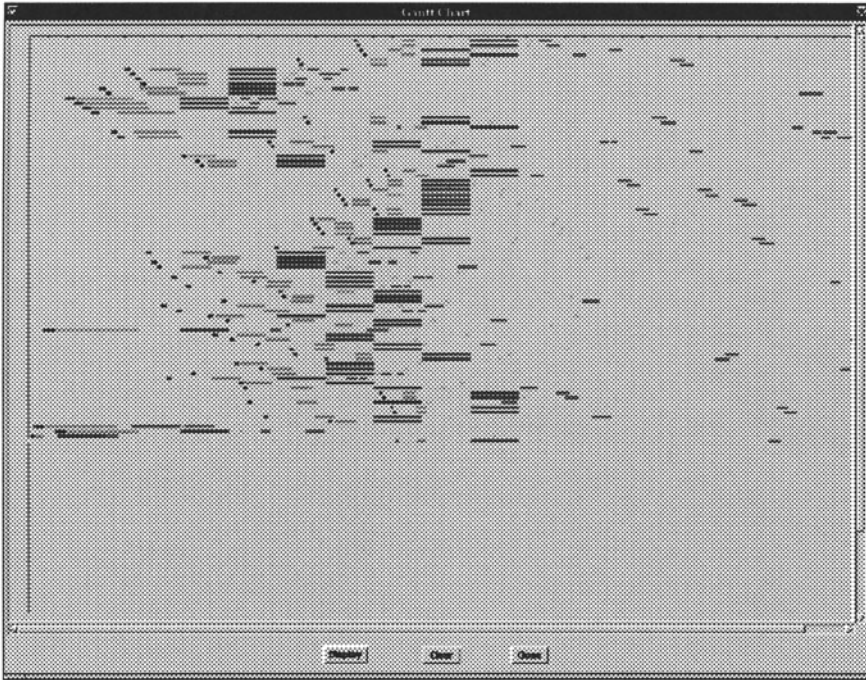
Figure 7 Example of schedule of manufacturing system for composite parts

It is shown, through the case studies, that the holonic real time scheduling methods proposed here can generate suitable manufacturing schedules for the manufacturing systems considered here.

5. CONCLUSIONS

A basic architecture of the holonic manufacturing systems was discussed, and an object oriented modeling technique was proposed aiming at describing the status and the activities of the holonic manufacturing systems. Prototypes of real time production scheduling system were implemented based on the holonic architecture. The following remarks are concluded.

(1) An object oriented modeling method is proposed to describe the information processing and decision making functions of the holonic components.
(2) Objects needed for the holonic real time production scheduling system are established, which represent the components such as the manufacturing equipment, the workpieces/lots, the processes and the operations.
(3) Prototype production scheduling systems have been implemented in Small-talk/Visual Works and applied to some scheduling problems of the manufacturing system for the mechanical assemblies and one for the composite parts.

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7. BIOGRAPHY

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Keiichi Hozumi received B.S. in engineering from Kobe University, Japan, in1970. He is working in Research & Development Division of ShinMaywa Industries, Ltd. from 1970, which company products Aircraft, Factory Automation Related Products, Truck Bodies & Equipment etc. in Japan. He had researched and developed control systems, sensors for Welding-robots and AC motors until 1985. Since 1986, his research interests are simulation and scheduling for manufacturing systems. Since 1997, he is a manager of Production engineering center in his company. He received a ph. D degree in engineering from Kobe University in 1997.