Using Intelligent Vehicle Control Rules to Improve AMHS Performance in Highly Dynamic Manufacturing Environments

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USING INTELLIGENT VEHICLE CONTROL RULES TO IMPROVE AMHS PERFORMANCE IN HIGHLY DYNAMIC MANUFACTURING ENVIRONMENTS

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To my parents,

inspired,

and inspiring.

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ABSTRACT

USING INTELLIGENT VEHICLE CONTROL RULES TO IMPROVE AMHS PERFORMANCE IN HIGHLY DYNAMIC MANUFACTURING ENVIRONMENTS

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Automated Material Handling System (AMHS) is crucial for a 300-mm manufacturing fab as to reduce ergonomic related problems, wafer contamination, and wafer damage. The main purpose of the AMHS is to optimize the fabrication process by reducing the manufacturing cycle time, and increasing equipment utilization. Researchers have experimented with dispatching rules in order to optimize the wafers delivery in the AMHS. However, many proposed dispatching rules cannot anticipate dynamic, and frequent changes in the environment (i.e., vehicle breakdown, tool breakdown, changing demand, etc). Therefore, implementation of Intelligent Vehicle Control Rule (IVCR) can be a solution in solving this problem. The purpose of this thesis is to develop an IVCR useful in the design of vehicle-based AMHS that show statistically superior wafer delivery time (DT), retrieve time (RT), transport time (TT), and throughput than the static dispatching rules under tool breakdown, vehicle breakdown, number of moves, and load priority. The first contribution of this thesis is to simulate and compare all experimented rules (i.e. First-Encounter-First-Served [FEFS], modified Norman's algorithm [MODNORMAN], and IVCR) at different levels of detail. The second contribution is to explain the superiority of IVCR against other rules. A method for analyzing its performance and the influence of experimental factors are measured using the Design and Analysis of Experiments.

CHAPTER I

INTRODUCTION

Background

Integrated Circuit (also known as IC) is a miniaturized electronic circuit in electronic devices that most modern life needs. IC has been manufactured in the surface of a wafer (i.e. a circular, thin, and flat piece of silicon). The manufacture of ICs consists of four main steps (i.e. wafer fabrication, wafer probe, assembly, and final testing). The wafer fabrication process is really complex, yet critical since the 300mm wafer travels approximately 8-10 miles during processing and typically visits more than 250 process tools, and undergoes several hundreds of individual processing steps (SEMATECH, 2000). In details, groups of wafers (known as lots) undergo seven major processes (i.e. cleaning, film deposition, photolithography, etching, ion implantation, metallization, and inspection). Lots may revisit the same process areas several times (i.e. reentrant flows) due to their multiple layers. Moreover, approximately 400 production steps also make the wafer fabrication more complex.

According to Semiconductor Industry Association (SIA) press room, with $227.5 Billion in sales worldwide in 2005, the semiconductor industry has become a vital contributor to the world economy (SIA press release, 2005). The development in the semiconductor industry from 200mm to 300mm wafer fabrication is expected to produce

2.5 times more chips per wafer at a cost 1.4 times more than the 200mm wafer (Bonora and Feindel, 2001). This is one of the reasons why the wafer fabs are need to be highly automated, and they will be highly dependable on the Automated Material Handling System (AMHS). Moreover, due to the increased weight and size of 300mm wafers, AMHS has become a necessity for a 300mm manufacturing fab to reduce ergonomic related problems, wafer contamination, and wafer damage (Lin, Wan, Fu-Kwun, and Yen, 2001). According to the International Technology Roadmap for Semiconductors (ITRS), the future development of AMHS system needs to fulfill the requirement for 450mm wafer fab that by 2013, expects the wafer cycle time per mask to be decreased by 33.3%, while the average delivery time to be decreased by 37.5% (ITRS, 2003).

By definition, AMHS is a generic term for robots and autonomous transport devices that move and store wafers between different processing steps (Subramaniam and Kryder, 1997). Existing AMHS technology is based on Over Hoist Transporters (OHT) – space efficient vehicles traveling suspended on tracks above the main fab floor. The main purpose of the AMHS is to optimize the fabrication process by reducing the manufacturing cycle time and increasing equipment utilization (ITRS, 2003).

Overhead hoist transport (OHT) has been put into research and extensively used in 300mm fabs AMHS. It consists of an overhead track with vehicles, stockers, and process tool along with load/unload ports. A stocker is placed in each bay to store work-in-process (WIP), when the process tool required for a lot is unavailable when the lot arrives to the bay. The wafer fabrication process is done by transporting the material within a bay (i.e. intrabay) and also between different bays (i.e. interbay). In an intrabay AMHS, the material is moved between stockers and process tools by using OHT technology. In an interbay AMHS, there is a shop control system communicates with AMHS and automated control system. They both provide information on delivery location.

Problem Statement

Delivering wafers on-time is one of the major design priorities of wafer fabs development. Egbelu and Tanchoco (1984) indicate that delivery time is affected in most part by dispatching rules. A dispatching rule is a simple rule that is used for deciding and selecting the sequence in which wafers will access the material handling system. The benefit of using dispatching rules is to improve one or more performance metrics such as on-time delivery, vehicle utilization, throughput, etc. Egbelu and Tanchoco (1984) classify dispatching rules into workstation-initiated and vehicle-initiated rules. Moreover, they explain that the shop-locking problem occurs whenever the vehicle-initiated rules are used in a system with large volumes of material flow. De Koster, Le-Anh, and Van der Meer (2004) test dispatching rules used by three companies: a distribution centre for computer components, a production plant for packaging glass, and a container transshipment terminal for sea containers. The waiting time problem is addressed by proposing a new rule, nearest vehicle first with time priority. Bartholdi and Platzman (1989) state that a highly decentralized greedy heuristic will enable a fleet of automated guided vehicles to deliver unit carrier quickly on a simple loop track. The First Encountered First Served (FEFS) heuristics proposed by Bartholdi and Platzman (1989) was motivated by cost, vulnerability to disruption, and flexibility. In their rule, the AGV circulates continuously in the loop, and picks up the first load that the vehicle encounters. The algorithm has shown to decrease the average waiting time and delivery time. Due to this significant result, we are going to use FEFS dispatching rule in our baseline model that is compared with our proposed Intelligent Vehicle Control Rule (IVCR).

The problem is that most of recent studies on dispatching rules cannot anticipate dynamic and frequent changes in the environment. Therefore, there is a need for dispatching rules that account more effectively for dynamic events (i.e., vehicle breakdown, tool breakdown, changing demand, etc.) (Uzsoy, Lee, and Martin-Vega, 1994). In this situation, implementing intelligence to the vehicle is really in need. Thus, the vehicle can be more proactive in responding to the dynamic of its environment. To put the situation in more detail, take for example a situation where one of tools in the system is down. Thus, it makes the vehicles need to find alternative tools to where the lot needs to be delivered. Therefore, in order to avoid congestion, approaching vehicles need to make a decision: whether it wants to take the congested route and pay the high cost of waiting, or to take an alternative route. This kind of dispatching decision will surely affect the performance of AMHS system. Kim and Tanchoco (1991) explain that vehicle dispatching rules determine the operating effectiveness of the total OHT system. Research has been developed in order to respond to the dynamic conditions that most researchers usually take those into assumptions. Kim, Oh, Chae, and Lee (2007) proposed a dynamic adjustment of vehicle-load assignment according to given system conditions to answer this problem. They consider few requirements to reassign a job to a vehicle, such as shortest travel time or distance. However, vehicles decisions are not only need to respond changes in environment but also need to give a better contribution to the system. Higher vehicle utilization and faster delivery times are achieved by using this approach.

In our research, we address the issue by implementing the IVCR for the system could give a correct response whenever it faces one of those problems related to the dynamic environment. As a result, higher factory efficiency can be accomplished by ensuring that the material processing and delivery will be done correctly at the right place and at the right time.

Moreover, from the model complexity point of view, there is a need of simulating a closer picture of the actual AMHS system. By all means, an accurate AMHS system that leads to an estimation of the effect of factors configurations (i.e. lot priority ratio, number of vehicles, and number of moves) will be represented by using simulation modeling. A model fab with six bypasses with the existence of vehicle and tool breakdowns are developed to fufill this purpose.

Research purpose and scope

The primary objective of this research is to develop an IVCR useful in the design of vehicle-based AMHS that show statistically superior number of throughputs, wafer delivery time (DT), wafer retrieve time (RT), and wafer transport time (TT), than the static dispatching rules under tool breakdown, vehicle breakdown, number of moves, and lot priority. The IVCR will be based on an algorithm that can push not only vehicles but also the whole system to respond to the dynamic environment in an intelligent way. The algorithm will be an extension of previous research topics in the literature of intelligent system, such as traffic management, route selection, job selection and lot priority.

Simulation approach will be used to test the performance of the proposed rule in comparison to the existing rule (i.e. see traffic management proposed by Norman, M. (2002) in Chapter 3 Literature review). The simulation model will act as a tool for evaluating various factors that play vital roles in the successful operation of an AMHS system. Performance analysis of developed IVCR will be conducted under the effects of two or more operational factors such as number of vehicles, number of moves, lot priority ratio, mean-time-to-failure (MTTF), and vehicle speed. The effectiveness of an intelligent vehicle control rule will be measured based on several performance measures. These measures are available through the simulation model and will be discussed in later chapters:

1. average throughput,
2. average delivery time,
3. average retrieve time,
4. average transport time.

Proposed Procedure

This study proposes a new approach to model the multi-vehicle material handling system that dynamically checks the status of the system. First, we determine three of the dynamic environment conditions that are frequently used as assumptions by other authors. They are vehicle and tool breakdowns, congestion and lot priority. Second, we consider factors affecting this environment (i.e. lot priority ratio, number of moves, number of vehicles, and mean time to failure [MTTF]). Third, we develop the IVCR that does these tasks:

1. Use decision points on every path intersection in the system.
2. Evaluate all alternative paths that meet at decision points based on priority of lots, which is calculated by taking into consideration the following criteria:
    a. Hot lots/regular lots availability,

  b. Congestion along the path,

  c. Latest vehicle travel time that corresponds to the path.

3. Cancel and reassign vehicle to do a job with higher priority.

4. Schedule vehicle to do pickup job with higher priority.

Organization of Thesis

The organization of the remaining part of the thesis is as follows. Chapter 2, entitled ”Literature Review”, provides a comprehensive overview of IVCR. It reviews previous research efforts of this area and explains the various stages of the research. It also discusses drawbacks and strengths of the current research.

Chapter 3 entitled “Proposed Intelligent Vehicle Control Rule (IVCR)”, presents the proposed method to improve AMHS performance in a highly dynamic manufacturing system, such as semiconductor manufacturing. It also presents a detailed description of the AMHS experimental environments, factors affecting its performance, and the proposed IVCR.

Chapter 4, entitled “Experimentation” presents design and analysis of experiments and discussion of results in response to performance measurements.

Chapter 5 entitled “Conclusion and Future Research“ presents the conclusions of this research effort and its contribution to the research literature. It also discusses suggested future research topics.

CHAPTER II

LITERATURE REVIEW

Throughout the research literature, the importance of the AMHS system to deal with the dynamic semiconductor manufacturing environment has been repeatedly addressed. This chapter provides not only an overview of the strategies for mitigating the effects of highly dynamic manufacturing environment. It reviews published literature and discusses their drawbacks and strengths.

Dispatching Rules

Vehicle scheduling systems decide which vehicle should transport which load and when. This can be done by solving a complicated optimization model or by assigning vehicle's load based on some intuitive dispatching (or assignment) rules. Dispatching rules are extensively developed and mentioned in previous literature related with AMHS system. Vehicle dispatching is created when (a) a vehicle reaches its parking location; (b) a new load arrived; (c) a vehicle drops off a load. In order to control vehicles, a dispatching system uses dispatching control rules. The general purpose of using dispatching rules are minimizing load waiting time, maximizing system throughput, minimizing queue length, and guaranteeing a certain service level at stations. There are two types of dispatching rules: centralized and decentralized dispatching rules. In the context of the dispatching rules study, this thesis makes some key contributions as follows: (1) evaluating commonly used dispatching rules (i.e. First Encounter First Served, FEFS); (2) proposing IVCR algorithm; (3) evaluating and comparing the performance of the control rules (i.e. IVCR, FEFS).

Discussions on dispatching rules are put into two separate sections. Literature on centralized dispatching rules are discussed on the next subsection, while the decentralized dispatching rules, in which proposed to respond a more dynamic environments are discussed on the next section under "Responding to Dynamic Environments".

Centralized Dispatching Rules

Centralized control systems dispatch vehicles based on global information maintained by central controller. The controller assigns loads to vehicles (or vice versa) according to specified rules. Egbelu and Tanchoco (1984) present a characterization of AGV dispatching rules using simulation. They propose experimentations with several workstation-initiated rules such as Nearest Vehicle First (NVF), Farthest Vehicle (FV), and Longest Idle Vehicle (LIV). They also included vehicle-initiated rules such as Modified First Come First Served (MFCFS), Shortest Travel Time First (STTF), and Longest Travel Time First (LTTF). Although the FV rule had the worst performance in its response time, all workstation-initiated rules do not show different results (Bischak and Stevens, 1995). In a dynamic environment, a need for a vehicle to be dispatched based on its own decision, (i.e. without central controller interference) is more flexible due to its simplicity in system computation (Berman and Edan, 2002).

De Koster, Le-Anh, and Van der Meer (2004) rank dispatching rules under real-life environments, including a distribution center, a production plant, and a container transshipment terminal. From series of experiments, they conclude that the distance-based dispatching rules (i.e. NVF and NWF) perform better with respect to average load-waiting time than time-based dispatching rules (MODFCFS), regardless of vehicle utilization rates. This is because distance-based dispatching rules attempt to minimize empty vehicle travel time; they prove to outperform the other rules. However, minimizing the average load waiting time makes the NVF and NWF rules tend to maximize the maximum load waiting time. In order to overcome the shortcoming, they propose NVFTP rule (a truncation rule based on NVF). This rule has a difficulty in determining the best truncation parameter.

Hodgson, King, and Monteith (1987) propose a dispatching rule for unit-load or double-load automated guided vehicle (AGV) systems, named RULE. Under RULE, an empty vehicle find the best destination station by checking its system status for the best alternative location and alter its destination accordingly. They demonstrate the rule's effectiveness in a simple system with one vehicle.

Responding to Dynamic Environments

Several dispatching rules has been proposed in order to respond the dynamic system environment. Jeong and Randhawa (2001) propose a multi-attribute dispatching rule using a weighted sum of normalized attributes. They consider weighted sum of normalized attributes (i.e. the distance from idle vehicle to the move request, the remaining input buffer space of the destination workstation, and the remaining output buffer space of the outgoing workstation) that can be applied for flexible manufacturing system environment. Queue size and capacity of input buffer and output buffer are the kinds of manufacturing environment considered in their research. Parameters adjustments are done by using neural network.

Sabuncuoglu and Hommertzheim (1992) use a dynamic dispatching algorithm for scheduling machines and AGVs in a flexible manufacturing environment. Their proposed algorithm applies a different decision criteria to identify the best workstation to be served. They use four hierarchical logic levels: push logic, buffer logic, pull logic, and push-pull logic, in which priority rules are applied to do workstation selection task. Their algorithm do not give a good performance on complex dispatching rules. Similar heuristic rules are introduced by Yim and Linn (1993), Taghaboni (1997), Tan and Tang (2001), and Kim, Tanchoco and Koo (1999).

Dispatching rules that consider reassignment of moving vehicles are also proposed to respond the dynamic environment. A vehicle reassigns their original move request to a better move request. Bozer and Yen (1996) propose Modified Shortest Travel Time First (MODSTTF) and bidding based device dispatching (B^2D^2). MOD STTF assigns empty vehicles to move requests based on the proximity of the vehicle and the load location, and each vehicle has only one request at a time. Empty vehicle may be reassigned to another move request or an empty vehicle may “release” another emtpy vehicle. B^2D^2 rule works in a similar sense to MOD STTF, but it is more complicated. They show that MOD STTF and B^2D^2 outperform STTF. Le-Anh and De Koster (2006) confirm Bozer and Yen findings on their report.

Decentralized Dispatching Rules

Decentralized control systems dispatch vehicles based on local information only. The main advantage of decentralized control systems is its simplicity; its efficiency is, however, low. Bartholdi and Platzman (1989) obtain the mean time required to traverse a single-loop, and derived a condition under which the system would meet the required throughput for the case where travel time is equal to transport time. They propose a decentralized greedy heuristic FEFS. In FEFS, a fleet of AGV can deliver unit loads quickly on a simple loop track. In their research, a vehicle, which can carry up to three loads, travels in a unidirectional loop and transports loads according to the FEFS rule. While a vehicle circulates a loop continuously, it picks up the first load encountered whenever it has space available, and deliver the load whenever the destination is reached. In our study, FEFS is used as our baseline model to be compared with IVCR. In summary, FEFS has some advantages such as a simple implementation due to the dispatching decisions that are made based on local information and its good performance in the unidirectional loop. However, FEFS rule has drawbacks such as no lot priority implementation, no job cancellation and reassignment, and its disability in a complex system.

Koster and Van der Meer (1998) compare the performance of several control rules such as MODFCFS and NVF in a large-scale practical case study. A demonstration of centralized control rules shows a lower average load-waiting time than those obtained by decentralized control rules. However, most vehicle dispatching rules proposed did not consider congestion and changing demand on the system. Therefore, research on extending decentralized dispatching rules to more dynamically changing conditions is needed.

Smart Vehicles

Berman and Edan (2002) describe decentralized control as a vehicle control strategy that provides the flexibility to maintain complex applications by distributing computation load among various units, thus decreasing overall computation complexity.

They also mention that decentralization increases fault tolerance and system scalability that could create problem in maintaining unit coordination. They propose decentralized control systems in order to tackle vehicle system functionality: system management, navigation, and load transfer. Agents representing smart vehicles collect the workstations' states directly and dynamically to decide their next task.

Lindeijer (2003) uses an agent-based-technology to determine the best, deadlock-free route a vehicle can take, though the deadlock can be avoided in several other ways such as the use of single-loop or tandem-loop guided-paths. There are well known expert systems based on stochastic optimization. Naso and Turchiano (2005) propose a multicriteria dispatching strategy based on computational intelligence to simultaneously take into account multiple aspects (i.e. nonneglible dimensions of the vehicles with respect to the distances traveled, the possibility of conflicting routes, vehicle or workstation blocking, and related circumstances) in every dispatching decision. They adopt Genetic Algorithms (GA) to adjust the weights associated to each decision criteria in the global decision algorithm. They obtain significant results in their experiments proving that the genetics algorithm can be implemented on vehicles.

The main advantage of the decentralized control system, including smart vehicles, is its simplicity. However, these control systems are inefficient. The centralized control system is more complex to implement but can provide a better performance (De Koster, Le-Anh, and Van der Meer, 2004). Another approach to respond the dynamic manufacturing environment is proposed by Norman (2002).

Traffic Management (Norman, 2002)

Norman (2002) proposes a simulation model of the routing of vehicles along the path system where alternate paths exist and a path selection is determined at the decision point based on the dynamic analysis of traffic congestion along each possible route towards some destinations. He develops a recursive search algorithm to iteratively evaluate each possible route when a vehicle encounters a routing node. The vehicle, then, is directed along the least congested path towards it destination. The route evaluation is done whenever a vehicle reaches the routing nodes or the so called decision points. Simulation results show that the algorithm works well in finding the best path and avoiding congestion for a vehicle to travel from its initial position to the destination position. However, this algorithm may create an efficiency problem since a vehicle has a higher probability to take a longer route in reaching the destination. This situation can be solved by an implementation of vehicle cancellation and reassignment which is applied in our proposed rule. By its definition, a vehicle cancellation occurs whenever a vehicle terminates its current job, and vehicle reassignment occurs whenever a vehicle adopts a better job to replace the original one. In our study, vehicle cancellation and vehicle reassignment are done by moving-to-park vehicles and moving-to-pickup vehicles.

In summary, Norman's traffic management has several main advantages such as (1) a balance number of vehicles on every alternative path; (2) vehicles choose the least crowded path among every alternative paths; (3) congestion is no longer put under assumption in AMHS design. However, in Norman's traffic management, lots selection based on job priority is still not considered. Moreover, vehicle breakdowns and tool breakdowns are still assumed to be not in existence. We developed the modified

Norman's algorithm for a comparison with our proposed IVCR. Unlike the original Norman's traffic management algorithm, the modified Norman's algorithm (MODNORMAN) responds to the lot priority. *Pseudo code* representation of Norman's algorithm is shown as follows:

```
If a vehicle approaching a node as a result of alternate routing:
      Set final destination to temporary destination
      Set vehicle destination to final destination
If it is a routing node, then:
      Call (Route Selection Function)
If constructed path is not null then:
      Dispatch vehicle
      Update the move-job
```

Route Selection Function

```
Increase recursion level.
if location is a final dest or recursion level has reached preset
depth, then:
      if distance from considered location to final destination
      is less than the total distance, then:
      if new weight is less than previous best weight saved
            save new weight as new best weight
      decrement recursion level
      remove last location from current constructed path
      return
else:
      determine next adjacent control point to the last point
      evaluated.
      if it is a current location, then:
            decrement recursion level
            remove this location from the evaluated path
            return
      else:
            insert this loc into the path for evaluation.
            call route analysis func
if all adjacent control points have been checked, then:
      decrement recursion level
      remove last loc from the path under evaluation
return
```

CHAPTER III

PROPOSED INTELLIGENT VEHICLE CONTROL RULE (IVCR)

This chapter provides a thorough explanation of the proposed IVCR. It is organized as follows: introduction to AMHS description; explanation of experimental environment and setup; factors affecting AMHS, and finally a discussion on rules and followed by IVCR.

AMHS description

The development of 300mm wafer manufacturing provides a high yield and reduced cycle time per chip. However, it also raises the need for an automated material handling system (AMHS) because of the following reasons:

1. Various processes are performed at least once on the wafers.
2. It travels close to 8-10 miles during the processing and visits 250 process tools to undergo several processes.
3. The 200% larger of the area and heavier of the weight of 300-mm wafers.

The production system of AMHS has both physical components and informational elements (Nazzal and McGinnis, 2007). In the physical components there are several general devices implemented in the system, which will be explained thoroughly as follows (i.e. AutoMod based SEMATECH model) (Agrawal, 2006):

1. Intrabay: a unidirectional closed loop that contains several process tools. Typically each bay contains similar process tools and material handling is supported by various AMHS devices.
2. Interbay: an unidirectional closed loop connecting all intrabays together.
3. Stocker: a work-in-process (WIP) storage that is located in each bay. It serves as a connection point between interbay and intrabay transport systems.
4. Wafer carrier: an object being transferred by the AMHS, of which there are two types being considered in 300-mm wafer manufacturing. The first type is an open cassette (OC), which exposes to cleanroom, while the second type is a front-opening unified pods (FOUP), which encloses wafers (SEMATECH, 1999).
5. Automated-guided vehicle (AGV): a vehicle that works automatically.
6. Overhead hoist transport (OHT): a space efficient vehicle travelling above the main fab floor.
7. Process Tool: a workstation that will do various job processing activities (i.e. cleaning, film deposition, photolithography, etching, ion implantation, metallization, and inspection). Typically, each process tool consists of an input port, and an output port.
8. Loadport: an input/output port that is located in each workstation for loading and unloading purposes. Each port can accommodate one vehicle at a time.

According to Nazzal and McGinnis (2007), two of AMHS informational components are dispatching policies and AGV velocity (Nazzal and McGinnis, 2007).

From the operation point of view, this research considers a typical semiconductor fabrication line for 300mm AMHS consisting of an interbay system, and several loops branch on both sides to intrabay systems. Figure 1 shows a layout of the wafer fabrication under study. FOUPs arrive in a system with the interval of the exponential distribution (Nazzal and McGinnis, 2007).

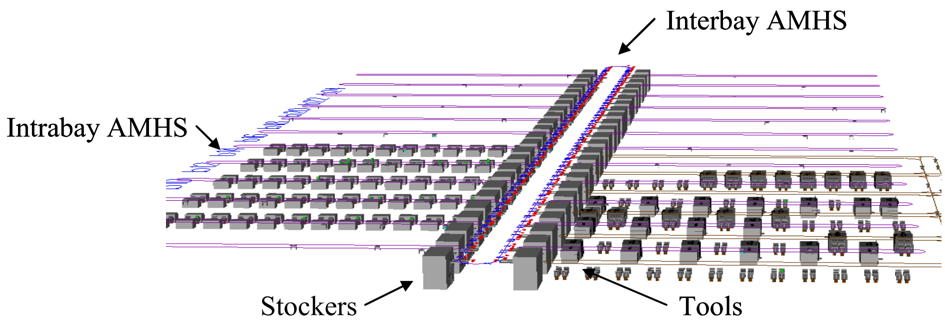

Figure 1 Typical Wafer Fab Layout with the AMHS.

The basic model presented here assumes that vehicles travel on a unidirectional closed loop with six bypass tracks. These bypass tracks are used to prevent a congestion caused by one or more dynamic factors such as vehicle breakdowns, tool breakdowns or high demand on stations. The model is designed without the ability for vehicles to pass each other, even when they make a stop to drop off/pick up a load at a stocker. Each process tool and each stocker has an input port to where vehicles drop off FOUPs, as well as an output port from where a vehicle picks up and delivers FOUPs to the next destinations. These load ports are interaction points between production and storage systems. FOUPs are moved in four different ways: those whose source location and destination location are within the same bay, those whose source location and destination location are within the same cell but are in different bays, those of which one of the source and destination location are a stocker and process tool respectively (Kim, Oh, Chae, and Lee, 2007).

The assumption of the whole operation works as follows: The FOUP that has finished its process by a process tool is taken to the nearest stocker within the same bay. The transporting process is done by an intrabay vehicle such as AGV or OHT. Next, the FOUP is delivered to the destination stocker and carries out the next process. Then, the FOUP at the destination stocker waits to be picked up based on a request from the production equipment in the next process step. It is unloaded from the destination stocker and delivered to one of the process tools by intrabay equipment. This sequence is repeated until a FOUP finishes its entire process plan. In order to model the environment, the software used for simulation is AutoMod 12.1. (Brooks Automation, 2001)

AMHS Simulation on AutoMod

In this thesis, simulation has been used as an important tool for modeling and analyzing behaviors of dispatching rules. Law and Kelton (2000) mention the simulation as one of the main tools to study real-life systems. The main advantage of the simulation approach is that complex, real-world systems which cannot be accurately explained by a mathematical model can be evaluated analytically. However, simulation results can be difficult to interpret. Simulation models have to be constructed, validated and verified carefully. Since each run of simulation model gives an estimation of the model's response for a particular set of input factors, there is a need to apply statistical analysis techniques in order to get valid and reliable results (Lin, Wan, and Yen, 2001). This section will discuss the experimental environment, the experimental setup, and the statistical analysis.

Experimental Environment

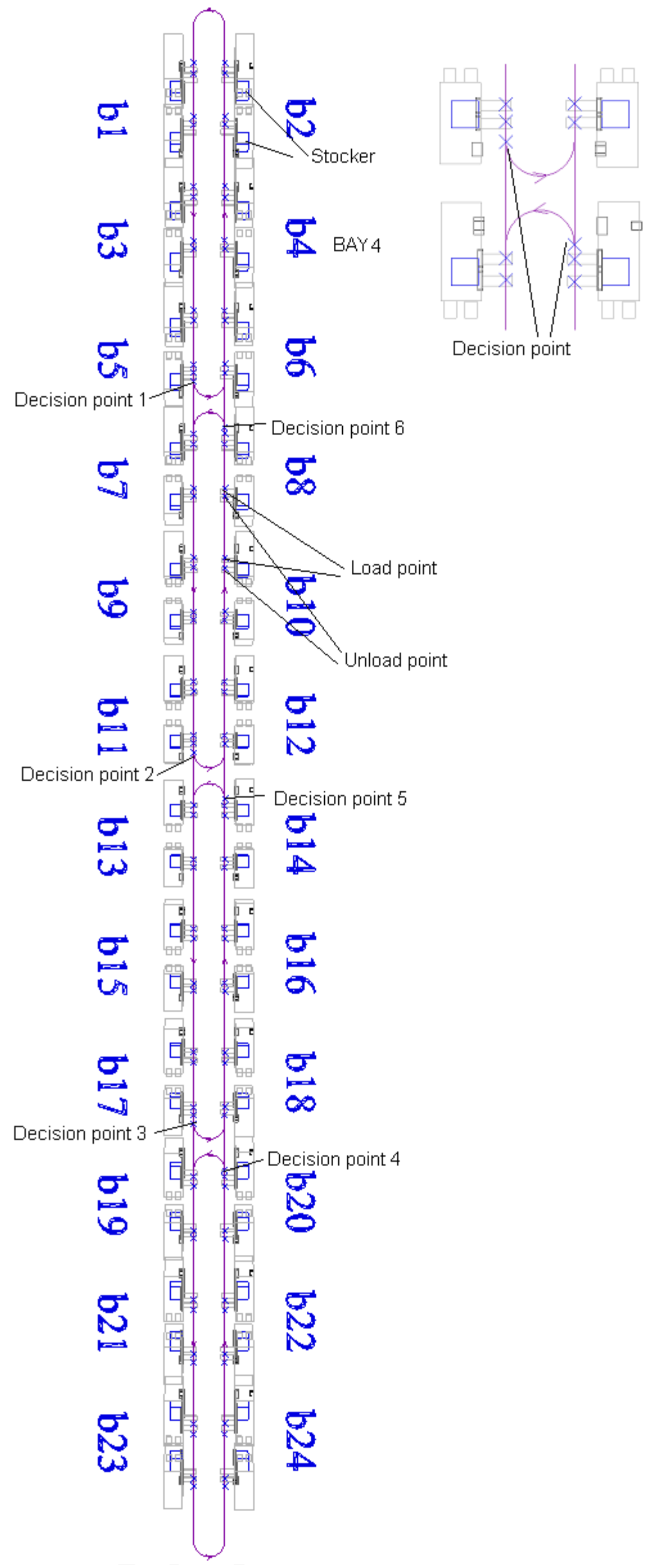

Figure 2 AMHS Interbay System.

Simulation model used in this study is a generic 300mm wafer fab model (SEMATECH, 2000). This SEMATECH model has 24 bays. Each bay is 105 ft long, and the aisle that separates the production equipment is five feet wide. There are two stockers that connect every bay to the interbay system, one acts as an input port to store the incoming carriers to the bay and the other acts as an output port (SEMATECH, 1999).

Our experimental AMHS layout is modeled based on the following assumptions:

- Vehicles operate with breakdowns.
- Stockers operate with breakdowns.
- All vehicles have uni-load capacity.
- There is no operational time lost due to recharging vehicles.
- There is sufficient space of waiting loads.

Experimental Setup

The simulation model starts idle and empty. The simulation runs until it reaches a steady state before collecting and analyzing the performance statistics. The simulation is run for 10 days with a 1 day warm-up. One replication of warm-up and ten replications are run to make this analysis

Rules

In this study, the performance of intelligent vehicle control rule is compared with other rules. The first rule that works as a baseline model is First-Encounters-First-Served (FEFS) dispatching rule. This rule assigns a workstation to a vehicle based on the first request a vehicle encounters. The second rule is a proposed rule that is modified version of Norman's traffic management algorithm (MODNORMAN). The rule recursively evaluates prospective paths along the vehicle's travel path from an initial location to a destination location and considers the best path as the solution (Norman, 2002). However, instead of using the number of claims that is proposed by Norman, shortest distance and the status of the next location are maintained in order to perform this task. The last rule is the Intelligent Vehicle Control Rule (IVCR). Inspired by Dijkstra's shortest path (Koster and Van der Meer, 2002) and Norman's traffic management (Norman, 2002), our proposed algorithm uses both the workstation-initiated dispatching rule and the vehicle-initiated dispatching rule. IVCR utilizes a threshold value in order to determine system congestion. This value will be compared with the sum of the number of claims on the path, the average latest travel time of vehicles using the path, and latest travel time made by a previous vehicle that has the same original and destination location. The proposed IVCR works as follows:

I. Workstation-initiated dispatching rule.

1. Lot arrives at the system, and waits in one of the available stockers.
2. Lot sends a vehicle request.
3. Next, idle vehicle responds to the request upon arriving at a decision point on the system.

II. Vehicle-initiated dispatching rule.

In this thesis, the vehicle-initiated dispatching rule goes by a new name, Intelligent Vehicle Control Rule (IVCR) and it works as follows:

1. Vehicle reaches a decision point in the system.
2. Check the status of the vehicle. If it is a moving-to-pickup vehicle, it will execute the Retrieve algorithm, as shown in Figure 6, if it is a moving-to-park vehicle, it

will execute a Move algorithm, as shown in Figure 7, and otherwise it will execute the original job scheduled for the vehicle, as shown in Figure 5.

Note: Scheduled job cancellation and reassignment are applied only to these two types of vehicles. Due to hardware limitations, it cannot be applied to moving-to-deliver vehicles (i.e. an extra queue is needed to store a temporary moving-to-deliver a vehicle' load whenever it finds a better job to do).

3. Check congestion on a path for the job selected. Congestion algorithm will be applied to all three types of vehicles (i.e. moving-to-park vehicle, moving-to-pickup vehicle, and moving to deliver vehicle). This algorithm will use the threshold value in order to determine the congestion status (i.e. congested or not congested).

Retrieve algorithm (see Figure 6)

1. Search for hot lots between the decision point where the vehicle is location and all connected decision points, and put all the hot lots in an array, a hot-lot array.
2. Check the status of location of each hot lot's location in an array. If no congestion occurs, the vehicle claims the lot and updates its job schedule; otherwise, it checks the next available hot lot's location in the array. If all hot lots are within a congested path, begin to search for a regular lot.
3. Search for regular lots within a range and put all the available regular lots in an array.
4. Check the status of each regular lot's location in the array. If there is no congestion, the vehicle claims the lot and updates the vehicle's job schedule;

otherwise, it checks the next available regular lot's location in the array. If all regular lots are within a congested path, execute the original retrieve job.

5. Search for available locations within a range and check for a congestion at each location.
6. Dispatch vehicle to the next location by using the path with less congestion.
7. Update the vehicle's job schedule.

Move algorithm has similar steps to the Retrieve algorithm described above (see Figure 7). The algorithm works as follows:

1. Search for hot lots between the decision point where the vehicle is location and all connected decision points, and put all the hot lots in an array, a hot-lot array.
2. Check the status of location of each hot lot's location in an array. If no congestion occurs, the vehicle claims the lot and updates its job schedule; otherwise, it checks the next available hot lot's location in the array. If all hot lots are within a congested path, begin to search for a regular lot.
3. Search for regular lots within a range and put all the available regular lots in an array.
4. Check the status of each regular lot's location in the array. If there is no congestion, the vehicle claims the lot and updates the vehicle's job schedule; otherwise, it checks the next available regular lot's location in the array. If all regular lots are within a congested path, go to step 5.
5. Search for available locations within a range and check for a congestion at each location.
6. Dispatch vehicle to the next location by using the path with less congestion.

7. Update the vehicle's job schedule.

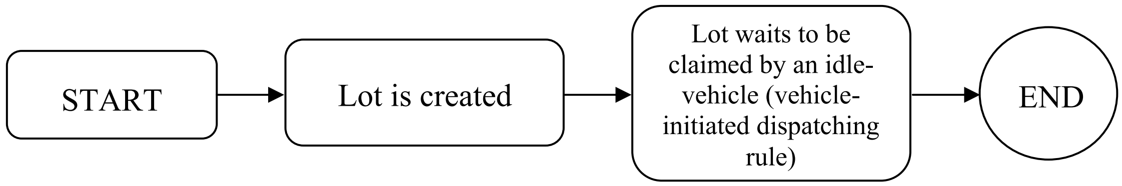

Figure 3 Workstation-initiated Rule.

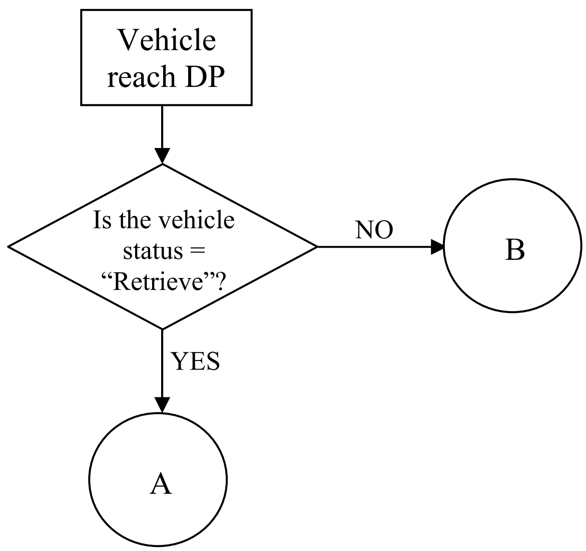

Figure 4 Vehicle-initiated Rule.

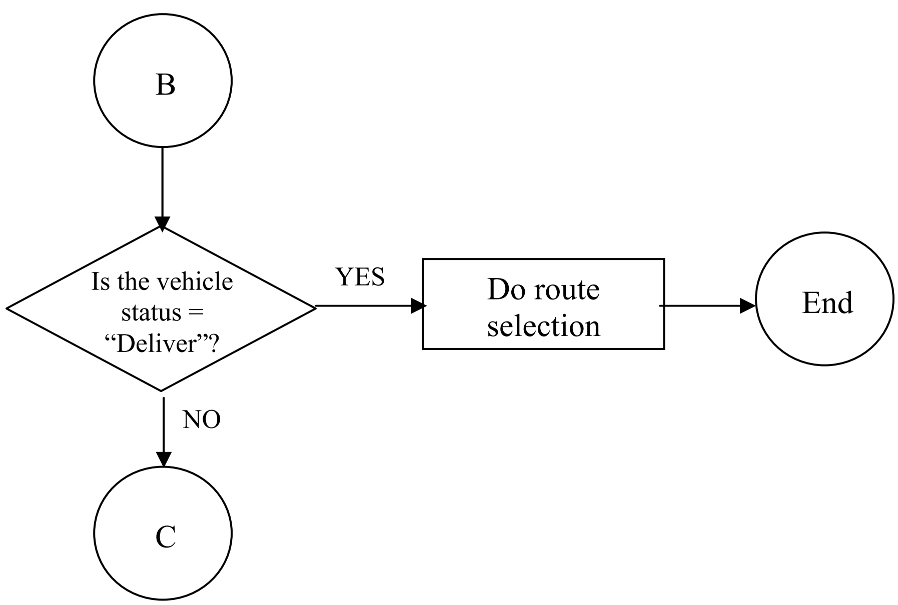

Figure 5 Deliver Algorithm.

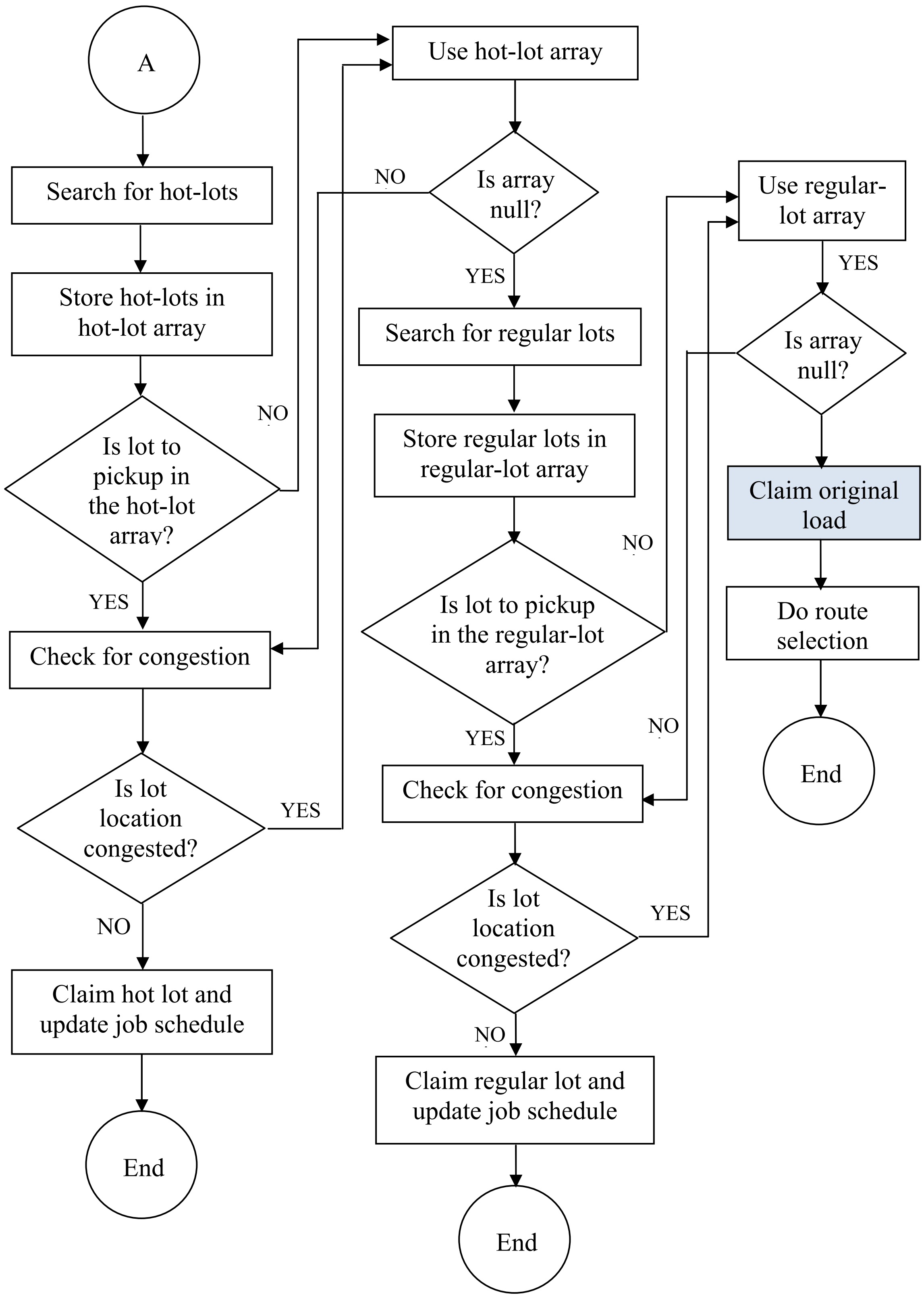

Figure 6 Retrieve Algorithm.

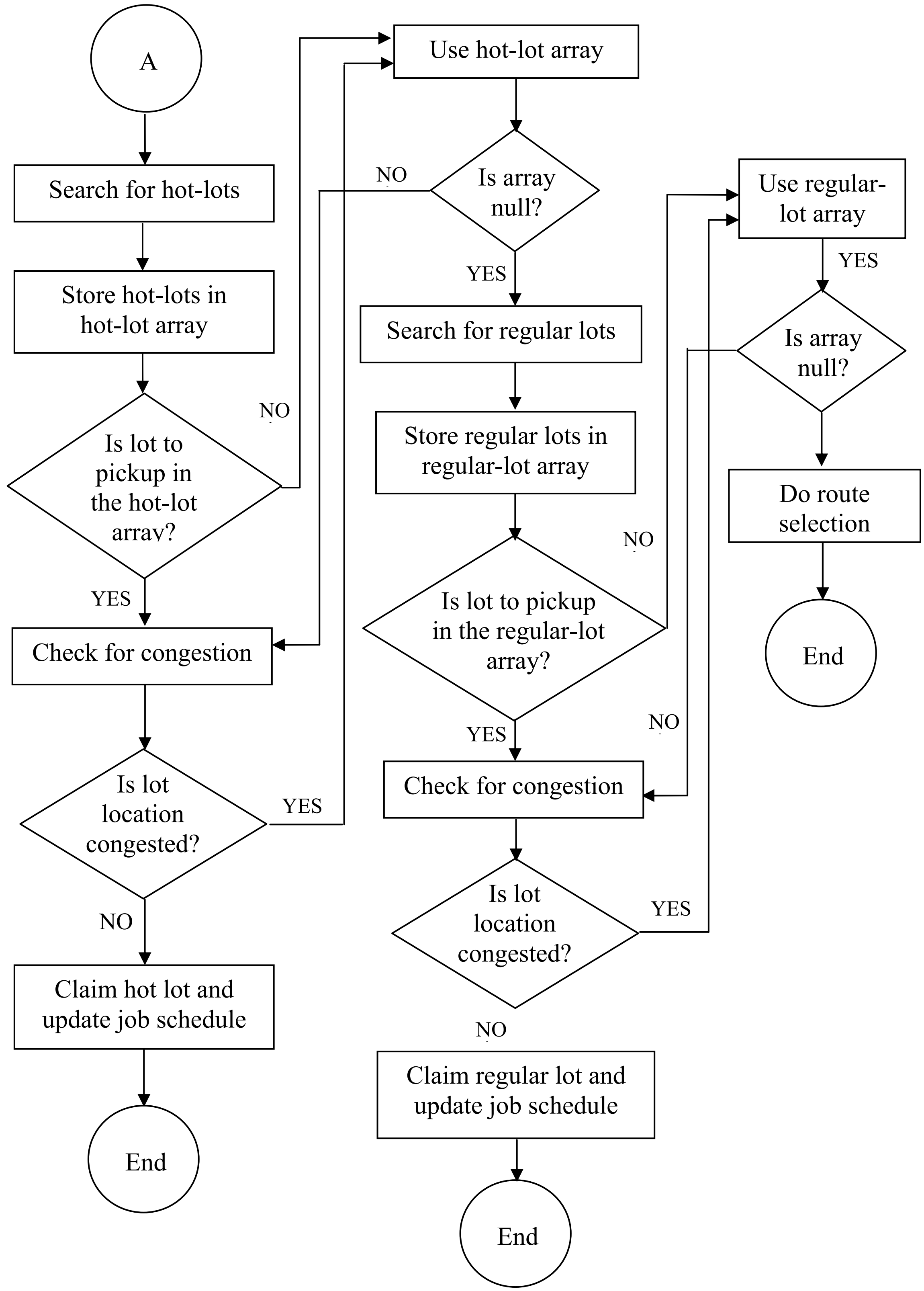

Figure 7 Move Algorithm.

In order to evaluate the status of the location for congestion, we consider and rank the following prerequisites:

1. Latest travel time from an origin decision point to the destination location.
2. Average latest travel time from an origin decision point to every location on the considered path.
3. Number of locations along the considered path that are being claimed.
4. The status of the next location. If the next location is claimed, it will be marked with value 1, 0 otherwise.

We, then, sum the values of all the above prerequisites and standardize its value. This value is compared to a pre-defined threshold value (θ). The value has to be less than θ.

CHAPTER IV

EXPERIMENTATION

Simulation approach experiments are conducted using AutoMod 12.1 and AutoStat to compare performance of rules. Statistical Experiments were run and analyzed to determine the effectiveness of IVCR. Experimental results are discussed in this chapter.

Design and Analysis of Experiment

We use two regular FOUPs as our transport carriers; the first is used to transport hot lot and the second is for regular lot. Hot lot has higher priority than the regular lot. In our experiment, the lot priority ratio is put into two level cases. The first level has 20% of hot lots and 80% of regular lots of the entire lot system, and the second has 10%-90% of hot lots and regular lots. The corresponding carrier has a release rate of 20,000 wafers/month (wpm) (800 carriers/month) (Nazzal and McGinnis, 2007). Two levels of the factor number of vehicles are used: 15 vehicles and 30 vehicles. We use three constant factors such as Mean-Time-To-Failure (MTTF), load time, vehicle velocity, and threshold value, which are 180000 seconds, 15 seconds, 6.6 feet/second, and 100, respectively. Table 2 summarizes experimental factors used in the experiments. For each combination of experimental factors, a replication of ten runs was implemented in order to determine the result. The length of one run is 50 days for each rule. Each run has a warm up period of 1 day. Average delivery times (DT), and average throughputs (TU) are the main performance criterion.

Statistical analysis is used to interpret our experimental results. Law and Kelton (2000) indicate the importance of confidence intervals in stochastic simulation. The confidence interval comparison of two responses shows better results than by simply comparing the average values of the corresponding responses (of the two alternatives). Design Expert version 7.1 is used to perform the statistical analysis (Stat-Ease, 2008).

Table 1 Experimental Factors.

Factor	*Levels*
Load Time	15 sec
MTTF	180000 sec
Speed	6.6 feet/sec
Number of moves	1, 2
Number of vehicles	15, 30
Lot priority ratio (Hot lot – Normal lot)	20-80, 10-90
Threshold value	100

Results

Performance Evaluation of All Rules for 15 and 30 Vehicles

The purpose of this experiment is to compare the performance of First Encounter First Served (FEFS), Modified Norman (MODNORMAN), and Intelligent Vehicle Control Rule (IVCR) in terms of DT and TU. We develop four experimental cases in order to perform this experiment (see Table 2). The first case uses the number of moves 1 and the lot priority ratio 20-80; the second case has the number of moves 2 and the lot priority ratio 20-80; the third case uses the number of moves 1 and the lot priority ratio

10-90. The last case uses the number of moves 2 and the lot priority ratio 10-90. These tables show other experimental responses, including:

1. Hot lot throughput (Hot Lot TU)
2. Regular lot throughput (Regular Lot TU)
3. Hot lot delivery time (Hot Lot DT)
4. Regular lot delivery time (Regular Lot DT)
5. Hot lot retrieve time (Hot Lot RT)
6. Regular lot retrieve time (Regular Lot RT)
7. Hot lot transport time (Hot Lot TT)
8. Regular lot transport time (Regular Lot TT)

Table 2 Experimental Cases.

Cases	*Factors*	
	Number of Moves	*Lot priority ratio*
Case 1	1	20-80
Case 2	2	20-80
Case 3	1	10-90
Case 4	2	10-90

The effect of the number of vehicles can be seen throughout the experimental cases. Results show that larger number of vehicles leads to higher TU (30 vehicles) for both hot lots and regular lots. On the other hand, shorter delivery times and retrieve times are achieved when 30 vehicles are used. However, a larger number of vehicles (30 vehicles) results longer transport times due to delays caused by congestion in the system.

Some of these results are not in steady state since there are not a sufficient number of vehicles, as indicated by the high DT and high RT. The situation can be seen from the performance of MODNORMAN. Table 4 shows that MODNORMAN rule has Regular Lot DT 2322355.41 seconds for 15 vehicles, 45480.23 seconds for 30 vehicles. Also, it has Regular Lot RT 232083.06 seconds and 45079.67 for both 15 and 30 vehicles, respectively. Results indicate that the IVCR positions itself on the first place among other rules in all cases. IVCR has the largest number of throughputs and the fastest delivery times. The second place is positioned by FEFS and is followed by MODNORMAN. Table 3 – 6 summarize the performance results of all rules.

Table 3 Summary of Results in the Case of Number of Moves = 1 and Lot Priority Ratio = 20-80.

Rules	*FEFS*		*MODNORMAN*		*IVCR*	
Responses	*15*	*30*	*15*	*30*	*15*	*30*
Ave-TU (hot lot)	47759.9 (±5789.65)	55108.5 (±6707.08)	27101.2 (±13201.02)	55153.3 (±6740.72)	47723.1 (±5660.98)	55158.3 (±6782.16)
Ave-TU (regular lot)	213798 (±5877.48)	206648.9 (±6724.93)	95545.4 (±42973.31)	201669.70 (±6220.78)	214194 (±5778.25)	206896.8 (±6702.42)
Ave-DT (hot lot)	656.44 (±9.99)	417.49 (±11.16)	40141.14 (±4727.1)	808.36 (±105.59)	284.07 (±9.64)	256.62 (±11.49)
Ave-DT (regular)	636.57 (±8.47)	419.48 (±4.34)	232355.41 (±102968.41)	45480.23 (±9117.88)	279.65 (±1.75)	254.69 (±1.8)
Ave-RT (hot lot)	389.76 (±7.38)	147.30 (±2.74)	39818.63 (±4724.71)	404.09 (±93.47)	101.21 (±2.85)	54.93 (±1.16)
Ave-RT (regular lot)	391.73 (±6.56)	147.05 (±2.66)	232083.06 (±102972.77)	45079.67 (±9113.97)	103.15 (±0.42)	55.98 (±0.69)
Ave-TT (hot lot)	266.67 (±12.39)	270.19 (±11.75)	332.57 (±11.78)	404.26 (±21.77)	182.85 (±8.66)	201.7 (±10.6)
Ave-TT (regular lot)	244.84 (±2.89)	272.43 (±2.77)	329.52 (±6.31)	406.18 (±5.82)	176.5 (±1.84)	198.71 (±1.98)

Table 4 Summary of Results in the Case of Number of Moves = 2 and Lot Priority Ratio = 20-80.

Rules	*FEFS*		*MODNORMAN*		*IVCR*	
Responses	*15*	*30*	*15*	*30*	*15*	*30*
Ave-TU (hot lot)	56992.6 (±6572.21)	51688.7 (±4953.6)	20059.1 (±12896.58)	51673.4 (±4948.5)	57054.2 (±6572.99)	51827.6 (±4897.96)
Ave-TU (regular lot)	204917.2 (±6778.82)	210397.8 (±5020.5)	57182.7 (±33875.32)	203931.7 (±4979.37)	204928.8 (±6335.31)	209914.8 (±4880.99)
Ave-DT (hot lot)	660.02 (±11.8)	417.91 (±15.39)	34980.66 (±4500.22)	866.2 (±101.12)	288.22 (±6.78)	256.39 (±10.1)
Ave-DT (regular)	643.67 (±5.99)	419.89 (±3.31)	153846.34 (±84836.55)	54313.99 (±13356.61)	278 (±2.25)	256.14 (±2.64)
Ave-RT (hot lot)	395.28 (±7.44)	146.64 (±2.06)	34653.41 (±4498.6)	436.67 (±92.7)	100.58 (±2.77)	53.7 (±1.14)
Ave-RT (regular lot)	399.55 (±4.89)	145.9 (1±.45)	153582.54 (±84835.36)	53919.14 (±1355.8)	103.28 (±0.97)	55.96 (±0.56)
Ave-TT (hot lot)	264.73 (±9.21)	271.26 (±14.77)	343.83 (±16.61)	429.53 (±23.53)	187.63 (±7.3)	202.69 (±9.8)
Ave-TT (regular lot)	244.12 (±2.73)	273.99 (±3.67)	322.11 (±6.66)	403.38 (±6.28)	174.72 (±2.05)	200.18 (±2.34)

Table 5 Summary of Results in the Case of Number of Moves = 1 and Lot Priority Ratio = 10-90.

Rules	*FEFS*		*MODNORMAN*		*IVCR*	
Responses	*15*	*30*	*15*	*30*	*15*	*30*
Ave-TU (hot lot)	55935.2 (8041.3)	58250 (±5377.16)	43329.6 (±13994.45)	58359.5 (±5362.09)	55989.6 (±8199.79)	58396.7 (±5340.29)
Ave-TU (regular lot)	205766 (8188.26)	203948.80 (±5269.68)	125412.6 (±34964.54)	197297.2 (±5421.28)	205925.4 (±8026.13)	203735.1 (±5410.17)
Ave-DT (hot lot)	651.07 (17.01)	416.45 (±14.58)	50261.01 (±13485.03)	1013.21 (±156.65)	278.29 (±5.28)	256.37 (±8.05)
Ave-DT (regular)	635.76 (7.58)	420.73 (±4.79)	335539.05 (±93255.27)	57690.04 (±13782.66)	280.96 (±0.87)	254.18 (±1.96)
Ave-RT (hot lot)	389.02 (7.37)	146.63 (±1.64)	49943.25 (±13484.43)	585.31 (±158.52)	100.57 (±2.56)	53.97 (±1.09)
Ave-RT (regular lot)	390.99 (8.04)	147.21 (±1.88)	335268.55 (±93260.7)	57297.5 (13782.57)	103.55 (±0.91)	55.2 (±0.56)
Ave-TT (hot lot)	262.04 (12.02)	269.81 (±15.32)	325.96 (±15)	427.95 (±12.84)	177.71 (±4.77)	202.39 (±7.77)
Ave-TT (regular lot)	244.77 (2.92)	273.52 (±3.96)	326.47 (±3.7)	401.24 (±4.19)	177.41 (±1.42)	198.98 (±2.02)

Table 6 Summary of Results in the Case of Number of Moves = 2 and Lot Priority Ratio = 10-90.

Rules	*FEFS*		*MODNORMAN*		*IVCR*	
Responses	*15*	*30*	*15*	*30*	*15*	*30*
Ave-TU (hot lot)	46384.9 (±2755.57)	42754.8 (±7096.04)	34267.8 (±7683.63)	42563.8 (±6986.9)	46427 (±2794.19)	42620.7 (±7055.63
Ave-TU (regular lot)	215555.6 (±2769.1)	219453.1 (±7082.38)	140341.90 (±27525)	212276 (±6580.37)	215711 (±2563.02)	219457.4 (±6936.89)
Ave-DT (hot lot)	642.41 (±15.25)	420.41 (±8.38)	44257.19 (±1804.3)	764.96 (±68.04)	280.95 (±7.89)	260.3 (±9.04)
Ave-DT (regular)	648.12 (±7.35)	417.85 (±2.83)	331716.3 (±71186.2)	57800.44 (±6587.56)	280.57 (±1.29)	255.1 (±2.6)
Ave-RT (hot lot)	398.88 (±9.41)	147.18 (±2.92)	43719.48 (±1881.9)	370.46 (±62.28)	101.63 (±2.2)	56.72 (±0.62)
Ave-RT (regular lot)	398.29 (±7.26)	145.67 (±2.09)	325384.3 (±70267.5)	57400.62 (±6586.2)	103.25 (±0.78)	55.57 (±0.62)
Ave-TT (hot lot)	243.53 (±12.22)	273.23 (±8.29)	329.51 (±10.83)	394.52 (±22.02)	179.32 (±6.67)	203.58 (±8.92)
Ave-TT (regular lot)	249.83 (±2.54)	272.19 (±1.63)	326.75 (±3.99)	411.6 (±5.04)	177.31 (±1.38)	199.53 (±2.26)

Table 7 – 10 represent the Analysis of Variance (ANOVA) of each rule in responding the performance measures. On the analysis, we consider throughputs and delivery times for both hot lots and regular lots. Table 7 shows that Hot Lot TU is significant to the rules at $\alpha < 0.05$. Moreover, the number of moves and the number of vehicles also give significant contributions to the system (i.e. $\alpha < 0.05$). Interaction factor between the main effect Rules and the main effect Lot Priority gives α equals to 0.0464, and both interaction factors Rules-Number of Vehicles and Lot Priority-Number of Vehicles have α less than 0.0001. Thus, these interaction factors have significant contributors to the system. However, the *R-Squared* value for Hot Lot TU's ANOVA is only 42.44%. This result indicates that the model does not model the TU variability, and more factors should be considered in the experiment.

Table 7 ANOVA for Hot Lot Throughput.

Source	*Sum of Squares*	*df*	*Mean Square*	*F Value*	*p-value Prob > F*
Model	23131850253.70	23	1005732619.73	6.92	< 0.0001
A-Rules	5654453497.76	2	2827226748.88	19.46	< 0.0001
B-Lot Priority	24638119.20	1	24638119.20	0.17	0.6809
C-No Moves	2259539076.70	1	2259539076.70	15.55	0.0001
D-No Vehicles	2955497368.84	1	2955497368.84	20.34	< 0.0001
AB	905162355.01	2	452581177.50	3.12	0.0464
AC	220053821.11	2	110026910.55	0.76	0.4701
AD	5655131736.18	2	2827565868.09	19.46	< 0.0001
BC	2422074916.84	1	2422074916.84	16.67	< 0.0001
BD	792004901.20	1	792004901.20	5.45	0.0205
CD	677856565.20	1	677856565.20	4.67	0.0319

Table 8 shows that all main effects, except the main effect Number of Moves, are significant to the Regular Lot TU at $\alpha = 0.05$. Therefore, we can conclude that the main effect Number of Moves does not give any important impact to the system since it has $\alpha > 0.05$ (0.3896). Similar case is experienced by the interactions effects. All interaction effects, except the interaction factor AC (i.e. the interaction between the main effect Rules and the main effect Number of Moves) give significant impact to the system. The R^2 for this experiment is approximately 75.39%.

Table 8 ANOVA for Regular Lot Throughput.

Source	*Sum of Squares*	*df*	*Mean Square*	*F Value*	*p-value Prob > F*
Model	409352001323.90	23	17797913101.04	28.76	< 0.0001
A-Rules	166479347800.36	2	83239673900.18	134.52	< 0.0001
B-Lot Priority	7576243851.04	1	7576243851.04	12.24	0.0006
C-No Moves	459822935.00	1	459822935.00	0.74	0.3896
D-No Vehicles	65451818799.04	1	65451818799.04	105.78	< 0.0001
AB	9733535421.52	2	4866767710.76	7.87	0.0005
AC	559482051.56	2	279741025.78	0.45	0.6369
AD	131254803477.52	2	65627401738.76	106.06	< 0.0001
BC	6845848121.70	1	6845848121.70	11.06	0.0010
BD	4288249230.10	1	4288249230.10	6.93	0.0091
CD	2485100505.10	1	2485100505.10	4.02	0.0463

Table 9 shows that the main effect Rules, the main effect Lot Priority, and the main effect Number of Vehicles to be significant to Hot Lot DT. They give significant impacts to Hot Lot DT. It can also be seen that changes in the number of throughputs per move does not impact the Hot Lot DT. Three interaction factors (i.e. Rules-Lot Priority, Rules-Number of Vehicles, and Lot Priority-Number of Vehicles) contribute significantly to Hot Lot DT. The R^2 for this experiment are approximately 91.81%.

Table 9 ANOVA for Hot Lot Delivery Time.

Source	*Sum of Squares*	*df*	*Mean Square*	*F Value*	*p-value Prob > F*
Model	59827773682.20	23	2601207551.40	105.30	< 0.0001
A-Rules	24049613279.45	2	12024806639.72	486.77	< 0.0001
B-Lot Priority	157935668.84	1	157935668.84	6.39	0.0122
C-No Moves	53627930.63	1	53627930.63	2.17	0.1421
D-No Vehicles	11651996844.74	1	11651996844.74	471.68	< 0.0001
AB	317377774.56	2	158688887.28	6.42	0.0019
AC	107534373.90	2	53767186.95	2.18	0.1159
AD	22871876567.54	2	11435938283.77	462.93	< 0.0001
BC	556275.22	1	556275.22	0.02	0.8809
BD	154427346.47	1	154427346.47	6.25	0.0132
CD	50235634.81	1	50235634.81	2.03	0.1553

Table 10 shows that the main effect Rules, the main effect Lot Priority, and the main effect Number of Vehicles to be significant to Regular Lot DT. The interaction effect Rules-Lot Priority, the interaction effect Rules-Number of Vehicles, and the interaction effect Lot Priority-Number of Vehicles are also shown give significant impacts to the system.

Table 10 ANOVA for Regular Lot Delivery Time.

Source	*Sum of Squares*	*df*	*Mean Square*	*F Value*	*p-value Prob > F*
Model	2442228418670.00	23	106183844290.00	30.54	< 0.0001
A-Rules	1334685788335.30	2	667342894167.66	191.92	< 0.0001
B-Lot Priority	36693141919.70	1	36693141919.70	10.55	0.0013
C-No Moves	2243002439.18	1	2243002439.18	0.65	0.4228
D-No Vehicles	293410651353.59	1	293410651353.59	84.38	< 0.0001
AB	73382452062.69	2	36691226031.35	10.55	< 0.0001
AC	4489183862.19	2	2244591931.09	0.65	0.5254
AD	584756555239.73	2	292378277619.86	84.08	< 0.0001
BC	1813111452.17	1	1813111452.17	0.52	0.4710
BD	29341564654.98	1	29341564654.98	8.44	0.0041
CD	3470045986.34	1	3470045986.34	1.00	0.3189

Through the set of experiment on delivery times, we observed that the changes in the number of moves does not give any significant impacts to both hot lot and regular lot delivery times.

Figure 8 – 11 show confidence interval (95% of mean) representations of hot lot delivery time and regular lot delivery time for three rules. There are no overlap intervals among the three rules performances. MODNORMAN performs the worst in delivering either hot lots or regular lots due to its lack of efficiency in dealing with congestion. MODNORMAN determines the congestion by comparing the number of locations that are claimed. The FEFS take the second place right after the proposed IVCR, which take the first place.

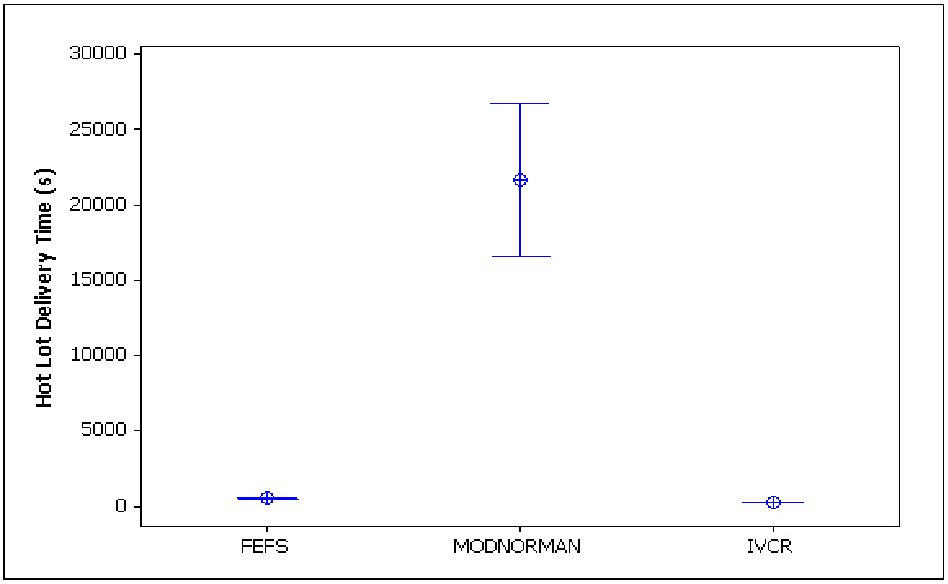

Figure 8 Hot Lot Delivery Times of 3 Rules (95% Confidence Interval).

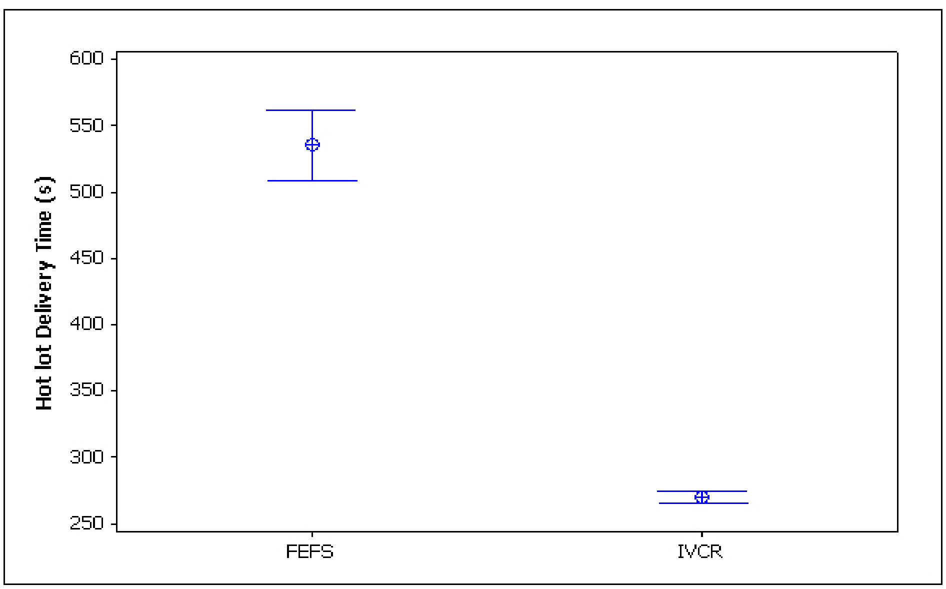

Figure 9 Hot Lot Delivery Times of 2 Rules (95% Confidence Interval).

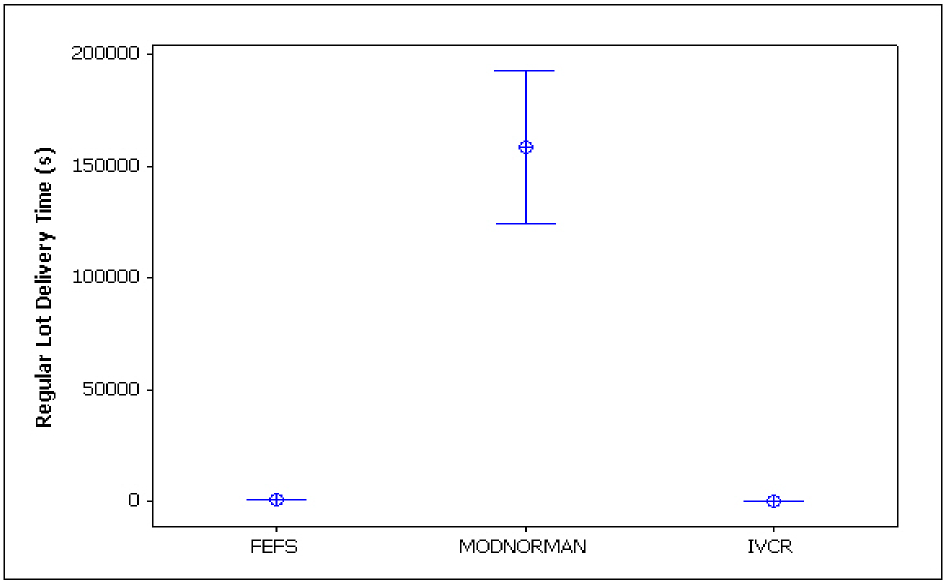

Figure 10 Regular Lot Delivery Times of 3 Rules (95% Confidence Interval).

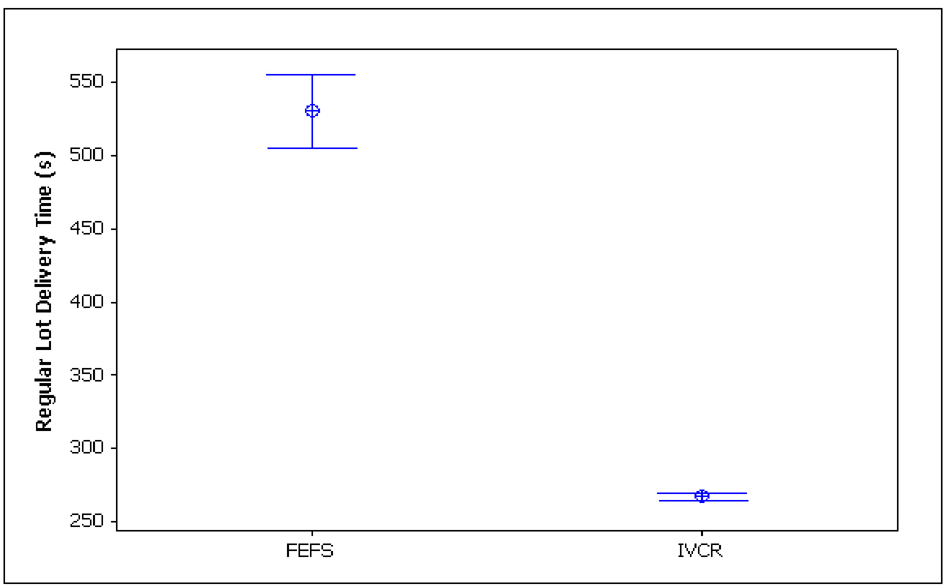

Figure 11 Regular Lot Delivery Times of 2 Rules (95% Confidence Interval).

CHAPTER V

CONCLUSION AND FUTURE RESEARCH

This research studies the vehicle control rule problem of Automated Material Handling Systems (AMHS). An improvement in AMHS system is needed due to the transition of wafer fab production from 300mm to 450mm. The model proposed by this research considers multiple vehicles operating in closed loop configurations with three bypasses. It takes into account the conditions that frequently occur in the dynamic environment.

Three rules including the proposed Intelligent Vehicle Control Rule (IVCR) were developed in order to present a simulation comparison of models performance; the first rule acts as a baseline of AMHS system. This rule is the original First Encounter First Served (FEFS) dispatching rule with assumptions of no existence of bypasses, congestions, breakdowns, and mixed lot production. The second rule is a modification of the traffic management system developed by Norman (2002), MODNORMAN. The evaluation done by this rule is based on the shortest distance taken from the vehicle's initial location to its destination location. The third rule, IVCR, is proposed by this thesis. IVCR uses a threshold value in order to overcome the considered dynamic environment conditions. The threshold value standardizes the sum-value of claimed stations, the average latest travel time between two decision points, and the latest travel time done by previous vehicle using the considered path.

Experimental comparisons of throughputs, delivery times, transport times, and retrieve times were conducted by using a hypothetical 300mm fab from International SEMATECH. A comprehensive set of experiments over a wide range of values for AMHS and the production system parameters that might influence the results was designed and analyzed in order to compare these rules. Our experiments show that IVCR is superior to the other rules in terms of DT and TU for both hot lots and regular lots. Vehicles under IVCR effectively search for available lots and followed by a congestion checking of the considered path.

Future Research

Technology of wafer fabs is developing over the years. Transition from 300mm to 450mm wafer fab should be followed by AMHS system improvement. A great need of 450mm wafer fab characterization should be done prior to the AMHS system experimentation. Since there is no generic approach for every wafer fab, thus, any dispatching rules and intelligent rules should tested under the conditions of the considered wafer fab.

Table 11 shows AMHS challenges in the next fabs generations, 450mm wafer fabs (Pettinato and Pillai, 2005). In the 450mm wafer fab, mix-product of wafers is introduced (i.e. hot lots and regular lots). Hot lots have higher priority than the regular one to be processed in the wafer fab production system. Moreover, though conveyors are recommended to reduce the risk of producing 450mm wafer fab, there is still no significant research on this area. Therefore, more intelligent systems are in great demand to fulfill this purpose.

Table 11 Wafer Fabs Requirement.

	300mm wafer	*450mm wafer*
Carrier size	Single carrier (25 wafers)	Multiple carriers, max 2 sizes:
		- Hot lots and high-mix production (5-10 wafers)
		- Low mix production (10-25 wafers)
Transport System	Tool-to-stocker/stocker-to-stocker deliveries.	Conveyors are recommended.
	Tool-to-tool delieries.	Vehicles with smarter control technology should be developed.
	Main technology used are vehicles based system and conveyors	
Vehicle capacity	Single carrier	Multiple carriers
Processing	Single or multiple wafer processing	Single wafer processing

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