Proceedings of the 1994 Winter Simulation Conference
ed. J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila

DISTRIBUTED SIMULATION MODEL FOR COMPUTER INTEGRATED MANUFACTURING

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ABSTRACT

In this paper, we firstly discuss the necessity of a simulation tool which can handle a large and complex manufacturing system under CIM environment, and then consider problems incurred by developing such a large system model. A distributed simulation model developed on a distributed computer system is then shown to be a promising method to cope with the problems. Lastly, a time bucket method with time warp mechanism is proposed for the synchronization of the distributed simulation and its computational features are investigated by modeling a virtual factory on six workstations connected by the ethernet.

1 INTRODUCTION

Computer simulation is recognized as one of the key techniques for the effective design and operation of manufacturing systems. As the computer integrated manufacturing (CIM) system becomes well equipped in an industry and factories are automated and integrated by computers and information network systems, the terms of design and operations of manufacturing systems becomes to cover wider and more complicated scope than ever. This environment requires that the tools to be used for those purposes need to have enhanced functions to meet the situation.

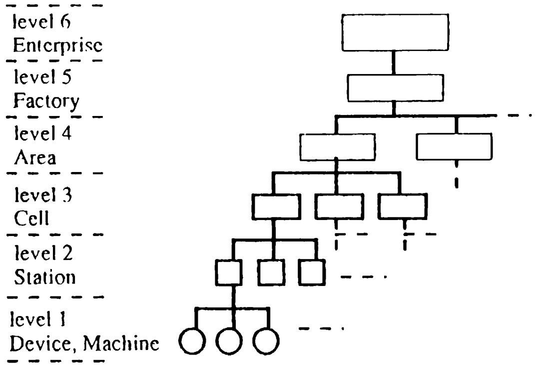


Figure 1: Hierarchical Structure of Manufacturing System

In this study, we investigate basic functions and structure of a simulation system through a discussion on the manufacturing system under CIM environment. The simulation system is a hypothetical factory or industry built in a computer system and serves as a test bed for the evaluation of a new system plan and for the efficient operational decision making at various levels in the factory. We firstly discuss the necessity and requirements for design and operation of manufacturing systems. Then a distributed simulation is proposed as a promising method to satisfy the requirements to certain extent and the basic structure of the system is investigated mainly from the viewpoint of physical distribution in the factory. A synchronization mechanism for the distributed simulation is then proposed and its computational features are studied by an illustrative factory model.

2 MANUFACTURING SYSTEM UNDER CIM ENVIRONMENT

2.1 Structure of Manufacturing System

The structure of a manufacturing system can be represented by a hierarchical one as shown in Fig. 1(ISO/TC184). Under ideal CIM environment elements at various levels are connected each other and can communicate through information networks. At the same time, by automation in the factory most of the machines and equipments are enabled to be operated automatically by the instructions generated by controllers, and transportation systems will carry works and products from one place to the other automatically. All elements in an industry are tightly interrelated information-wise and transportation-wise under such CIM environment. It is not in that level at present, but the interrelation among elements is becoming tighter as more computers and information networks are equipped at various levels of industry.

2.2 Necessity of Overall Performance Evaluation

Considering such situation, it is more important than ever to evaluate the performance of newly designed manufacturing systems in their planning stage or the operational decisions prior to their practice. The structure of a manufacturing system in Fig. 1 may be schematically shown as in Fig.2 at the factory level and lower levels. Ellipses in the factory correspond to the areas and D.M.'s are decision making units. Small circles may correspond to cells constituting an area. Areas are connected by information networks for data exchange and by transportation systems for physical distribution of works among areas. As the infrastructure of computer integrated manufacturing is more equipped, more D.M.'s are connected to the information network and more automated and sophisticated transportation systems, such as AGV's or new logistic systems, are installed. The higher level of automation in the area level will be materialized as well. On the course of this progress, the design of a new system and the decision making for the daily or middle ranged operational planning at the area will require new view points for the evaluation of the effectiveness of the plan.

1) Design of a new system

Most of the effort for the automation in factory was devoted within the area or lower level equipment in Fig. 1. As a result, when a new system is planned to be installed as a replace of former system as shown in Fig. 2, the performance evaluation of the new system at its designing stage was mostly limited to its performance as a stand alone system or isolated system. Typically, in a simulation study of a new FMS we usually assume that the input to the system is a source node generating arrivals of works randomly by a given probability distribution or regularly by a predetermined schedule as shown in Fig. 3(a). Also the output from the system is simply absorbed by a sink node and is not affected by the activity of the transportation system or the succeeding area which needs the output product as its input work.

In practice, the new system is tightly connected to the neighboring areas by information networks and transportation systems and thus both of the inputs and outputs of the system will have a strong influence with the neighbors. This indicates that the performance of the new system must be evaluated not only as an isolated system but also as a subsystem of larger system in its designing stage. The latter evaluation is especially important to reveal the problems incurred in the neighbors by the new system and to point out where to improve for the full utilization of the system. To establish such an evaluation system it will be essential to develop a factory wide simulation system which can describe not only the detail activities of the objective new system but also those in neighboring areas.

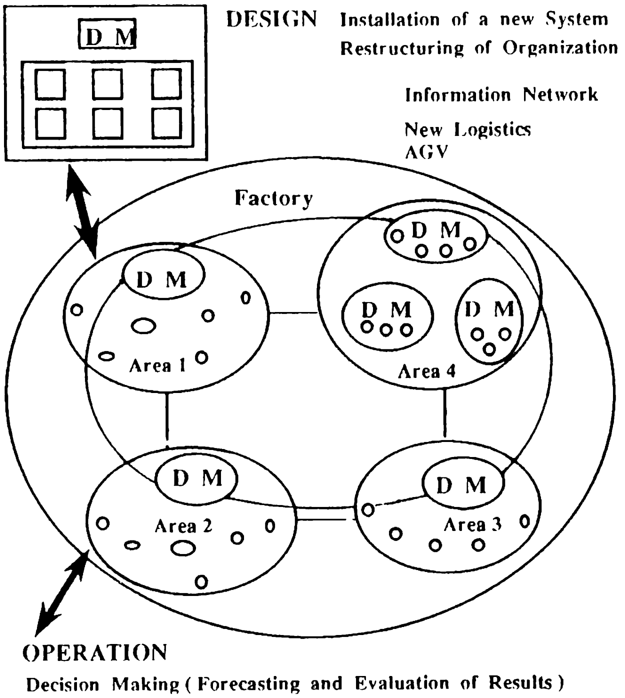
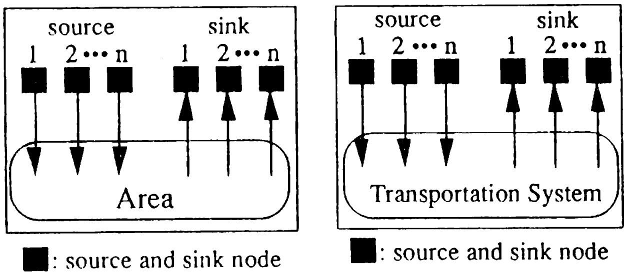


Figure 2: Schematic Factory under CIM Environment



(a) Processing System

(b) Transportation System

Figure 3: Conventional Simulation Model

Similar discussion is applicable for the design of a transportation system by referring to Fig. 3(b).

2) Operational decision making

When any D.M. in Fig.2 is going to make an operational decision, such as daily scheduling or rescheduling due to failure of machines or due to delay of processing, the resulting decision will be more preferable if it is made on the basis of information collected from inside and outside of

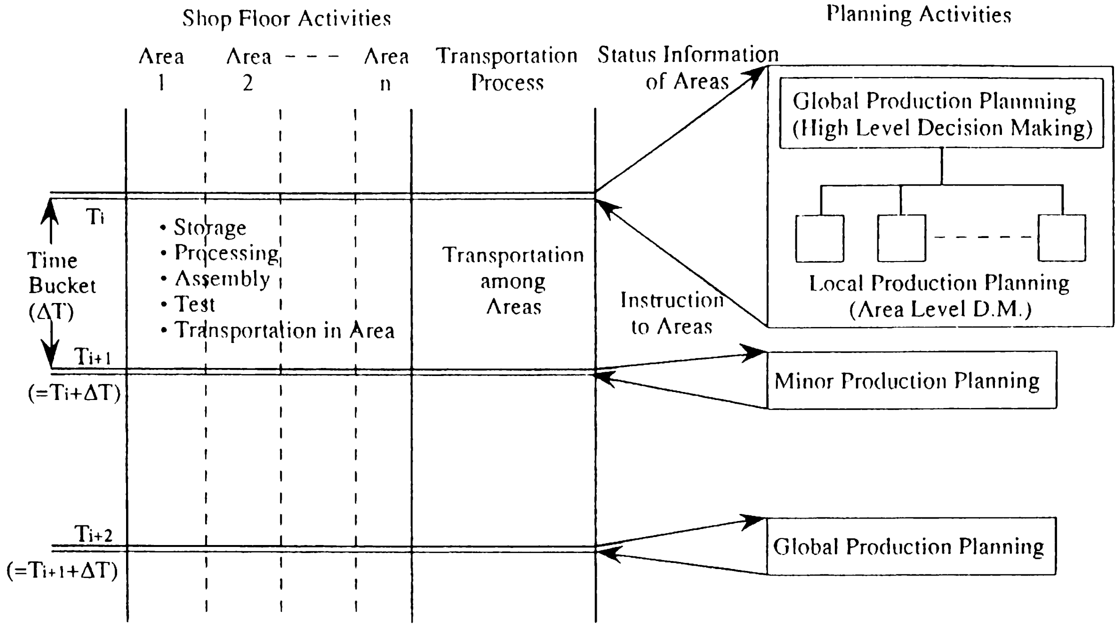


Figure 4: Activities in a Factory

the area and its influence to the schedule of inside and outside of the area is evaluated. Figure 4 shows the shop floor activities and planning activities. Only the decisions influencing neighboring areas are shown with the collection of status information and the dispatching of resulting instruction to the areas. Since the exchange of such information is not difficult by the information network of CIM factory, it will be the problem to have a tool for evaluation. Similarly to the case of design of new system, a factory wide simulation system will be one of promising solutions for the problem.

In the above we confined the total system in Fig. 2 to a factory, but the total system can be raised one level higher to the industry or enterprise level with factories as lower level subsystems.

3 FUNCTIONS OF SIMULATION MODEL UNDER CIM ENVIRONMENT

Base on the above consideration, we consider to develop a factory wide simulation system, sometimes called a virtual manufacturing system or a virtual factory. We presume in the following that the basic functions of general simulation languages and special functions for manufacturing simulation are all inherited in the proposed system, and we concentrate to clarify the features specially required to develop a factory wide simulation system satisfying the purposes described in 2.2.

1) Large scale and detailed model:
The system at the factory level is a large scale system in reality. In the conventional simulation, only limited part of the factory is modeled in its detail while other parts are simplified. However, for the evaluation of a new system or decisions in an area from the view point of the total factory, we need to model the total system in the same detail. This results in a large scale simulation system which is difficult in model building and in implementation and operation.

2) Spatial spread of areas:
Areas are widely spread in the factory and the transportation of works from one area to the other takes longer time than that in the area and is made by a transportation system different from that in the area. Transportation systems both in the area and between areas are to be modeled in detail. This incurs a problem to model various types of transportation systems in a hierarchical structure.

3) Different level of automation in areas:
Machines and devices processing works in areas differ in their level of automation. If the area is at a low level of automation, various logics are to be assumed for manual operations and human decisions and their appropriateness are to be tested. Local decision making such as scheduling is also different in the automation level and incurs the difficulty in model building.

4) Expansion and replacement in the model:
Although the final model to be developed is a large and detail one, model building in practice starts from a small and simplified one. Therefore the capability to extend the model gradually in its size and in its detailness is essential to the simulation system. It is also essential that some part

of the model can be easily replaced by a new system in planning stage for its evaluation or by a new system installed in reality.

4 STRUCTURE OF DISTRIBUTED SIMULATION MODEL

The above considerations and basic studies (Fujimoto(1990), Fujii et al(1989, 1992, 1993a, 1993b)) indicate that a simulation system for virtual manufacturing is properly modeled by a distributed simulation system utilizing a distributed computer system installed as the infrastructure of CIM system. By the requirements pointed out in the above, each subsystem at the area level is decided to be modeled on one processor and a transportation system connecting areas is modeled on one processor transferring works as shown in Fig. 5.

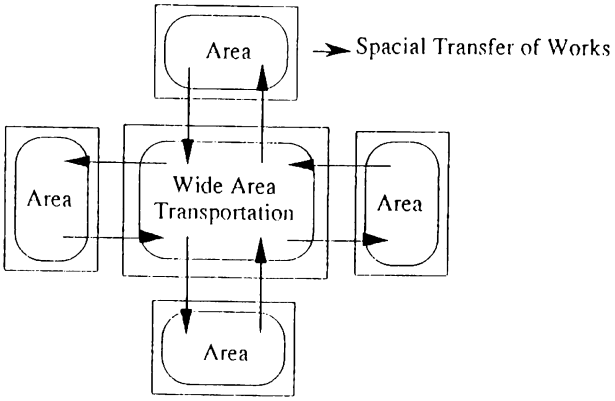
Each area model and the transportation process modeled by the conventional simulation method as in Fig. 3 are modified at the source and sink nodes as shown in Fig. 5 and other functions necessary for the distributed simulation, especially those related to the synchronization mechanism are added in this study. The information exchange functions among areas for special collection of specific information occurring time to time are also necessary to be prepared but are left for future study. The ordinary status report of areas for global and minor decision making in Fig. 4 is hypothetically modeled as a report to a monitoring processor informing that the simulation clock of each simulation process arrived at a certain time.

5 SYNCHRONIZATION MECHANISM

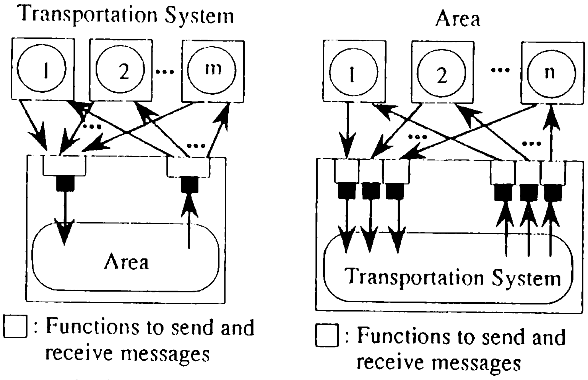
A synchronization mechanism called a time bucket method was proposed in (Fujii et al(1992, 1993a)) for a distributed manufacturing simulation. In this study, the method is further modified and improved by adding a function to roll back the status of an area as in the time warp mechanism (Jefferson(1985)) and a function to save the status of an area at predetermined time for time warp. To explain the basic procedure it is convenient to use a model in Fig. 6 simulating two areas and a transportation system.

5.1 Time Bucket Method with Time Warp Mechanism

In the model shown in Fig.6 we assume that a work is transferred from Area 1 to the transportation system and then from the transportation system to Area 2. A work is transferred from area to transportation system and vice versa without any time consumption and its transportation time from one area to the other is consumed in the transportation system. The transfer of work is represented by a message in Fig. 6.



(a) Distributed Model



(b) Area Model

(c) Transportation Process

Figure 5: Distributed Simulation Model

In the time bucket method, the size of the time bucket, i.e., bucket size, is set to ΔT and during that period each processor runs its simulation model independently. If the simulation in that period completes and the local simulation clock of the area arrives at the end of the period, i.e., a bucket time 0, T1 or T2 in Fig. 6, the processor waits for an instruction to resume the simulation in the next time bucket. Noting that each simulation process requires different processing of events and thus proceeds in a different speed of processing. Because of this unsynchronized processing of events on each processor, sometimes contradiction may occur. For example, the work from the transportation system is sent to Area2 at Time T32 but the process of Area 2 could be already at Time T21 which is greater than T32. To keep the occurrence of the events in chronological order, the status of Area 2 must be rolled back to Time T32. The roll back is realized by first rolling back to a certain time, t1 in this case, when the status of the area is saved a priori and then resume the simulation from that time to Time T32. The status of the area is saved at the end of the time bucket. We consider to save the status at prespecified times in the time bucket to lighten the roll back operation. If a simulation process has already made a transfer before the roll back, it is necessary to can-

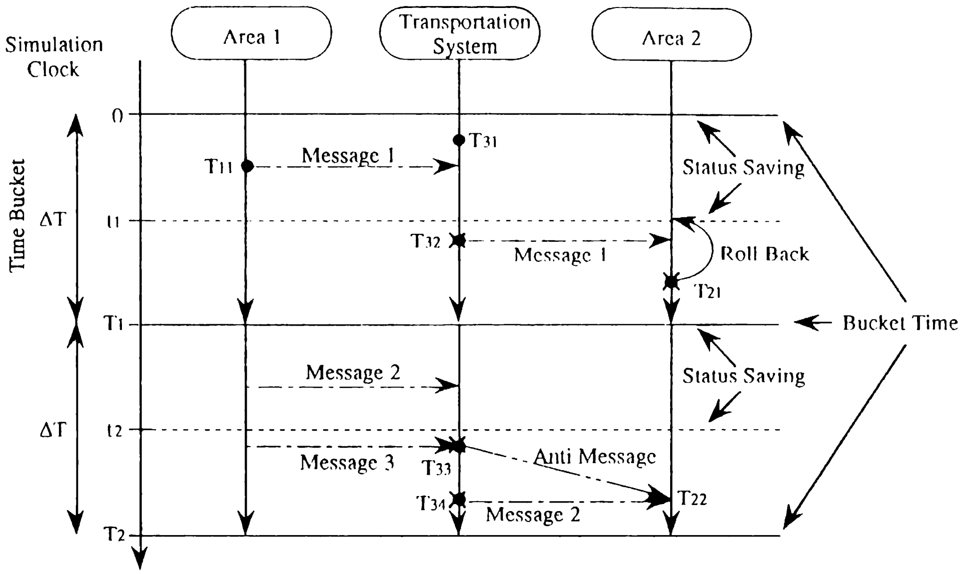


Figure 6: Illustration of Time Bucket Method with Time Warp Mechanism

cel the transfer by sending an anti-message as shown in Fig. 6. For example, a transfer of work at Time T34 from the transportation system to Area 2 is to be rolled back to Time T33 by the arrival of another work represented by Message 3, an anti-message is sent to Area 2 in the roll back operation in the transportation system.

5.2 Rationalization of Time Bucket Method

The concept of the time bucket in manufacturing and in distributed simulation is rationalized by pointing out special features in a manufacturing system.

1) Global or minor decision is made at a certain time of a day as shown in Fig. 4. For this activity the report of status information from all areas is necessary. This indicates that the simulation of each area will be suspended until status reports from all areas are collected, the decision is made and the resulting instruction is dispatched to resume the simulation.

2) Time bucket is a common concept used in the production planning such as the Material Requirement Planning and the schedule in the area is basically determined for the works in the time bucket.

3) Actual preparation of tools, jigs and works in any area are made at the same time, e.g., at the beginning of morning or afternoon work time.

4) The operations in warehouse or storage area are also made about the same time. This implies that even if some works shipped into an area in the morning (afternoon) may not be used or processed until the next afternoon (morning) or later. This implies the dependence among areas due to the transportation of the works is not so strong as that at lower levels. Thus, by assigning one area to one processor, simulation of each area can be made independently in most of the time.

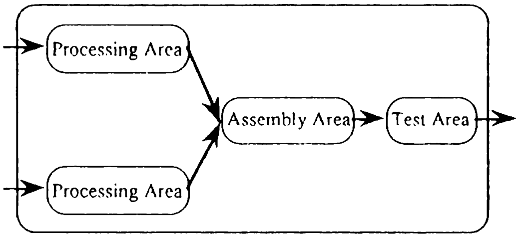


Figure 7: Factory Model

6 A MODEL FACTORY

For the evaluation of the computational feature of the proposed synchronization method, we developed a virtual factory consisting of four areas, i.e., two processing areas, one assembly area and one test area, connected as shown in Fig. 7. For simplicity, the production plan to the factory is represented by the arriving works at two processing areas and other areas are controlled by the push system represented by the transportation of works from preceding areas. The transportation is made by a lot base consisting of m pieces of same type of work. In the following the details of the model are described.

6.1 Area Model and Transportation Process

Each type of area consists of two storages at the entrance and at the exit, five cells and transportation system in an area connecting cells. The works transported by a lot are divided into a piece in the storage at the entrance of an area and are processed one piece base in the area. At the end of the area the works of same type are put into a lot again for transportation in the storage. The works are processed in the FIFO order in the area. The structure and function of the area and the transportation process are as follows.

1) Processing Area
A processing area is structured as shown in Fig. 8. Cell 1 is for preprocessing and Cell 5 is for postprocessing. Cells 2, 3 and 4 constitute a job shop and process works in the given order of processing of each type of work. By the processing sequence at these three cells, we have six different types of work.

2) Assembly Area
An assembly area receives works from two processing areas as shown in Fig. 9. Cells 1 and 2 preprocess works and Cell 3 assembles two works. At Cells 4 and 5 some postprocessing is made on the assembled product to complete a product.
3) Test Area
In the test area shown in Fig. 10, products are tested in four cells in a sequence. If any trouble in quality is detected on a product, the product is sent from Cell 4 to Cell 5 for rework. The rate of trouble of products can be prespecified and the trouble is generated by some probability distribution. Reworked products are also due to the trouble.

4) Transportation process
The works are transported from an area to the other by this transportation process. Various types of carriers can be modeled in this process. By a transmission of request for transportation from an area to the transportation process as shown in Fig. 11, the processing for transportation is initiated. When a carrier is dispatched to and arrived at the originating area by the request, the lot will be transferred from the area to the transportation process releasing the space occupied by the lot to the storage. When the carrier arrives at the destination area and finds a space in the input storage, the lot is transferred from the process to the area releasing the carrier.

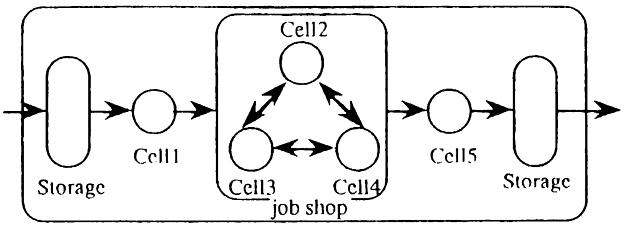


Figure 8: Processing Area

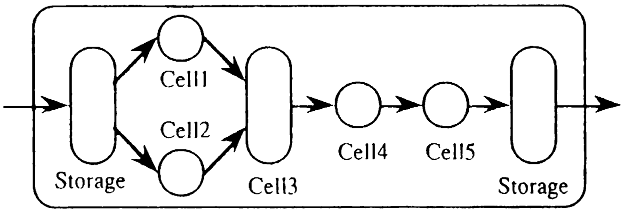


Figure 9: Assembly Area

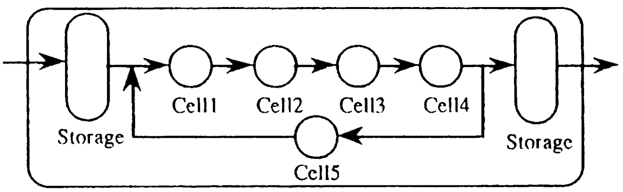


Figure 10: Test Area

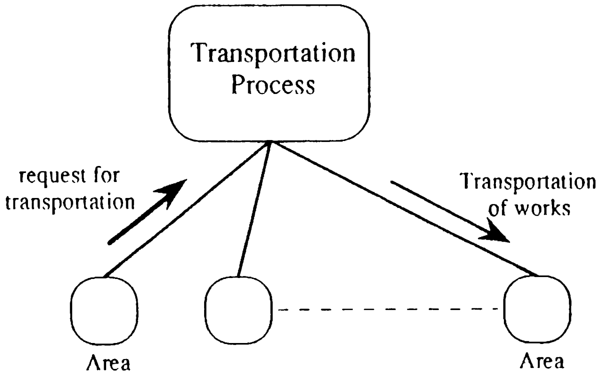


Figure 11: Transportation Process

6.2 Simulation Conditions

In this study conditions and assumptions for simulation are set as follows.

- A cell can process one work at a time. The processing time of any work at any cell is set to be constant and 20 minutes.
- Each cell has a buffer with infinite capacity.
- Cells do not fail and are available any time.
- There are six types of works of which processing order in the processing cells differ as described already.
- The lot size of work for transportation is five.
- In the test area the trouble of a work is detected at Cell 4 if any and reworked at Cell 5. The rate of finding a trouble is 10%.
- The storage has a sufficiently large space. Every work in an incoming and an outgoing lot stays 30 minutes in the

storage.

- The transportation system in any area simply provides a five minutes delay and carries a work between cells.
- The transportation process is modeled as a vehicle system with infinite number of vehicles for simplicity. The time delay for transportation between areas is set to one hour.
- Each processing area receives one lot of each type of works at predetermined time reflecting a production plan at the higher level. Six lots of all types arrive at processing areas every four hours at a time.

6.3 Configuration of Computer System for Simulation

The computer system used for this study is consisting of six engineering workstations, Sun SPARC station ELC(23.7MIPS), connected to the ethernet as shown in Fig. 12. Each of four areas and a transportation process of the factory model in Figs. 8, 9, 10 and 11 is assigned to one workstation as in Fig. 12. In this study, a simulation monitor is introduced to measure the computational features of the proposed system. This monitor serves as a hypothetical decision making processor described in the section 4 and as a time bucket controller. The functions of the controller in this study are to receive messages completing the simulation in the time bucket from area processors and to transmit a message resuming the simulation process of all areas and transportation for the next time bucket after receiving messages of completion from all processes.

The simulation models are basically described by a simulation language written by C, SMPL(MacDougall (1987)) and additional programs are written in C. The communication among workstations is made by using a message communication library p4(Butler and Lusk(1992)).

7 COMPUTATIONAL FEATURES OF TIME BUCKET METHOD

The factory model is used to verify the appropriateness of the proposed time bucket method for synchronization. It will be obvious that all simulation processes must be stopped at any time when global and minor decisions are made. Therefore the bucket size is set according to the time of such decisions. We considered four bucket sizes, i.e., 1, 2, 4 and 8 hours where 4 and 8 hours assumed to correspond to half and full day, respectively.

As described in Fig. 6, it is necessary to roll back to the time when the status of the area is saved and then the simulation is resumed to the target time of roll back, when some contradiction is occurred and time warp is activated. We changed the frequency of status saving in one time bucket from 1 to 4, and the simulation of ten days is run

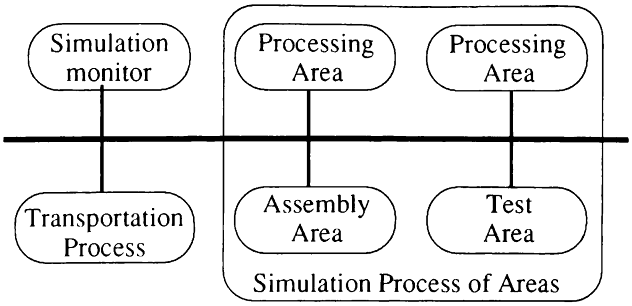


Figure 12: Configuration of Computer System

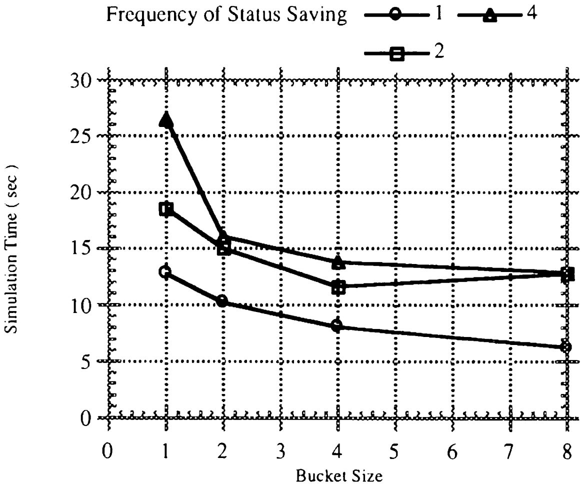


Figure 13: Effect of Bucket Size and Frequency of Status Saving on Simulation Time

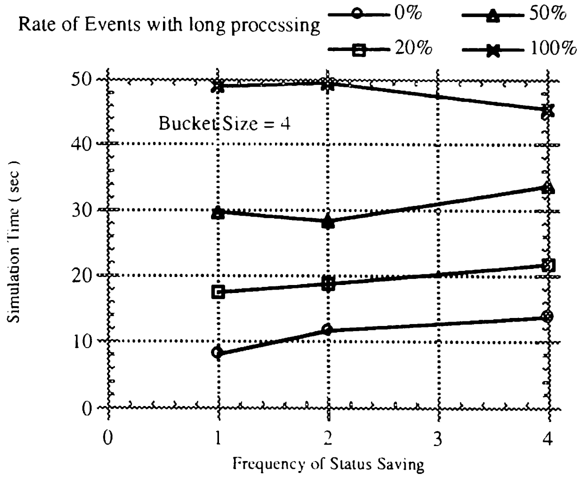


Figure 14: Effect of the length of event processing

for five times. The data of last five days are taken for evaluation. Figure 13 shows the effect of the bucket size and the frequency of status saving on the simulation time. The figure indicates that the frequency of status saving is to be set to minimum, i.e., once in one bucket and that large bucket size is effective to shorten the simulation time.

The reason of this feature may be explained by the fact that the time required to save the status depends on the data size, i.e., the size of the area and about 70ms in this case, which is relatively longer than the time required to simulate the area again from the beginning of the time bucket. To verify this, two types of events are considered such that the time for processing an event are different. Certain portion of the events are randomly selected to consume longer time for its processing as shown in Fig. 14 and the simulation time was measured. The bucket time was set to 4 hours. By increasing the rate of the events with longer processing time from 0 to 100 %, shorter simulation time is observed at larger frequency of status saving for a constant rate, especially for 100 % four times of status saving showed the shortest time. In this case, the actual time for simulation may be longer than the time for status saving. This suggest that the performance of the simulation model is affected not only by the bucket size and the frequency of status saving but also the size of the area and the complication in the processing of events. The last two factors are the keys in the model building and need to consider the balance between the size and complication of the area for one processor and the simulation parameters such as the bucket size and the frequency of status saving.

8 CONCLUSIONS

A distributed simulation model for virtual manufacturing is proposed in this study for the performance evaluation of a design of new system and /or the operational decisions at the area level. A time bucket method with time warp is also proposed as a synchronization mechanism of the distributed simulation and the computational features are evaluated by developing a factory model with five processes. The proposed method is shown to be useful especially when the actual simulation time becomes compatible to the time for status saving. These observations revealed the importance to consider the balance of subsystems assigned to one processor and the simulation parameters in modeling a distributed simulation model for virtual manufacturing.

ACKNOWLEDGEMENTS

The authors are grateful to Messrs. M. Hirano and M. Yamane and Ms. Y. Hirashima for their contribution founding the basis of this research. This study was partially supported by the Grant-in-Aid for Scientific Research (B) of The Ministry of Education, Science and Culture and the Research Grant from CSK Ltd.

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