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SIMULATION OF A SMART CARD-BASED MANUFACTURING SYSTEM

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ABSTRACT

A simulation model of a manufacturing system in which the information associated with the movement of pallets and material handling systems is handled by smart cards or tags is presented. The simulation model depicts a novel method for integrating information with the physical products, processes and material handling systems. The smart cards capture data on the shop floor and combine the physical entities with their associated information. The smart card-based manufacturing system offers several benefits; automated, reusable and reliable information handling media and possible reduction in redundant processors, software and networking tools. Using the simulation model, the design requirements and the performance characteristics of the smart card-based manufacturing system are examined. The results from the simulation model along with several research issues are discussed.

1 INTRODUCTION

In this decade, one of the most essential requirements for successful operation of a manufacturing facility is to produce the right items in the right quantities and deliver to the right location at the right time. The information associated with the status of processing stations, in-process inventory, physical locations of material handling equipment, actual starting time and completion time of a product, and number of completed products are critical for the successful operation of a manufacturing facility. This information should be integrated with shop floor control and resource planning systems to reduce delays and long lead times (Hsu and Rattner 1990). Further, for efficient control of these operations in real time, the volume of information must be kept minimum. One way to decrease this information overload is to apply artificial intelligence in the real-time controller design (Papp et al. 1989). A conceptual framework for designing a decision support system in CIM to acknowledge human cognitive abilities and to reduce information overload is presented by (Sharit, Ebertz and Salvendy 1988).

A flexible representation scheme is key to handling complex data and knowledge associated with the material handling systems in manufacturing cells (Fujiwara et al. 1986). A strong relationship exists between information handling and material handling in CIM environments (Anon 1987). Also, the efficient operation of material handling systems requires reduction in data processing and information overload (Dewar 1988). In this sense, the drive towards paperless production may solve these issues in many manufacturing facilities (Diehl 1991).

The evolution of novel methods for capturing, handling and processing information in real time has drawn considerable attention in industry. With total quality management (TQM) as a new goal, automatic identification and efficient information handling become essential. Emerging technologies such as RF tags, bar codes and smart cards are being used in material handling and component tracking (Kellock 1989). A survey of such technologies is discussed in (Byfield 1990).

In this paper, a novel approach to handling on-line information in a manufacturing cell is presented. One of the main features of this approach is the use of reusable smart cards for handling information associated with the in-process inventories, material movement and handling equipment. A simulation model using SIMAN language is developed for a smart card-based manufacturing system (SCBM). Several experiments are performed using the simulation model and the analysis of results are discussed. These results provide an insight into the characteristics and influence of various parameters in the SCBM system.

2 INFORMATION HANDLING PROBLEM

One of the major difficulties of managing a large number of processing stations, products and material handlers is data proliferation. Expensive on-board and off-line computers, software, networking tools and information handling media are required. Most of the automated manufacturing systems utilize a hierarchical control structure (Acar and Ozguner 1990). This structure depends upon the size and complexity of the system and includes central, area and onboard controllers. In such cases, transmission and reception of data between physical entities and shop floor controllers are either on-line or off-line. Radio-frequency and inductive signals are being used in on-line cases for communication, whereas infra-red and radio-frequency signals are used in off-line cases. In on-line cases, the resources transmit and receive information from anywhere in a factory on a time sharing basis. However, in off-line cases, the production or material handling equipment transfer data with the central controller only at specific points of a factory. This leads to another difficulty in controlling automated production cells. Data communication becomes a bottleneck and signals are affected by noise created by accessories and attachments to production equipment such as motors, transformers and welding machines. Also, the information transfer rate to a physical resource is nearly three orders of magnitude slower than that of local area computer networks. In such cases, the number of physical equipment that can be controlled in real time is severely restricted. There is a need to examine other means of information handling and communication.

3 SMART CARDS IN MANUFACTURING

Recently, the smart cards are conceived as a medium of acquiring, storing and distributing information in many manufacturing applications. These are portable storage devices with intelligence and provisions for identity and security (Bright 1988). They often resemble credit or bank card in size and dimensions, however, embedded within each card is an EEPROM chip incorporating complex control and protection circuits. The card can commonly store up to 64 Kilobits of data that can be easily read and written. It combines the advantage of paper systems in terms of physical association with the material handler without related disadvantages. At present, smart cards are mostly used in financial services, travel industry, military applications and electronic diagnosis (Svigals 1987). The reasons for selecting smart cards are that they can store, process and handle a significant amount of data in a compact, light-weight, reusable, inexpensive and reliable medium (Stefanides,1987). A complete survey of existing technology, current applications and future trends of smart cards is discussed in (Cordonnier 1991).

An exploded view of the various components of a smart card-based manufacturing (SCBM) system is shown in Figure 1. In the SCBM design, the pallets carry products. The material handling vehicles are fitted with an on-board console consisting of a smart card read/write mechanism and an operator interface. Smart card posts (SCPs) are installed at various strategic locations to exchange information via smart cards. SCPs are analogous to zone controllers or bank teller machines to collect information from vehicles, update the operation and product information and assign tasks to vehicles. The SCPs primarily interface with smart cards, provide data and instructions to smart cards, act as intermediate data storage devices and transmit data to other SCPs via the local area network. The SCP includes a read/write device, a carousel and a slot to receive and eject smart cards during the information transfer. The SCPs have limited processing power and maintain a common database. Finally, SCPs monitor WIP levels at various pickup and drop-off stations and interact with non-vehicle equipment such as AS/RS, conveyors and process machines for control purposes.

The SCPs receive information regarding the total load requirements, schedules and due dates from an SCBM computer. In addition to the vehicle control mechanism, each vehicle includes a read/write device to sense information on the smart cards and an operator interface to communicate with the SCPs. The SCPs determine the vehicle number and exchange the task information via smart cards carried by the vehicle operators. A task list for each vehicle is created and stored in a database maintained at SCBM computer. These task lists are generated using the standard optimization and/or heuristic procedures for assigning tasks to vehicles in a manufacturing cell.

This paper primarily focuses on organizing and handling information via smart cards to manage the product flow with the manual material handling vehicles such as pallet trucks, platform trucks and forklift trucks. The modeling and simulation of SCBM is restricted to tracking products moving on pallets in a manufacturing cell and performing operation control of various types of manual material handling vehicles. Typical activities performed in an SCBM system are product identification tracking and control, task assignment, route specifications and vehicle dispatching. Also, the information regarding materials, products, processes, plans and state changes are acquired and transferred via smart cards among processing stations, vehicle operators and SCBM computers in the manufacturing facility.

In this section, we describe the operation principles of an SCBM system shown in Figure 1. These principles are used to build a simulation model.

Step (1): A pallet containing raw materials is moved to the kitting area located at the exit of raw materials (R/M) store and then conveyed to an SCP located inside the R/M store.

(a) An operator keys in the necessary product information and pallet identification number using the read/write device connected to an SCBM computer.
(b) This information is written to a smart card by the SCP and the card is ejected out of SCP through a slot.
(c) The operator picks up the card from the SCP slot (pallet card) and inserts into the card holder of the pallet.
(d) The pallet is then moved to the end of the conveyor where it waits to be picked up by a material handler.

Step (2): A material handling vehicle travels to the R/M store. The operator picks up a smart card (vehicle card) from the SCP that specifies the raw material pallets to be transferred to the production area.

(a) Upon retrieval of pallets, the smart card on the pallet is scanned by the read/write device on the vehicle.
(b) The information on the pallet card is transferred to the vehicle card along with the pallet pickup time.
(c) The material handler travels to the first workstation specified by the vehicle card.

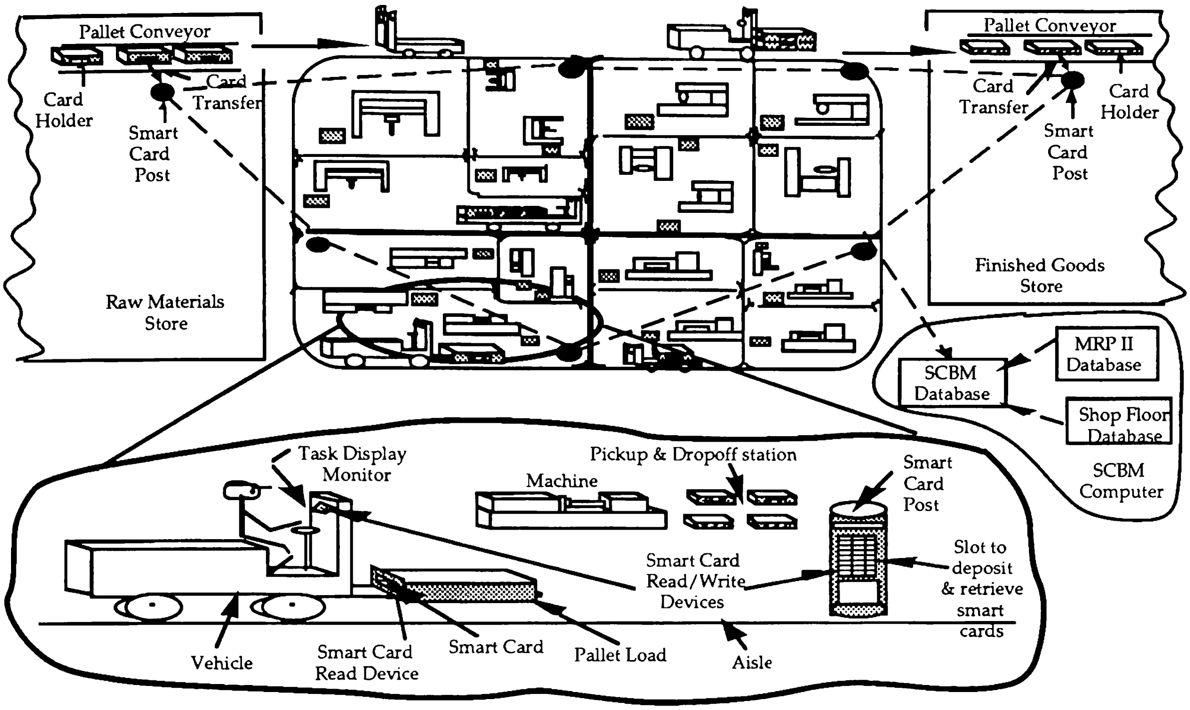

Figure 1: Various Components of a Smart Card-Based Manufacturing System

Step (3): The material handler travels to a workstation to drop off pallets with parts that require further operation.
(a) The pallet card is scanned using the read/write device on the vehicle before dropping off at a workstation.
(b) The pallet information is then written to the vehicle card along with the pallet drop off time.
(c) The pallet is transferred to the process queue at the workstation and located according to the operation sequence of that part. After drop off, the material handler continues to perform activities as per task list stored on the vehicle card.

Step (4): The material handler travels to a workstation to pick up a pallet consisting of parts.
(a) Upon pickup, the pallet card is first scanned using the read/write device on the vehicle.
(b) The information is written to the vehicle card along with the pickup time.
(c) The material handler then continues to perform various activities as per task list stored on the vehicle card.

Step (5): Once all the tasks on the vehicle card are completed, the material handler goes to the nearest SCP to exchange information.
(a) At the SCP, the material handler removes the current vehicle card and inserts it into the SCP card slot.
(b) The SCP reads the vehicle card to obtain the data on vehicle identification number, tasks completed and pickup/drop-off times at various workstations.
(c) The SCP updates the shop floor control and SCBM databases.
(d) Using the current tasks and data obtained from the vehicle card, the SCP assigns new tasks to a vehicle.
(e) Once a new task list is generated by the SCP, the vehicle card is updated. This card is now ready to be picked up by the material handler.
(f) The material handler picks up the card from the SCP slot and inserts it back into the read/write device on the vehicle.
(g) The new task is displayed on the monitor and the material handler begins to perform the next task.

Step (6): If the pallets contain only the finished parts, then it is transported to the finished goods store.
(a) The finished parts are dropped off at the beginning of a pallet conveyor at the entrance of the store and moved to an SCP located inside the store.
(b) The operator removes the pallet card and inserts it into the SCP slot. The SCP reads the card and updates the SCBM databases and other SCPs.
(c) The finished parts are kept in storage. After shipment, the empty pallets and the pallet cards are sent back to the R/M store for reuse.

4 MODELING AND ANALYSIS OF SCBM

An abstract representation of flow of pallets, material handling vehicles, smart cards and information in SCBM systems is shown in Figure 2. This abstraction has been utilized in designing a simulation model using the SCBM system described in Section 3.

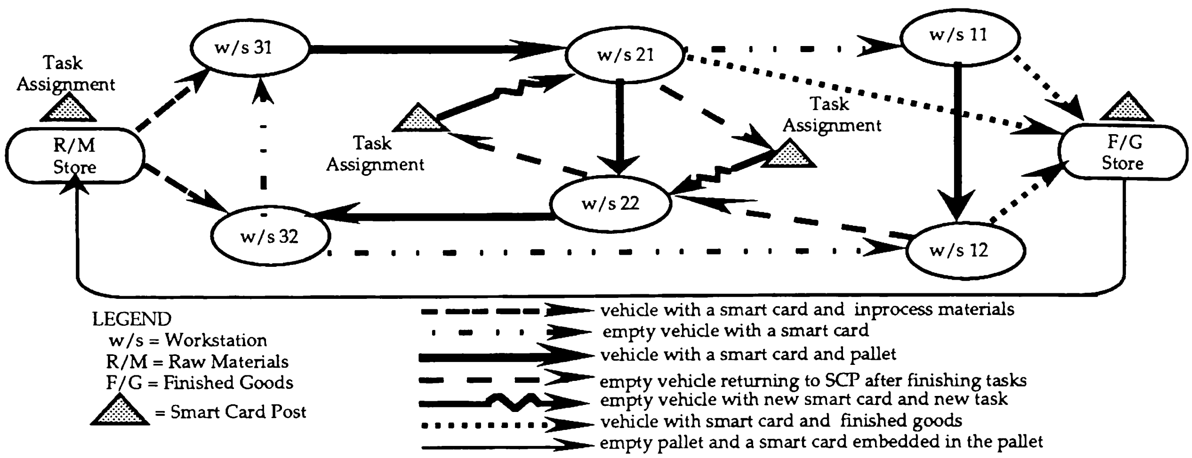

Figure 2: Abstract Representation of an SCBM System

The simulation model is used to depict the operations of SCBM, to study the information flow between the SCPs and vehicles and the vehicles and pallets in the cell and to examine the impact of number of tasks per vehicle card (determines the memory size of smart cards), task arrival rates and number of vehicles on SCBM performance.

4.1 SCBM Simulation using SIMAN/Cinema

A manufacturing cell consisting of eighteen workstations and three material handling vehicle types is considered. These vehicle types include pallet trucks, platform carts and forklift trucks. These are human operated vehicles and move products on pallets from one station to another. Tasks arrive continuously at the SCBM computer from the shop floor controller. Each task is associated with either a pickup or a deposit operation to be performed by a specific vehicle type. The task information is stored in the database (DB) which is accessed by the SCPs. Each vehicle carries exactly one smart card to exchange task information from one of the three SCPs located at strategic locations of the manufacturing cell. This smart card, in conjunction with a read/write device mounted on the vehicle, provides the operator with the list of tasks. Once all the tasks on the smart card are completed, the operator drives the vehicle to the nearest SCP to exchange information. Whenever the operator goes to an SCP, the smart card from the vehicle is inserted into the SCP slot. First, the information on the smart card is read by the SCP and then a new set of tasks are determined and written on the card. Currently, the simulation model considers (i) the issues of task arrivals, (ii) the SCP and vehicle interactions, (iii) the movement of vehicles and smart cards and (iv) the movement of pallets in the cell. The activities in the raw material store and finished goods store and the production process at the workstations have been ignored.

The SCBM system has been modeled using SIMAN simulation language on a Sun SPARC workstation. An animation using CINEMA software is created to visualize the operations of the cell. A flow chart shown in Figure 3 describes the approach used in the simulation model. The model consists of four segments; Segment 0 models task arrivals and interactions between tasks, workstations and vehicles; Segments 1, 2 and 3 model smart cards and information exchanges at SCPs for three vehicle types.

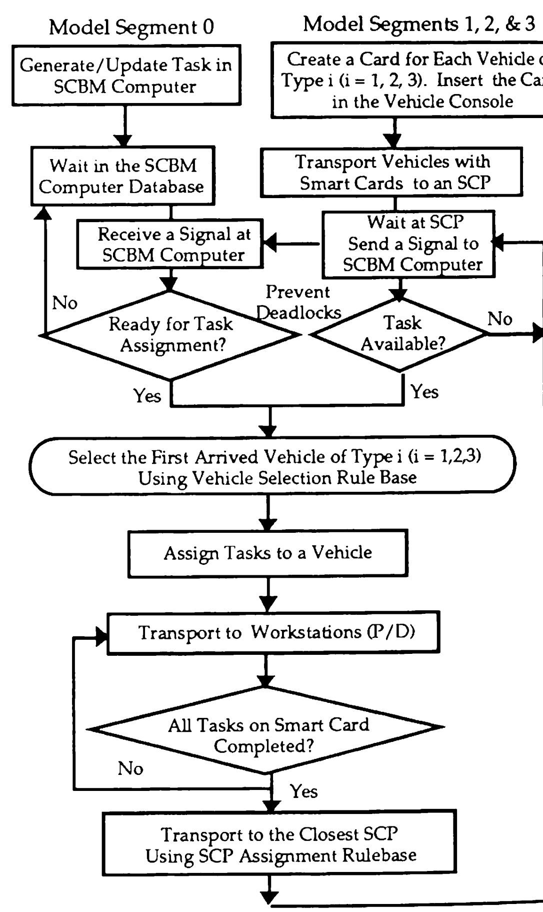

Figure 3: SCBM Modeling Approach

The SCBM simulation model is created to represent several complex issues. These issues are as follows:
(a) task generation at SCBM computer and distribution of tasks to vehicles when requested at any SCP,
(b) interactions between SCBM computer and SCPs,
(c) transfer of task information to the smart card whenever a vehicle requests for new tasks at an SCP,
(d) interactions between smart cards and SCPs,
(e) vehicle movements between SCPs,
(f) interactions between vehicles and SCPs,
(g) interactions between smart cards and vehicles and
(h) movement of pallets and vehicles between various workstations based on the task information provided by the smart card.

4.2 Simulation Experiments

The simulation model has been utilized to study the relationships between several parameters that affect the design of an SCBM system. In this section, we present various simulation experiments, each conducted for 14400 seconds, using the SIMAN model. The model creates five classes of outputs for the SCBM system as follows:
(a) average waiting time of task data at SCBM-DB (before the information is picked up by a vehicle),
(b) average task completion time (flow time) for different vehicle types,
(c) average number of busy pallet trucks, platform carts or forklift trucks that are dispatched by a specific SCP,
(d) average utilization of SCPs and
(e) total number of times the vehicle visited SCPs and exchanged smart card information.

The manufacturing cell in Section 4.1 and the input data provided in Table 1 have been utilized to perform the simulation experiments. In each experiment, one or more parameters are modified. The outputs are further analyzed to study the characteristics of SCBM systems.

Table 1: Input Data For SCBM Simulation

Input Variables	Value
Number of workstations in SCBM	18
Types of material handling vehicles	3
Velocity of pallet trucks	5.2 ft/sec
Velocity of platform carts	3.8 ft/sec
Velocity of forklift trucks	4.6 ft/sec
Number of vehicles in each type	15
Inter arrival times of tasks at SCBM-DB	Exp.(12)
Number of types of tasks/vehicle card	5
Pickup/deposit + smart card read/write time near workstations in the cell	15 seconds
Read/write time at SCPs whenever a vehicle requests for new tasks	25 seconds
Distances Between SCPs and workstations are fixed and range from	100 to 1000 ft

Table 2 provides a summary of simulation outputs generated during the experiments. The first four columns correspond to simulation runs in which the data from Table 1 is used; however, the number of vehicles in each type is changed to 9 (E_1), 12 (E_2), 15 (E_3) and 18 (E_4) respectively. The next three columns correspond to simulation runs that utilize Table 1; however, the inter-arrival times of tasks at the SCBM computer follow exponential distribution with a mean of 10 (E_5), 14 (E_6) and 16 (E_7). The last three columns correspond to runs that utilize data from Table 1; however, the number of tasks assigned to the vehicle card is changed to 3 (E_8), 4 (E_9) and 6 (E_{10}) respectively.

4.3 Analysis of Simulation Results

4.3.1 Amount of Data on a Smart Card

Let us consider the outputs shown in E_8, E_9, E_3 and E_{10} columns of Table 2. Using these outputs, we first studied the impact of the number of tasks per vehicle card

Table 2: Simulation Results From the SCBM Model

Description of Outputs Generated	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}
Average time task information waits in SCBM-DB	3397	1724	1052	17.2	2075	129	11.4	25.8	134	1443
Average flow time for pallet trucks	3734	2100	1464	474	2452	583	463	345	513	1866
Average flow time for platform carts	3844	2225	1590	612	2572	710	586	433	614	2007
Average flow time for forklift trucks	3798	2195	1542	506	2538	634	509	374	552	1954
Average number of busy pallet trucks utilizing SCP1	2.56	3.18	4.23	4.78	4.27	4.63	3.73	3.12	4.09	3.83
Average number of busy carts utilizing SCP1	2.07	3.43	4.02	4.28	4.23	3.46	3.42	3.13	3.55	4.29
Average number of busy forklift trucks utilizing SCP1	2.30	3.92	3.34	4.53	3.08	3.33	2.82	3.01	3.17	3.78
Average number of busy pallet trucks utilizing SCP2	2.53	3.00	4.04	3.64	3.54	3.60	3.07	3.11	3.68	4.13
Average number of busy carts utilizing SCP2	2.48	3.51	4.33	3.86	4.36	4.52	4.20	3.38	3.97	4.18
Average number of busy forklift trucks utilizing SCP2	2.09	1.97	3.42	3.76	3.97	3.62	3.09	2.69	3.26	3.58
Average number of busy pallet trucks utilizing SCP3	2.72	4.14	4.63	5.22	5.06	4.54	4.36	4.06	4.52	5.01
Average number of busy carts utilizing SCP3	3.34	3.52	4.64	5.85	4.35	4.82	3.73	4.24	4.79	4.57
Average number of busy forklift trucks utilizing SCP3	3.32	4.35	5.58	4.92	5.22	5.16	4.77	3.90	4.98	5.11
Utilization of the smart card post - SCP1	0.37	0.55	0.61	0.71	0.60	0.60	0.53	0.69	0.69	0.58
Utilization of the smart card post - SCP2	0.39	0.46	0.64	0.61	0.64	0.63	0.56	0.74	0.74	0.60
Utilization of the smart card post - SCP3	0.43	0.56	0.69	0.75	0.68	0.67	0.61	0.78	0.78	0.64
Number of smart card information exchanges at SCP1	212	315	350	409	348	345	305	395	395	332
Number of smart card information exchanges at SCP2	227	265	372	352	370	365	322	427	425	346
Number of smart card information exchanges at SCP3	250	325	395	430	390	387	350	448	448	370

E_j corresponds to a specific simulation run (runlength = 14,400 seconds); All time values are in seconds;

on the average flow times for various types of vehicles in the SCBM system. The flow time refers to the waiting time for a task at SCPs before assigning to vehicles plus the task execution time at the various workstations. From Figure 4, it can be inferred that the average flow times for all three vehicle types increase as the number of tasks per vehicle card is increased.

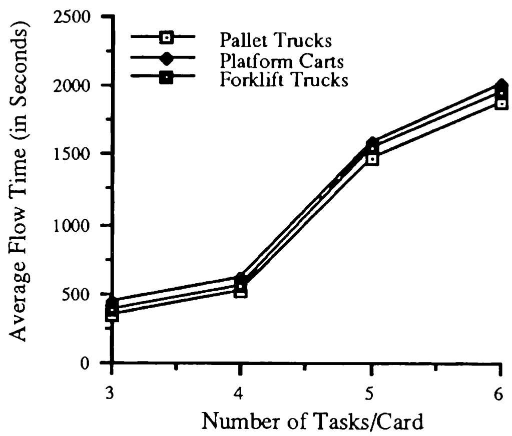

Figure 4: Average Flow times Versus Number of Tasks Assigned to a Vehicle Card

Similarly, using the data in E_8, E_9, E_3 and E_{10} of Table 2, we studied the impact of the number of tasks per card on the average number of busy vehicles that received information from a specific SCP (See Figure 5). From Figure 5, it can be inferred that the average number of busy vehicles increases as the number of tasks per card is increased. The reason being, the vehicles visit more workstations (as there are more number of tasks on the card) before they return to SCP for information exchange. This reduces the work load on SCPs.

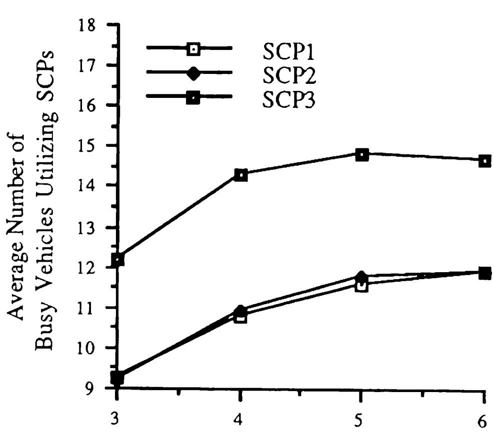

Figure 5: Average Number of Busy Vehicles at Various SCPs Vs the Number of Tasks per Vehicle Card

Again, using the data in E_8, E_9, E_3 and E_{10} of Table 2, we studied the effect of number of tasks per card on the average waiting time of tasks in the SCBM-DB. From Figure 6, it can be inferred that the average waiting time increases exponentially as the number of tasks per card increases. As the vehicles take longer time to return to an SCP to obtain new tasks and the tasks arrive at an exponential rate, we can infer this pattern.

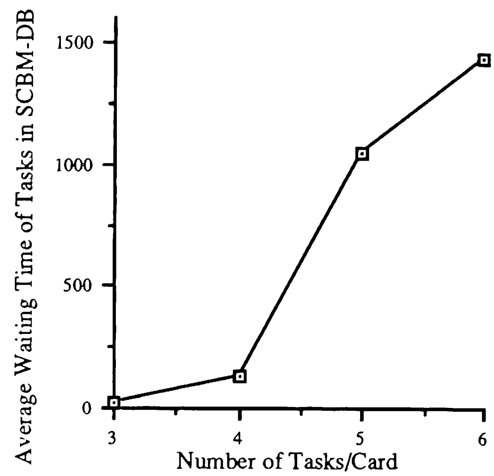

Figure 6: Average Waiting Time of Tasks at SCBM Computer Versus Number of Tasks per Vehicle Card

From Figures 4, 5 and 6, the SCBM designer can visualize the impact of the number of tasks per card on several performance measures. Accordingly, the designer may choose the appropriate number of tasks per card based on the desired average flow time for each of the vehicle types, average task waiting time in the SCBM computer and the average number of busy vehicles.

4.3.2 Information Exchanges at SCPs

Consider the results in E_5, E_3, E_6 and E_7 of Table 2. First, we plotted the effect of changes in the number of information exchanges at various SCPs due to the changes in task arrival rates at SCBM computer. It can be inferred from Figure 7 that the number of information exchanges at SCPs by various vehicles (on an average)

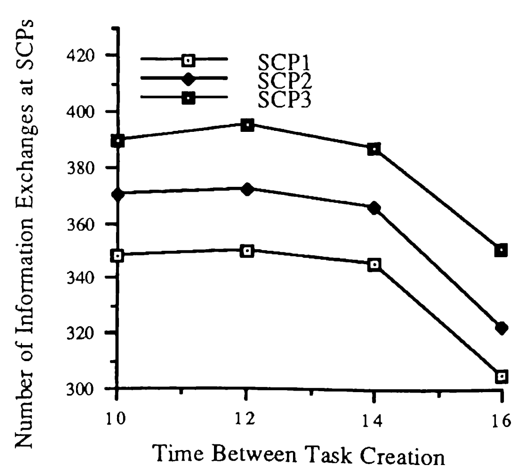

Figure 7: Effect of Task Arrival Rate at SCBM Computer on the Number of Information Exchanges at SCPs

reduces as the time between task arrivals to the SCBM computer increases. This leads to a reduction in SCP utilization as shown in Figure 8. Hence, for a fixed number of tasks per card, as the SCBM system becomes less busy, the number of exchanges between the vehicles and SCPs tend to drop leading to less workload at SCPs.

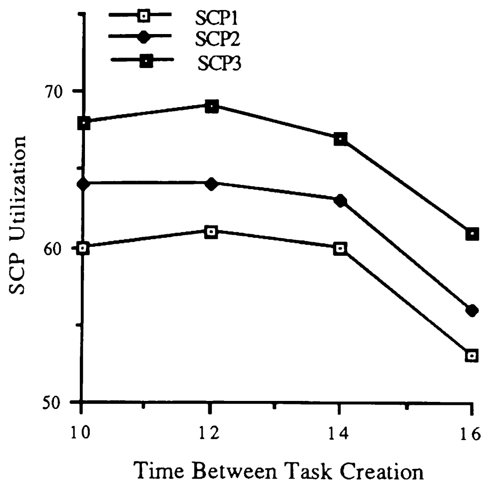

Figure 8: Effect of Time Between Task Creation at SCBM Computer on SCP Utilization

Likewise, using E_5, E_3, E_6 and E_7 of Table 2, we studied the impact of number of tasks per card on the number of information exchanges. From Figure 9, it can be seen that the number of information exchanges by vehicles at SCPs did not vary significantly for three and four tasks/card, however, it dropped sharply beyond four. This drop occurs because the vehicles return less frequently to SCPs for information exchange.

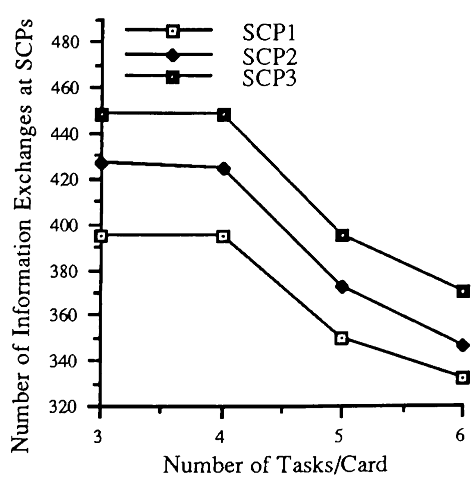

Figure 9: Effect of Number of Tasks per Card on the Number of Information Exchanges at SCPs

Finally, we studied the impact of number of vehicles in each type (using E_1, E_2, E_3 and E_4 of Table 2) on the number of information exchanges. In Figure 10, a steep increase in total number of information exchanges by various vehicles at all SCPs is noticed as the number of vehicles in each type is increased. This occurs because the additional vehicles cause heavy work loads at SCPs.

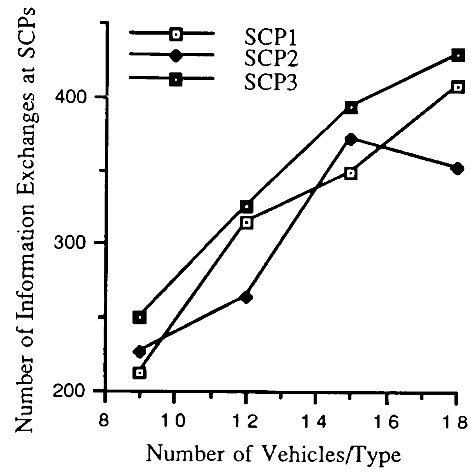

Figure 10: Effect of Number of Vehicles of Each Type on the Number of Information Exchanges at SCPs

From the graphs shown in Figures 7, 8, 9 and 10, the SCBM designer can visualize the impact of (i) change in the task arrival rates at the SCBM computer, (ii) the number of vehicles of each type and (iii) the number of tasks per card. From these experiments, we may conclude that as the number of vehicles increase, the number of information exchanges at SCPs increases. This requires the number of tasks per card to be kept higher so that the vehicles do not return frequently to SCPs. However, this leads to delays in updating the SCBM computer due to infrequent exchange of information by vehicles at SCPs. Hence, tradeoffs between (i), (ii) and (iii) are required.

4.3.3 Number of Busy Vehicles

The purpose of this experiment is to obtain the total number of busy pallet trucks, platform carts and the forklift trucks at any point in time. The data provided in Table 1 is utilized to run this experiment. Figure 11 shows nine graphs plotted using the OUTPT processor of the SIMAN language. Each plot is associated with a particular type of vehicle that went through one of the three SCPs. The plot provides the total number of vehicles that are busy at any given time. The vertical line in the graph corresponds to a vehicle either returning to an SCP after completing all tasks or leaving an SCP with a new task list. The horizontal line indicates the length of busy periods before a state change has occurred.

The plots are grouped such that it is easier to obtain the number of pallet trucks (or platform carts or forklift trucks) that are busy at any given time. For instance, if the total number of busy pallet trucks is of interest at time 2000 seconds, then select the plots for pallet trucks and draw a vertical line passing through 2000 seconds. The number of busy vehicles that received smart card information from SCP1 is four, SCP2 is one and SCP3 is eight. The total number of pallet trucks that are busy at time 2000 seconds is therefore thirteen.

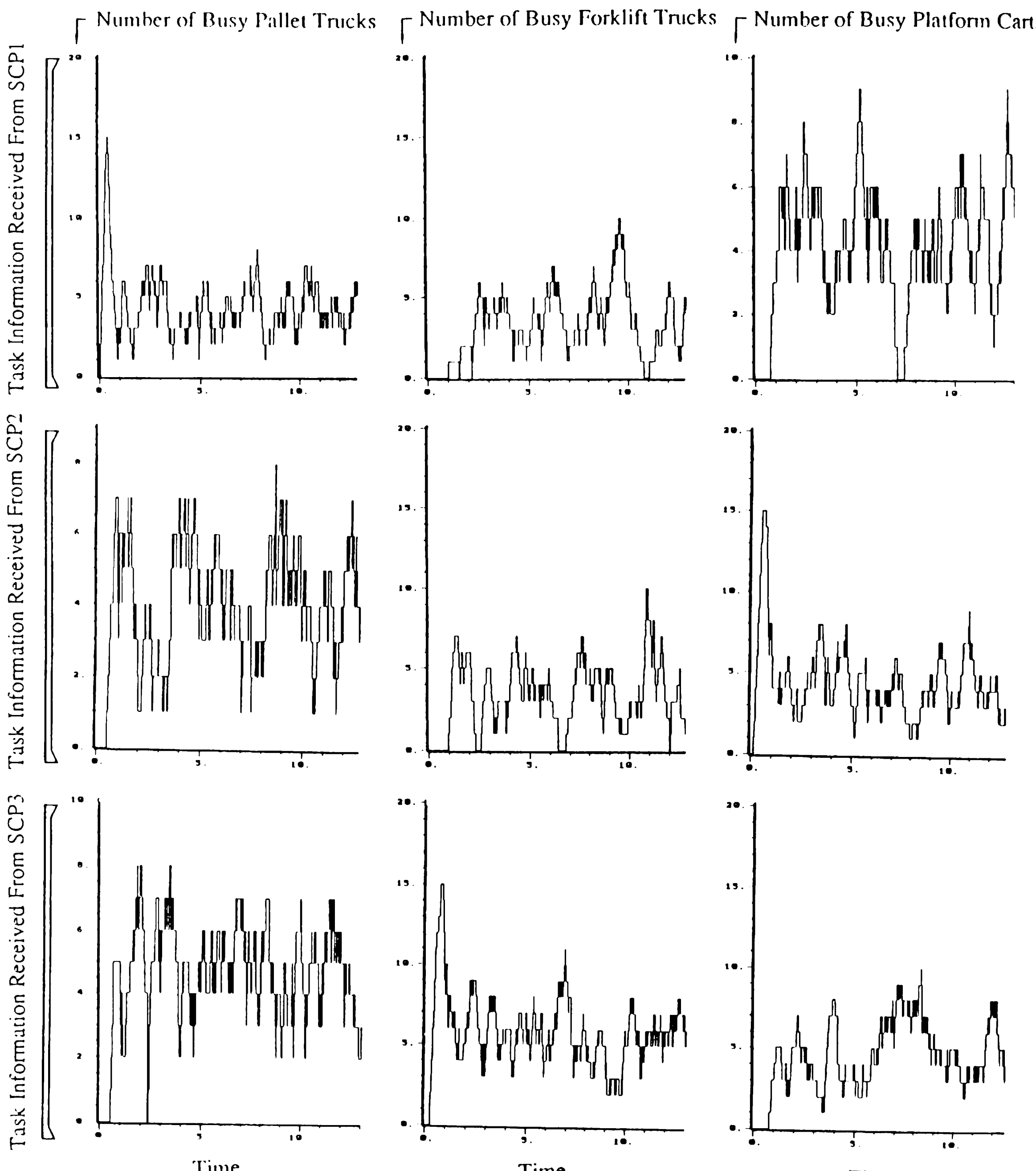

Figure 11: Total Number of Busy Vehicles of Each Type Vs Simulation Time (x1000 Seconds)

From the foregoing analyses, it can be concluded that the selection of suitable values for the design parameters is critical for a successful implementation of an SCBM system. Using the simulation model, the SCBM designer can study the interrelationships between these parameters. Some of these parameters are as follows:
(a) rate of task creation at the SCBM computer,
(b) number of SCPs and their locations in the cell,
(c) number of tasks per vehicle card,
(d) type, speed and memory capacity of smart cards,
(e) number of vehicle/pallet cards (=1 in our example),
(f) maximum number of vehicles of each type and
(g) number of smart card information exchanges.

5 BENEFITS OF SCBM SYSTEMS

The SCBM system has several new design features that can greatly enhance the state-of-the-art techniques in integrating information with the physical entities in manufacturing. The SCBM system and the simulation model offer several significant benefits:

(a) The new information handling media leads to a faster, more reliable and cost-effective communication means in industry.

(b) The simulation model can be used for examining the impact of the number of smart cards and the smart card posts on the performance of the SCBM system.

(c) By using visible smart cards (both contact and non-contact types) and the simulation model, the user can pinpoint information overload and backlog in the network and take remedial actions accordingly.

(d) The simulation model provides a modeling vehicle to study the operating characteristics of SCBM systems. Also, it assists the designer in examining the various implementation problems associated with the SCBM system envisioned.

6 SUMMARY

In this paper, the design requirements and the operating principles of a smart card-based manufacturing system are discussed. A simulation model is developed to examine the design parameters that are critical to the successful operation of SCBM systems. The simulation model is built using SIMAN/Cinema language and is currently running on a Sun/SPARC computer. Several experiments have been conducted to verify the simulation program as well as to study the impact of various design parameters on the performance characteristics of the SCBM system. The results from these simulation experiments along with the benefits are also discussed.

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