USING SIMULATION IN DESIGN OF A CELLULAR ASSEMBLY PLANT WITH AUTOMATIC GUIDED VEHICLES

Dr. Onur M, Ulgen

Production Modeling Corporation
One Parklane Blvd.
Suite 1604 West. Parklane Tower
Dearborn, MI 48126

Pankaj Kedia

Dept. of Industrial & Systems Engineering
University of Michigan-Dearborn
4901 Evergreen Road
Dearborn, MI 48128

ABSTRACT

The paper has two main purposes. The first purpose is to give a comprehensive summary of previous research done in design and analysis of Automatic Guided Vehicle Systems (AGVS) and present a hierarchical taxonomy of the factors to be used in design of AGVS. The second purpose is to analyze the main and interaction effects of a large number of design and operational variables on the performance of a relatively complex cellular assembly system with AGVs.

In review of the previous research on AGVS, eighteen objectives are identified with the most common objective being the determination of the minimum number of AGVs required by the system. The techniques used by previous researchers in design of AGVS are classified into three categories, namely; optimization techniques, mathematical heuristic techniques, and simulation techniques. Factors and their levels to be considered in an AGVS arc classified into eight levels hierarchically, the highest level being the *Process Focus and* the lowest level being the Schedule-Related Considerations.

The cellular assembly system with AGVs considered in the study is a simplified version of a real AGVS previously investigated by one of the authors. The effect of transit paths is studied in the design of the system. The operational variables studied include AGV and job dispatching rules (rules for contention, job request selection, idle *vehicle disposition,* vehicle request selection, and release rules at the control points), and assembly time ratios between the mainline and subassembly processes. The result of the study showed that effective use of transit paths in a track layout design may eliminate the differences among the scheduling rules. The most significant scheduling rule in increasing the throughput is the job request selection rule by an AGV for a design with a minimum number of transit paths. Other scheduling rules do not appear to be significant in design of a cellular system with AGVs. Cycle time ratios between the subassembly and main assembly times have a significant effect on the minimum number of AGVs required to maximize the throughput of the system

1. INTRODUCTION

The material handling equipment manufacturers are developing and installing new AGV equipment and technologies before analytical models for optimum design and operation of such systems can be formulated and tested for applicability [Wilhelm and Evans 1988]. It is is taking place due to the competitive pressures in the market to rapidly increase the flexibility, reliability, and quality of the manufacturing systems. The manufacturers are also reluctant to publish their successful design due to the competitive nature of their business. The problems considered by researchers in the past have been fairly simple and do not allow for much of the real-life complexity to be incorporated in such models. Due to the complexity and combinatorial nature of the problems associated with large-scale AGVS, it is computationally intractable to develop mathematical models of such systems, except possibly those which are heuristic in nature. Simulation appears to be a common tool used in analysis and design of large-scale AGVS.

This study has two main purposes. The first purpose is to give a comprehensive summary of previous research done in design and analysis of Automatic Guided Vehicle Systems (AGVS) and present a hierarchical taxonomy of the factors to be used in design of AGVS. The second purpose is to analyze the main and interaction effects of a large number of design and operational variables on the performance of a relatively complex cellular assembly system with AGVs.

The cellular assembly system with AGVs considered in the study is a simplified version of a real AGVS previously investigated by one of the authors. The effect of transit paths is studied in the design of the system. The operational variables studied include AGV and job dispatching rules (rules for contention, job request selection, idle vehicle disposition, vehicle request selection, and release rules at the control points), and assembly time ratios between the mainline and subassembly processes. The result of the study showed that effective use of transit paths in a track layout design eliminates the differences among the scheduling rules. The most significant scheduling rule in increasing the throughput is the job request selection rule by an AGV for a design with a minimum number of transit paths. Other scheduling rules do not appear significant in design of a cellular system with AGVs. Cycle time ratios between the subassembly and main assembly times have a significant effect on the minimum number of AGVs required to maximize the throughput of the system.

In what follows, we first review the previous research Then, a hierarchical taxonomy for AGVS is given. The following section describes the cellular assembly system considered in the study. Factors considered in the cellular assembly system are explained next followed by a discussion on the major findings of the study. The final section of the paper gives the conclusions based on the results of the study.

2. REVIEW OF PREVIOUS RESEARCH

As a result of an extensive literature survey, a large number of variables (factors) were identified in the design and analysis of an AGVS [Kedia 1990]. These decision variables, in most cases, are interdependent. In other words, changing the value of one can change the optimal values of the other variables. Much of the published literature on AGVS consists of case studies, which are specific to a system. As a result, the objectives considered, factors used and assumptions made by one study are inapplicable to other cases. In general, the assumptions made in these studies greatly simplify the complexity of the problem. The assumptions made by previous researchers include the following:

- Blocking time is assumed to he zero.
- Vehicles do not pass each other.
- Travel times do not incorporate acceleration and deceleration.
- Empty vehicle travel is not accounted.
- Number of AGVs is fixed.
- Vehicles are always dispatched to pick up or drop off
- complete loads (i.e., load splitting is not permitted).
- Travel times between load/unload points are based on
- shortest route distances
- Track layout is fixed.
- Guide path direction is fixed.
- Load-unload points are fixed.
- The following is a list of the objectives considered by past researchers:
  - Determine minimum number of AGVs required.
  - Minimize total travel of loaded vehicles.
  - Minimize total travel of vehicles (loaded + unloaded).

- Determine near optimal unidirectional flowpath.
- Determine optimal location of pickup/transfer stations.
- Determine vehicle routing schedule.
- Estimate the effects of blocking.
- Maximize expected number of loads delivered per unit time over an infinite horizon
- Develop an intelligent controller, operable in real time, for a fleet of vehicles.
- Analyze global and local control systems for an AGVS.
- Investigate the timings at which unit loads should be introduced into assembly systems to achieve full system utilization.
- Postulate likely effects of some heuristic rules for dispatching AGVs on the performance of a job shop.
- Investigate the effect of the number of jobs allowed into an FMS on its system performance.
- Test the relative performance of different machine and AGV scheduling rules against the mean flowtime performance criterion.
- Investigate the effects of uni-directional and bi-directional flow.
- Investigate the effect of several key factors related to the AGVs on the overall performance of a Flexible Manufacturing System.
- Test effectiveness of an algorithm for the near optimal routing of AGVs in a Flexible Material Handling System.
- Investigate the effect of the number of jobs allowed into an FMS on its system performance.

The techniques used for AGVS design may broadly be divided into three categories :

(i) Optimization approaches.
(ii) Mathematical heuristic approaches
(iii) Simulation-based approaches.

The optimization approach was suggested by a number of researchers. Maxwell (1981) and Maxwell & Muckstadt (1982) were among the first to consider the problems in AGVS design. Their approach consisted of employing a mathematical model to determine the minimum number of AGVs to be used in a time independent model. Maxwell & Muckstadt (1982) also presented some analysis tools that could be used to evaluate the time dependent behavior of an AGVS. However, since time was essentially ignored, the authors assumed no blocking or congestion in the system. Newton (1985) presented a shortest path algorithm to determine the number of AGVs needed to operate with maximum effectiveness. He also presented a simulation model in FORTRAN that can be used to obtain the same objective. Gaskins and Tanchoco (1987) used a zero-one integer programming approach to determine the directional flow on a unidirectional path. Their study did not include factors such as travel of unloaded vehicles, vehicle blocking, and congestion.

Usher, Evans & Wilhelm (1988) suggested a mathematical-based heuristic approach. They developed a two-phase heuristic approach to determine the direction of AGV travel along the perimeter of each department and to locate the pickup/dropoff stations along the track such that the total travel of loaded vehicles per shift is minimized. Phase I was based on Gaskins and Tarichoco's (1987) integer program for choosing directional flows. Phase 11 used a heuristic to find improved locations for the load transfer stations. The overall efficiency of the system was based on total travel and not just upon loaded travel. Rabeneck, Usher & Evans (1989) developed an analytical model to simultaneously determine near optimal unidirectional flowpaths and locations for load transfer stations within an AGVS. Their model minimized the total distance traveled by the vehicles. It was an extension of Gaskin and Tanchoco's (1987) zero-one integer program and included loaded vehicle travel time.

Ashayeri, Gelders, and Van Looy (1985) were the first to use interactive simulation to study the dynamics of a system. They demonstrated the advantages of an interactive simulation package using a real-life case study. They used the model to determine the minimum number of AGVs required, the traveling routes of AGVs, operating rules for dispatching vehicles, bottlenecks, and the effects of different load conditions, speed of AGVs, conveyor lengths, etc. on the throughput of the system.

Egbelu (1987) compared the performance of four analytical approaches to vehicle estimation as compared to those obtained through detailed simulation under various dispatching strategies. He found that the non-simulation techniques far under-estimated the requirement under most of the dispatching strategies.

A number of researchers studied the effectiveness of AGV control rules on the performance of AGVS. Hodgson, King, Monteith, and Schultz (1987) have attempted to model an AGVS using Markov decision processes. Due to a large number of states in even a relatively simple AGVS, several constraints were set in order to make the Semi-Markov problem tractable. Taghaboni and Tanchoco (1988) have described the development of an intelligent controller for a fleet of free-ranging AGVs. Under the present circumstances, a simulation model is probably the only tool capable of handling many of the system complexities, functionalities and interaction characteristics of AGVs. Computer simulation modeling has been a relatively popular vehicle to study the scheduling rules in a system (Prasad and Rangaswami (1988), Egbelu and Tanchoco (1984, 1986), Sabuncuoglu and Hommertzheim (1989).

3. A HIERARCHICAL TAXONOMY FOR AGVS

In reviewing the previous literature, one can classify the decision variables to be used in AGVS as shown in Table 1. This table can be used to define a taxonomy for factors to be considered in an AGVS. The different levels at which decisions must be made may be summarized as follows:

(i) Process Focus.
(ii) Equipment Considerations.
(iii) Facility Considerations.
(iv) Workstation Considerations.
(v) Task-Related Considerations.
(vi) Travel-Related Considerations.
(vii) Schedule-Related Considerations.

It should be noticed that while the first two are hardware-based issues, the last five are design issues. This study considers most of the lower level design and operation factors included under Facility, Travel-Related and Schedule-Related Considerations. At each of these levels, decisions must be made for the successful implementation and operation of such systems. The taxonomy outlines the variables that need to be considered at different stages (limited to three stages of detail) of this decision making process.

At the topmost level, Process Focus, one has to decide on the type and number of vehicles to be present in the system. Once the decision about the type and number of vehicles has been made, the related equipment considerations come into the picture. These include the type of steering control needed for the vehicles, the routing method to be followed, the manner in which traffic would be managed in the system, load transfer mechanisms at the load and unload points, vehicle dispatch, vehicle guidance and the monitoring of the AGVS. The market place presents a number of combinations and a thorough study should be conducted to determine the optimal choices.

In order to ensure that the AGVS works optimally, not only are the equipment related considerations important but the facility considerations become significant too. The optimal number, location and arrangement of buffer, Lit, subassembly, mainline, and AS/RS have to be decided. An effort should be made to utilize the space in the most efficient manner. This would make the decision to be made at the next step easier.

The workstation related considerations include the layout and hence the work envelope and the length of the workplace. The processing time also gains importance and an effort should be made to distribute the time evenly over all the stations in the system. The design of the workstation directly affects the task-related considerations when transportation times are to be determined. The number of job types, lot size descriptions, and intensity of flow collisions and other issues that have to be considered.

In addition to the above considerations, one has to consider the travel and schedule related issues. These form the lowest level of the decision tree but are very important in the efficient operation of the system. At this stage, one has to decide on the type of flowpath in the system, track layout zoning considerations, dedication of AGVs, presence of battery change segments, staging areas, spurs

Table I : A Hierarchical Taxonomy of Design and Scheduling for Automatic Guided Vehicle Systems

Level	First Stage decisions(s)	Second Stage Decision(s)	Third Stage Decision(s)	Level	First Stage Decision(s)	Second Stage Decision(s)	Third Stage Decision(s)
Process Focus	Vehicle Type	AGVS Towing Vehicles	How many of each type?		Available Buffer Space		
		AGVS Unit Load Vehicles			at Each W/S		
		AGVS Pallet Trucks			WIP Inventory		
		AGVS Fork Trucks			Location Restriction		
		Light Load AGVs			WIP Inventory		
		AGVS Assembly Line Vehicle.....			Space Restriction		
		....			Turns at Bend	Sharp or Smooth	
		....		Workstation	Multiple/Parallel		
Equipment	Steering Control	Differential Speed Steer Control.		Considerations	Stations		
Considerations		Steered Wheel Steer Control			Station Work Envelope	Open or Closed	If Open - Restricted or
	Routing	Frequency Select Method					Unrestricted
		Path Switch Select Method			Station Length	Unrestricted or Restricted	
	Traffic Management	Zone Control	Distributed Zone Control		Processing Time	Fixed or Variable	If Variable - Deterministic
			Central Zone Control				or Stochastic
			On-Board Control				
		Forward Sensing	Sonic	Task-Related	Transportation Times	Fixed or Variable	If Variable - Deterministic
			Optical	Considerations			or Stochastic
			Bumper		Number of Job Types	Single or Multiple	
		Combination Control					
	Load Transfer	Manual Load Transfer			Lot Size Description		
		Automatic Couple & Uncouple				Intensity of Flow	
		Power Roller, Belt, Chain			Collisions		
		Power Lift/Lower	Pallet Fork Lift/Lower				
			Unit Load Lift/Lower	Travel-Related	Basis	Shortest Time/Distance	
			Fork Truck Loft/Lower	Considerations	Type of Flowpath		
		Power Push/Pull			Travel Time	Fixed or Variable	If Variable - Deterministic
	Vehicle Dispatch	Onboard Dispatch					
		OffBoard Call System			Track Layout		
		Remote Terminal			Zoning	Length of Zone	Maximum Number of AGVs
		Central Computer					in a Zone
		Combination			Dedication of AGVs	Number of Segments	Maximum Number of AGVs
	AGVS System Monitoring		Locater Panel				on a Dedicated Segment
		CRT Color Graphics Display				Battery Change Segments	
		Central Logging & Reporting				Blocking/Congestion	
	Operating Policy	After Last Job, Vehicle	If Moves - Cruises of Goes		Staging Area	Single/Multiple	Location
		Stops or Moves	to Staging Area		Presence of Spurs	Location	Length
	Guidepath Type	Uni, BI, or Mixed	If Mixed, Where Uni & Bi		Presence of Bypassses	Location	Length
	Elevator	Maximum Height			Real Time Consideration	Time Independent or	
	Bar Code Reading					Time Dependent	
	Speech Module				Travel Speed	Fixed or Variable	Acceleration/Deceleration
	Maximum Load Capacity						Considered
	Number of Loads if can	Single or Double Deck			Amount to be Carried	Fixed or Variable	
	Carry				Loading/Unloading	Known/To be Determined	Stochastic/Deterministic
					Times		
Facility	Optimal Number of						
Considerations	Workstations (W/S)			Schedule	Static/Dynamic		
	Optimal Number	Minimum Distance Between the		Related	Sequencing of Move	Restricted/Unrestricted	
	Of Buffers	Buffers		Considerations	Requests		
		Location of the Buffers			Intersection Problem	Control Zone	
	Optimal Number	Minimum Distance Between the			Dispatching Rules	Rule for Contention	Fifo/Closest/Priority
	Of Kits	Kits				Rule for Idle Vehicle Dispostion	Stop/Cruise
		Location of the Kits				Rule for Job Selection by AGVs	Priority/Closest
	Optimal AS/RS	Maximum/Minimum Number				Rule for Vehicle Selection	Fifo/Closest/Priority
	Parameters	of Input/Output Points				Release Rule at the Control Points	Match/Top
		Location of the AS/RS			Buffer Search Rules		
	Optimal Number						
	Of Machines per W/S						

and bypasses, load and unload times and travel speed of the AGVs. The AGV and job dispatching rules and sequencing of move requests also contribute towards the functioning of the system.

Thus, it may be apparent how the focus has shifted from the type of AGV best suited for the process in the system to the scheduling rules under which it should be operated. This taxonomy presents a systematic way to decide on an AGVS. Every decision taken at any level depends on the decisions taken at higher levels and affects the decisions that would be taken under the lower levels.

Also, the more appropriate the decision is at the higher levels, the easier it becomes to decide at the lower levels. This paper addresses this very issue. The travel and schedule related considerations in the system are based on how the facility considerations art handled. The dispatching rules in the system that are of tremendous importance under one design may be insignificant for some other design of the same system. Conversely, some scheduling rules may nullify the effects of a relatively poor track layout design of a system.

4. A CELLULAR ASSEMBLY SYSTEM: A CASE STUDY

The study described in this paper is based on a real-life cellular assembly system with AGVs. The original system consists of two major assemblies in two different sections within the plant as given in Figure 1. At each assembly area there are a number of mainline assembly cells and subassembly cells. The subassembly cells feed the mainline cells with the subassemblies for the final assembly. The assembly plant also has two High-Rise automatic storage systems which supply the mainline and subassembly cells with kits and/or parts that are used during the assembly processes. Buffers are used between the mainline and subassembly cells to store the (palletized) subassemblies and the empty subassembly pallets. Locations also exist by the mainline and subassembly cells to store the (palletized) kits/parts and the empty kit/part pallets. Two types of AGVs are used in the system depending on the type of load carried. Most of the subassemblies require at least one kit at the kit locations adjacent to the subassembly locations. These kits need to be transferred from the ASIRS to the kit location at the subassembly areas. In some of the cases, parts have to be transferred directly from the AS/RS to the subassembly locations to enable the start of the subassembly process. The completed subassemblies are stored at the buffer locations. Each subassembly has a set of buffer locations assigned to it to store the empty and full subassembly pallets. The original system was too large and it could be roughly decomposed into two smaller models. It was decided to modify the original system in such a way that it still represented the complexity of a cellular assembly system and at the same time was computationally less demanding in terms of computer execution time.

The above problem was taken and made generic by making the following changes:

* The number of cell locations was reduced by nearly 50 percent so that the problem becomes more manageable. Note that the reduced system still had a large number of locations (122) and pickup/dropoff points (92) in the system.

* The distances between the various subassembly and main line locations were indexed in such a way that they were spaced at equal distances from each other.

* The flip/flop nature of the mainlines was still kept but the flip/flop subassembly cells were eliminated.

* The operating logic of some of the cells was simplified (e.g., all kits were delivered to the kit locations in the cell and deliveries made directly to the assembly locations were eliminated).

It is expected that the results generated from the analysis of this study would be applicable to systems possessing the following characteristics:

(i) The system is cellular in nature and contains both the subassembly and main line assembly processes in such a way that the outputs from the subassembly processes go to the main line assembly processes.

(ii) Buffer storage exists between the subassembly and main line assembly cells.

(iii) A high variability in the cycle times of the various cells, both at the subassembly and main line locations is pm-sent.

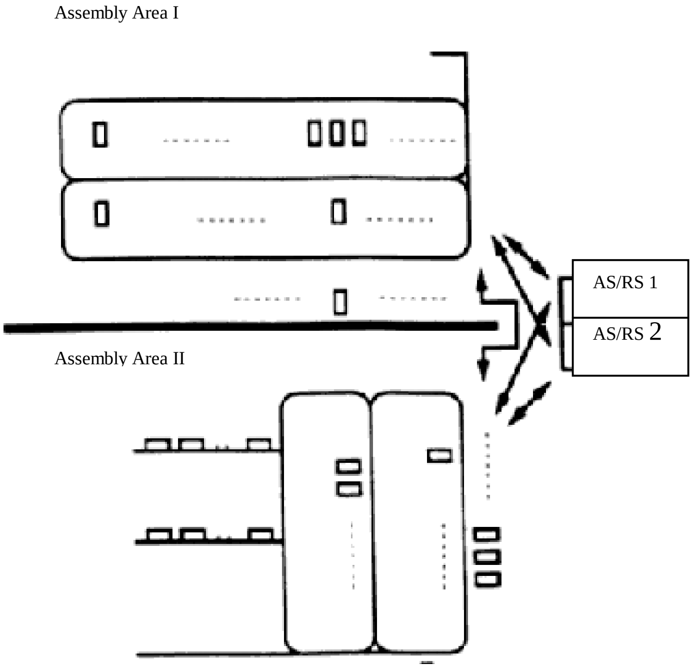

Figure 1 : Schematic Layout of Cellular Assembly System

Figure 2 shows the kit, subassembly, buffer, and mainline locations for subassembly cell I of the cellular assembly system considered in this study. Figure 2 design is called AGVS Design A in the study.

All the material handling in the system is done with AGVs. The AGVs are requested to carry palletized kits to the subassembly area from the AS/RS as well as returning empty kit pallets to the AS/RS from the subassembly area. Figure 3 depicts the states of an AGV in the system. An AGV may be in one

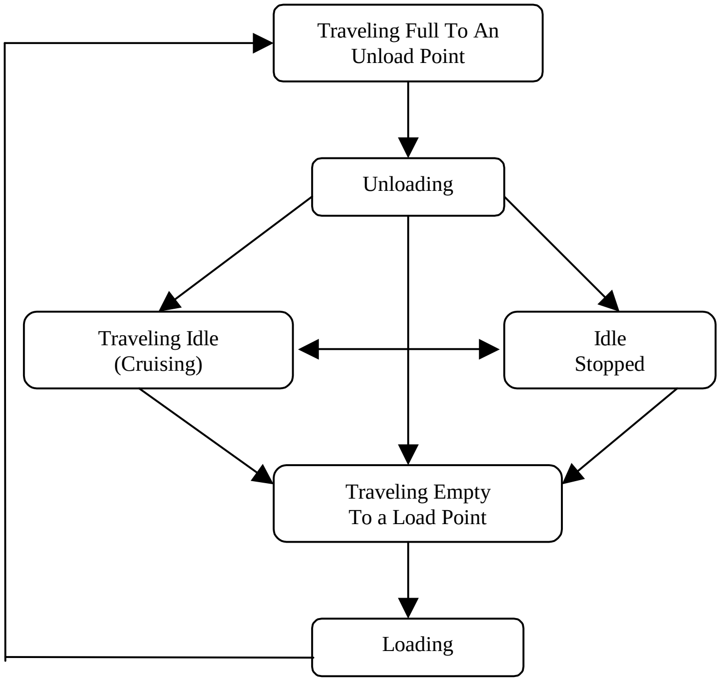

Figure 3 : AGV Movement Characteristics

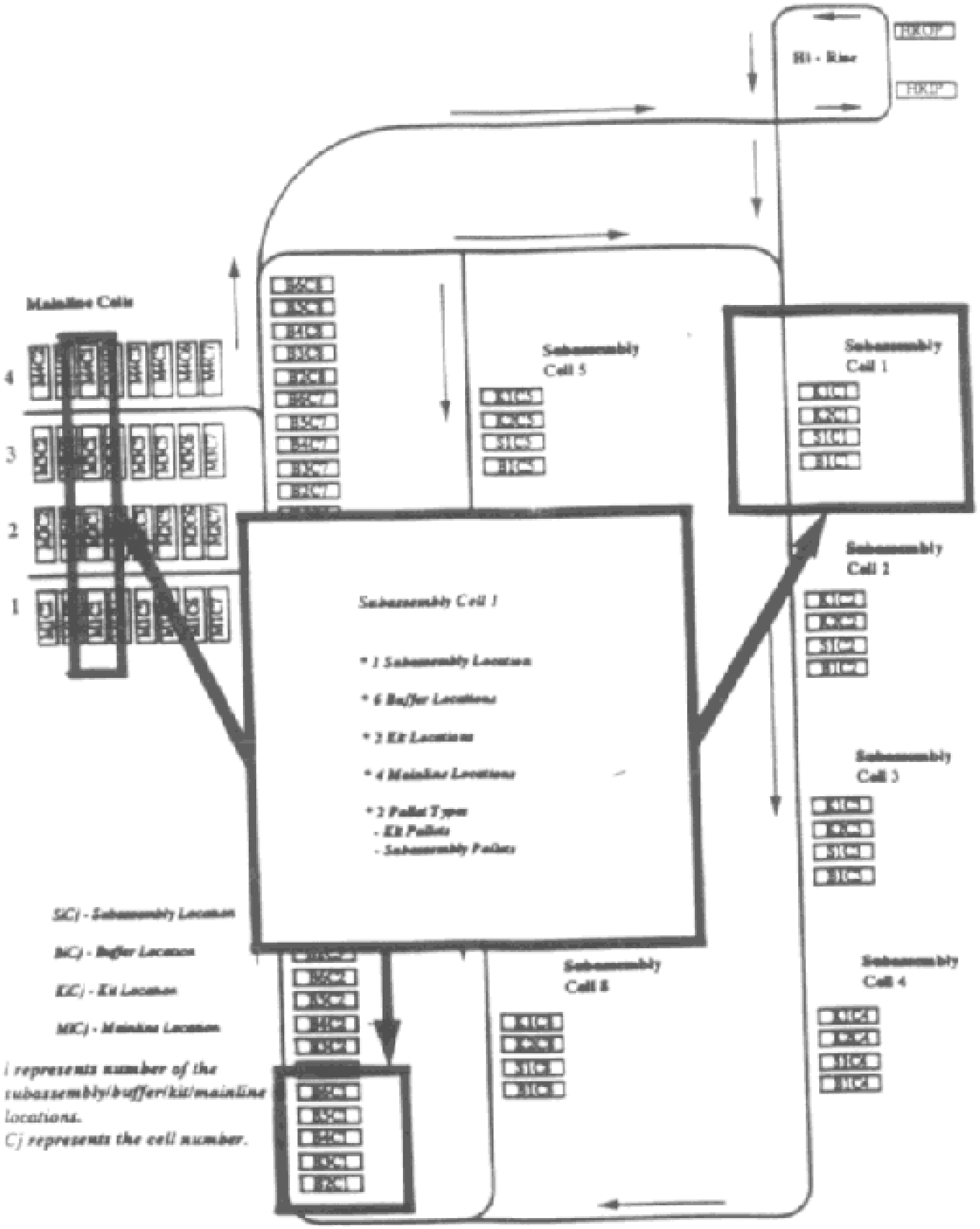

Figure 2 : AGVS Design A

of the following states at any time:

Traveline Full to an Unload Point

The following are some of the requests in the system that will have the AGV in the Traveling Full to an Unload Point state :

- Carrying a full kit pallet from the AS/RS and proceeding to drop it at an idle kit location.
- Carrying a full subassembly pallet from a subassembly location and proceeding to drop it at an idle buffer location.
- Carrying a full subassembly pallet from a buffer location and proceeding to drop it at an idle mainline location.
- Carrying an empty kit pallet from a kit location and proceeding to drop it at the AS/RS.
- Carrying an empty subassembly pallet from a buffer location and proceeding to drop it at a subassembly location.
- Carrying an empty subassembly pallet from a main line location and proceeding to drop it at an idle buffer location,

Traveling Empty to a Load Point

The AGV might be moving empty to the various locations after a request has been made to accomplish one of the tasks above.

Loading/Unloading

The AGV would have to load/unload an empty/full pallet (kit or buffer) after one of the above requests has been made

Travel Idle/ldle Stopped

After an AGV has completed all outstanding requests, it becomes idle. The AGV may either be allowed to cruise along a certain path or stop at a particular location as soon as it becomes idle.

The following assumptions were made in the development of the model for the AGVS :

1. There are two main assembly lines which possess a flip-flop characteristics. This means that while one side of a flip-flop line is being replenished. assembling is done on the other side.
2. The cellular system has eight subassembly cells where different subassemblies are made. Eight main assembly requires one subassembly from each of the eight cells to start the cycle.

3 It has been assumed that the cycle times for both the subassembly and mainline distributions follow a given triangular distribution.
4. The loading/unloading time at all locations is assumed to be a constant 24 seconds.
5. After a signal is sent to the AS/RS, it takes a constant 300 seconds for the AS/RS to look for the appropriate kit and make it available at its output point.

6. The travel speeds for the AW, s are constant and known. Acceleration and deceleration of the vehicles has not been considered.
7. Each load station and unload station can be reached by AGVs located at any other station.
8 A vehicle picks up only one load per mp.
9. Vehicles do not pass each other on a guidepath.
10. All distances in the system are assumed known.
11. Failures and repairs art not modeled. However, the presence of large variances in the cycle times may be viewed as being caused by machine outages, repairs, and maintenance.
12. Battery charging has not been considered.
13. It has been assumed that a facility layout has been provided. However, we do have some flexibility as long as the following guidelines are met:

* There art eight subassembly cells in the facility.

* Each cell has two kit locations which are next to the subassembly locations.

* Each cell has six buffer locations, one of which should be placed next to the subassembly location. The other buffer locations are to cover the entire range of the main path and should be spaced equally

* Spurs/By-passes and transit paths may be incorporated into the design to make it more efficient.

* The direction of the paths may not be changed - except at spurs/by-passes.

5. FACTORS CONSIDERED IN THE STUDY

A number of factors/alternatives were considered in this study. These include

* Alternate track layout designs
* Effect of scheduling rules
* Effect of different cycle time ratios

These factors are briefly described below:

5.1 Alternate Layout Designs

Two alternative layout designs were considered in addition to the basic AGVS Design A, namely Alternate AGVS Design B and Alternate AGVS Design C.

5. 1.1 Alternate AG VS Design B

Figure 4 shows the facility and track layout for Alternate AGVS Design B. The layout and operating characteristics of the system in this design are exactly the same as in AGVS Design A. However, it was envisaged that the addition of transit paths to the design would considerably reduce the vehicle blocking and congestion in the system. Since one objective of the study is to determine the optimal throughput obtainable from the system, an effort was made to eliminate blocking and increase the throughput of the system. It was anticipated that the vehicles would be able to move more freely because of the presence of these paths, alleviating the blocking in the system.

At each of the points, Pl, P2, P3. P4, P5, and P6. a decision is to be made by the vehicle to choose the path it would traverse. The decision logic is such that if an AGV is present at a cell location in the system, the coming AGV will then take the transit route at point Pk (k = 1, 2,…, 6) to avoid blockage.

Transit paths were also added near the buffers and mainline locations. Small segments connect Path A, path with buffer locations, to Path B, transit path. These segments are unidirectional, going from Path A to Path B. This implies that as soon as an AGV has accomplished its task on Path A, it can get out of this path and move on the transit path, Path B. It is expected that this design would considerably reduce the traffic on Path A and would alleviate congestion problems. Note that it was assumed that Path A was the default path and the AGVs would travel on this path until they reach their destination buffer and after that they leave Path A.

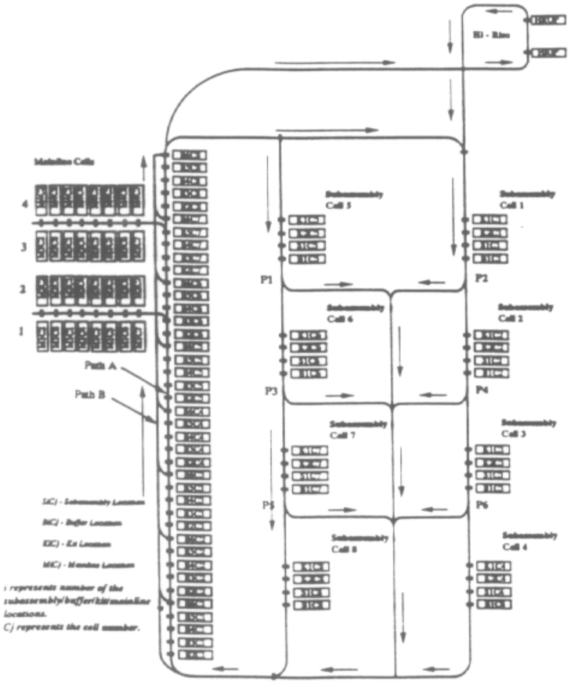

Figure 4 : Alternate AGVS Design B

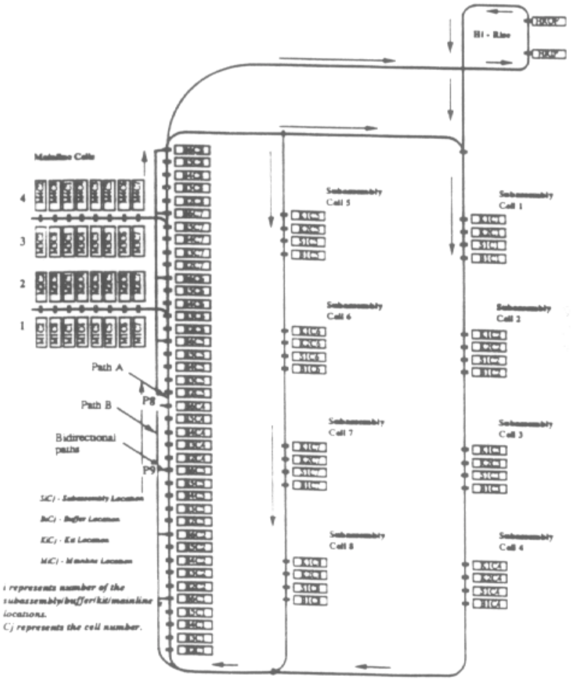

Figure 5 : Alternate AGVS Design C

5.1.2. Alternate AGVS Design C

After it was determined that the presence of transit paths between the subassembly cells 1 through 8 were ineffective, these paths were eliminated from the design. Also, the segments joining the two paths, Paths A and B were made unidirectional. Figure 5 depicts the layout of the system under Alternate AGVS Design C.

Now, the AGVs would go to Path A only when they have to perform some loading/unloading. Otherwise, they would be traveling on Path B for the majority of the time. For example, if an AGV has to drop an empty buffer pallet at the buffer location B2C4, it would move to P9 on Path B, get into Path A at P9, unload at 132C4, and then again get out from Path A to Path B at P8.

All the other characteristics of the system are exactly the same as in AGVS Design A.

5.2 Effect of Scheduling Rules

The study considers five types of AGV and job scheduling rules. These are:

a. Rules for Contention.
b. Rules for Idle Vehicle Disposition.
c. Rules for Job Selection by AGVs
d. Rules for Vehicle Selection.
e. Release Rules at the Control Points.

For each type of scheduling rule, two levels are considered as given in Table 2.

Table 2 : AGV and Job Scheduling Rules Considered in the Study

Factors	Treatments	
Rule for Contention	FIFO	CLOSEST
Rule for Job Request Selection	PRIORITY	CLOSEST
Rule for Idle Vehicle Disposition	STOP	CRUISE
Rule for Vehicle Request Selection	FIFO	CLOSEST
Rule for Job Request Selection	MATCH	TOP

In design of an AGVS, one has to define the vehicle control points in the system. These are locations on the guidepath network at which an AGV begins to travel on a segment or where it stops to load/unload, or to wait for instructions from a controlling computer. A contention for a control point resource occurs when more than one vehicle is waiting to enter the control point. A list of the waiting vehicles is kept in their order-of-arrival to the control point. The contention rule specifies which vehicle is to be given the right-of-way when the control point becomes available. In this study, two rules are used - FIFO and CLOSEST. The CLOSEST rule selects the vehicle with the shortest path distance to its ultimate destination. If the rule specified if FIFO, then the control point is captured by the vehicle in the order in which they arrive at the control point.

When an AGV completes delivery of material to an unload location, the vehicle is released to perform other tasks. The vehicle will become idle if there are no transport jobs waiting to be performed. This rule is used to specify the logic to be applied when positioning idle vehicles. Two options have been used in the study STOP and CRUISE. When the first one is used, the vehicle will stop at its current location on the guidepath and wait until request is made. When CRUISE is used, the vehicle will move on a specified quidepath subnetwork until requested.

Job requests waiting to be performed by a vehicle fleet are listed in a file. When a vehicle has completed a previous job, it interrogates the file to determine if there are any outstanding requests. The manner in which the outstanding requests are selected is based on this rule. In this study, PRIORITY and *CLOSEST* have been used as two options for this rule. If the rule for job request r, PRIORITY, the vehicle will always Lake the highest priority request. In the system studied, highest priority value is assigned to the mainline requests, second highest value has been assigned to the subassembly requests, and the lowest priority has been assigned to the kit requests. On the other hand. *CLOSEST* selects the job that is at the shortest path distance from the vehicle.

Rule for vehicle selection is used to select among idle vehicles when more than one vehicle is idle at the time a vehicle is requested. This study investigates two different options - FIFO and CLOSEST. When FIFO is used, it causes the vehicle that has been idle the longest to be dispatched and accomplish the completion of the job. On the other hand, the vehicle with the shortest path distance to the enury requesting pickup will respond to the request when CLOSEST is used.

When a vehicle arrives to the pickup control point~ the job is removed from a file according to the release rule at the control point. There are two options available -MATCH and TOP. When MATCH is used. it specifies that the job issuing the request for the particular vehicle is to be removed from the file even if the job is not first in the file. When TOP is used, the job ranked first in the file is removed.

5.3 Effect of Different Cycle Time Ratios

The subassembly and mainline cycle times follow a triangular distribution. The effects of changing the values of ft parameters of these distributions were considered. The changes were made in such a way that the percentage variability in the cycle time was not effected. Thus, if the distribution is given by TRIAG(A, B, C), it was altered to TRIAG(A/T, B/T, C/T) where T was given the values 1, 1.33, 2, 5, 10. For example, if the original cycle time was TRIAG(650, 800, 2500), when it was reduced by a factor of 0. 1, it became TRIAG(65, 80, 250). This assured that the percentage shift between the mean and mode for the triangular distributions Remained the same in both cases. The mean for the former cycle time is 1316.67 ((650 + 800 + 2500)13) and for the latter, it is 131.67 ((65+ 80 + 250)13). Hence, the percentage shift remains the same at CRUISE 64.58 ((1316.67 - 800)/800 or (131.67 - 80)/80) for both the cases. This was done for both the mainline and subassembly cells. Thus, there were five values of cycle times for the mainline assembly and five values for the subassembly processes. The effects of these variations and the combinations of different mainline and subassembly cycle times were studied.

6. COMPARISON WITH MAXWELL AND MUCKSTADT'S (1981) APPROACH

Maxwell & Muckstadt (1981) in their paper discussed a three stage process to design an AGVS in order to determine the minimum number of vehicles under which it should be operated. Their approach did not consider the time when the loads became available for shipment or were needed at the appropriate stations. Since time was essentially ignored, the authors were unable to account for blocking or congestion in the system. An analysis was conducted for our system using their time-independent approach. Several simplifying assumptions were made in order to model the system as a transportation problem. The number of AGVs obtained from this analysis should help in determining the conditions under which a time-independent analysis is reliable.

7. SIMULATION OBSERVATIONS AND RESULTS

The simulation model of the cellular assembly system studied was built using SLAMSYSTEM simulation software. Availability of the built-in AGV material handling control logic in SLAMSYSTEM made the modeling task relatively easy to implement the different variables in the system - especially the scheduling rules.

A pilot simulation study was conducted firm to estimate the length of the uwment and warm up periods as well as the number of replicates required for the analysis. Verification and validation runs were also made in this phase of the study. The pilot study was conducted under the AGVS Design A (Figure 2) of the system for a default of scheduling rules. Once the pilot study was completed satisfactorily, different sets of experimental runs were made to study

the effects of different designs and operational variables on the performance of the AGVS.

(i) The effects of five scheduling rules (described earlier) were studied on the operation of Design A. A two-way ANOVA design was used to observe the main and interaction effects of different scheduling rules in the study. Only one of the five rules, the rule for job request selection, had a significant impact on the throughput of the system. Thc average throughput of the system went up from 4.889 assemblies per shift (74.2 % of the maximum possible throughput) to 6.33 assemblies per shift (96.2 % of the maximum possible) when this rule was changed from PRIORITY to CLOSEST. The other rules, rule for contention, rule for idle vehicle disposition, rule for vehicle request selection, and rule for job request selection were ineffective. Also, no interactive effects were observed.

(ii) The percentage of vehicles blocked in the system went up from 1.06 % for 3 AGVs to 47.3 % for 4 AGVs and 75.74 % for 5 AGVs under Design A. This was a very large increase and the blocking took place near the bi-directional mainline spurs on the main path.

(iii) The average wait time for the vehicles in the system decreased as the number of AGVs in the system were increased from 2 to 4. Thereafter, it started increasing.

Alternate AGVS Design B was then analyzed and the following results were obtained:

(i) The alternate design showed no major changes in the results when it was operated with 3 vehicles even though a large number of transit path& were added to the system (The average throughput changed from 4.88 vehicles per shift to 4.92 vehicles per shift).

(ii) There was, however, a significant change in the operation of the system when it was operated with 4 AGVs. The percentage of vehicles blocked increased from 473 to 70.78, average throughput declined from 2.47 assemblies per shift to 1.94 assemblies per shift and the average wait time for vehicles showed a sharp increase from 641 seconds to 4802 seconds. Table 3 summarizes the results under Designs A and B.

(iii) The effect of scheduling rules was the same as in AGVS Design A with the rule for job request selection making a significant impact and the others being ineffective.

There was, however, a significant change in the performance of the system under Alternate AGVS Design C. The major results obtained under this configuration are as follows:

(i) The system produced an average throughput of 6.44 assemblies per shift when there were 4 AGVs in the system. This throughput increased as the number of AGVs were increased beyond 4, the throughput remained fairly constant and blocking did not come into the picture. On the other hand, in AGVS Designs A and B, the throughput went up as the number of AGVs w as increased from I to 3 and then it started going down as the number of AGVs was increased beyond 3. In fact, 47.3 % of the AGVs in AGVS Design A and 70.78 % in Alternate AGVS Design B were blocked when there were 4 AGVs in the system.

(ii) Alternate AGVS Design C produced almost the same throughput irrespective of the rule for job selection used. When there were 4 AGVs in the system, 6.44 assemblies were produced per shift for either of the two options considered for the rule - PRIORITY or CLOSEST. This shows that the choice of a good track layout design can eliminate the difference between the scheduling rules.

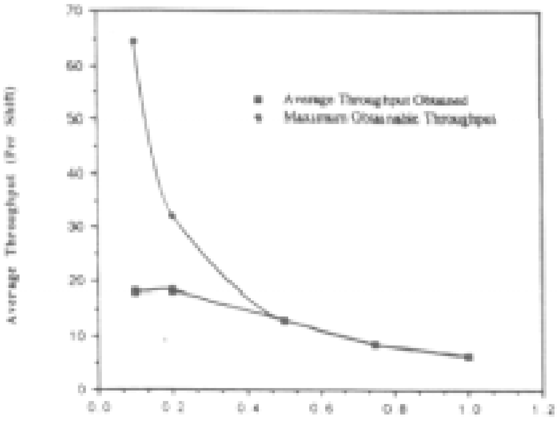

Figure 6 : Effect of Cycle Times on Maximum Theoretical and Observed Throughput

(iii) , Since blocking is almost absent in this design, the average wait Urne keeps decreasing as the number of AGVs are increased. In AGVS Design A, the wait time decreases as the number of AGVs increased from I to 3. Similarly, in Alternate AGVS Design B, the average wait time decreased as the number of AGVs was increased from I to 4. However, there was a sharp increase when the AGVs were increased beyond 3 for AGVS Design A and 4 for Alternate AGVS Design B.

AGVS Design A was then operated under the optimal set of scheduling rules and the cycle U=s at the mainline and subassembly locations were varied. The following results were obtained :

(i) As the cycle times for the mainline assembly and subassembly processes were reduced from their original values to one-tenth of the original value, the optimal (minimum) number of AGVs in the system went up from 3 to 11. Subsequently, the throughput of the system increased from 6.33 assemblies per shift to 18 assemblies per shift as shown in Figure 6. However, this increase in throughput was not linear with the changing cycle times and the difference between the maximum throughput obtainable from the system and the actual throughput obtained increased significantly from 0.16 assemblies per shift (6.49 -6.33) for 3 AGVs to 46.24 assemblies per shift (64.24 - 18.0) for 11 AGVs.

(ii) Even when the system was operating under I I AGVs, the combination of scheduling rules was such that them was almost no blocking in the system. Whenever the system was operated with more than the optimal number of AGVs required, the excessive number of AGVs were traveling idle. This may lead us to believe that if the same conditions were to prevail, the rule for vehicle disposition would make an impact on the throughput of the system.

(iii) The operation of the system depends both on the mainline assembly and subassembly processes. However, as the mainline assembly cycle time is increased and the subassembly cycle time is decreased, the mainline assembly process starts dominating the picture, and vice versa. Figure 7 shows the effects of subassembly and mainline cycle times on the average throughput of the system.

Table 3: Effect of Number of Vehicles

Number of Vehicles	Percentage Blocked		Average Throughput		Average Wait Times for Vehicles	
	DesignA	Design B	Design A	Design B	Design A	Design B
2	0	1.1	344	1,42	1245	1322
3	1.06	1.67	4.88	4,92	817	815
4	47.3	70.78	2.47	1.94	641	4802
5	75.74	76.04	1.69	1.67	5985	4947
6	82.13	78.73	1.5	1.47	9578	8289

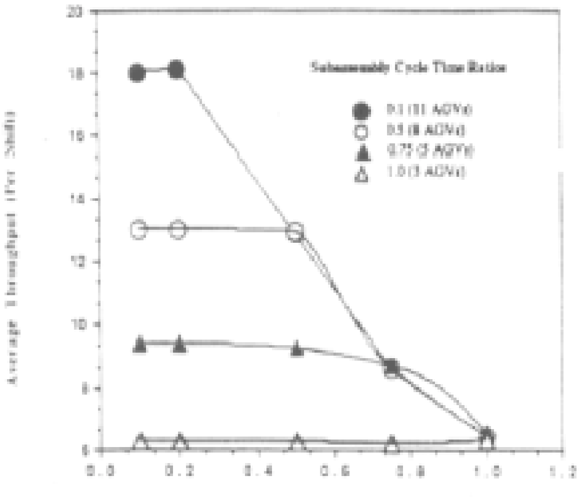

Figure 7 : Effect of Subassembly & Mainline Cycle Times on Average Throughput

After the effects of changing the cycle times were analyzed, a time independent model based on Maxwell & Muckstadt's (1981) study was built for the system. The model was used to calculate the minimum number of vehicles under which the system should be operated if time-phased requirements were ignored. The approach gave 2 vehicles when the system is operated under the original values of cycle times. The simulation results had calculated 3 vehicles. However, when the cycle times were reduced to one-tenth of their original value, the time independent approach gave only 5 vehicles as compared to 11 vehicles obtained from simulation results. This shows that as the material handling time in the system increases relative to the largest processing time in the system, the time independent approach starts becoming less reliable. In our study, when the ratio of largest processing time to the material handling time was about 10, the time independent approach gave very reliable results but when the ratio reduced to one, the result of the time-independent approach was unreliable.

8. CONCLUSIONS

In summary, the following conclusions can be made based on the results of this study :

The scheduling rules which are effective under one design may not be as effective in another design. Thus, if enough attention has been paid to the design aspects in the system, the schedule-related problems may not be encountered. In our study, the rule for job selection by AGVs was very important in AGVS Designs A and B but was virtually ineffective in Alternate AGVS Design C.

As the cycle time in the system is reduced, the demand on the AGVs increases as expected. In our study, the number of AGVs in the system went up from 3 to 11, when the cycle time was reduced to 1/10th of its original value. Thus, the material handling component in an AGVS depends on how the cycle times of the various processes in the system are distributed

The results showed that as the cycle times were reduced, i.e., as the material handling component within the system increased, the results obtained from the static model started losing their accuracy. in general, if material handling time is one-tenth of the largest cycle time, the time independent models can still be reliable.

REFERENCES

Ashayeri, Jalal, Gelders, Ludo F. and Van Looy, Paul M., " Micro-Computer Simulation in Design of Automated Guided Vehicle Systems", Material Flow, 2, pp 37-48, 1985

Blair, E.L., Charnsethikul, P., Vasques, A., "Optimal Routing of Driverless Vehicles in a Flexible Material Handling System", Material Flow, Vol. 4, No. 1, 1987.

Egbelu , P. J., "'The Use of Nonsimulation Approaches in EstimatingVehicle Requirements in an Automatic Guided Vehicle Based Transport System", Material Flow, Vol. 4, No. 1, pp 17-32, 1987.

Egbelu, P. J., Roy, N.. "Material Flow Control in AGV/Unit Load Based Production Lines", International Journal of Production Research, Vol. 26, No. 1, pp 81-94, 1988.

Egbelu, P. J., Tanchoco J. M, A.. "Characterization of Automatic Guided Vehicle Dispatching Rules ",International Journal o Production Research, Vol. 22, No. 3, pp 359-374, 1984.

Egbelu, P. J,, Tanchoco, J. M. A.. "Potentials for Bi-Directional Guidepath for Automated Guided Vehicle Based Systems", International Journal of Production Research, Vol. 24, No, 5, pp 1075-1097, 1986.

Gaskins, R. J., Tanchoco, J. M. A., "Flow Path Design for Automated Guided Vehicle Systems", International Journal Production Research, Vol. 25, No. 5. pp 667-676, 1987.

Hodgson, T. I., King, R. E., Monteith, S. K., Schultz, S. R., "Developing Control Rules for an AGVS Using Markov Decision Processes", Material Flow, Vol. 4, No. 1, 1987.

Kedia, P., "Design and Analysis of a Cellular Assembly System with AGVs", Master's Thesis, Industrial & Systems Engineering, University of Michigan - Dearborn, 1990.

Maxwell, W. L., "Solving Material Handling Design Problems with OR", Industrial Engineering, Vol. 13, No. 4,pp 58-69, 1981.

Maxwell, W. L., Muckstadt, J. A., "Design of Automatic Guided Vehicles", IIE Transactions, Vol. 14, No. 2, pp 114-124, 1982.

Newton, D., "Simulation Model Helps Determine How Many Automatic Guided Vehicles are Needed ", Industrial Engineering, Vol. 17, No. 2, pp 68-79, 1985,

Ozden, M., "A Simulation Study of Multiple Load Carrying Automatic Guided Vehicles in a Flexible Manufacturing System", International Journal of Production Research, Vol. 26, No. 8, pp 1353-1366, 1988.

Prasad, K. and Rangaswami, M., "Analysis of Different AGV Control Systems in an Integrated IC Manufacturing Facility using Computer Simulation", 1988 Winter Simulation Conference Proceedings, pp 568-574, 1988.

Rabeneck, Craig W., Usher, John S. and Evans, Gerald W., "An Analytical Model for AGVS Design", 1989 Ititernational Industrial Engineering Conference & Societies' Manufacturing and Productivity Symposium Proceedings", p191, 1989.

Sabuncuoglu, I. and Hommertzheim, D. L., "An Investigation of Machine and AGV Scheduling Rules in an FMS ", Proceedings of the Third ORSA/TIMS Conference on Flexible Manufacturing Systems, p 261, 1989.

Taghaboni, F., Tanchoco, J. M. A., "A LISP Based Controller for Free Ranging Automatic Guided Vehicle Systems ", International Journal of Production Research, Vol, 26, No. 2, pp 173-188, 1988.

Tanchoco, J. M. A., Egbelu, P. J., Taghaboni. F., "Determination of the Total Number of Vehicles in an AGV Based Material Transport System", Material Flow, Vol. 4, No. 1, pp 33-52, 1987.

Usher, J. S., Evans, G. W., Wilhelm, M. R.. "AGV Flow Path Design and Load Transfer Point Location", Proceedings of the International Industrial Engineering Conference, Orlando, Florida, pp 174-179, 1988.

Wilhein-4 M. R., Evans, G. W., "The State-Of-The-Art in AGV Systems Analysis and Planning", Proceedings of the International Industrial Engineering Conference. Orlando, Florida, pp 174-179, 1988.

outing of