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OCA PAD AMENDMENT - PROJECT HEADER INFORMATION

02/21/92

Active

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Center #: R6594-0A0

Cost share #:  
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Rev #: 11  
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Prime #:

Mod #: ROD 2/21/92

Subprojects ? : N  
Main project #:

CFDA:  
PE #:

Project unit: MHRC Unit code: 03.010.204  
Project director(s):  
MCGINNIS L F ISYE (404)894-2363

Sponsor/division names: SIEMENS RTL / PRINCETON, NEW JERSEY  
Sponsor/division codes: 218 / 067

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Title: INTEGRATION OF AGVS ANALYSIS

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Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N  
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N/A NONE PROPOSED.

Administrative comments -

THIS REV. EXTENDS PERIOD OF PERFORMANCE AND FINAL REPORT TO 4/30/92.  
THE ADDRESS OF SPONSOR IS ALSO CHANGED.



GEORGIA INSTITUTE OF TECHNOLOGY  
OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 07/17/92

Project No. B-04-693\_\_\_\_\_

Center No. R6594-0A0\_\_\_\_\_

Project Director MCGINNIS L F\_\_\_\_\_

School/Lab MHRC\_\_\_\_\_

Sponsor SIEMENS RTL/PRINCETON, NEW JERSEY\_\_\_\_\_

Contract/Grant No. S/129817\_\_\_\_\_

Contract Entity GTRC

Prime Contract No. \_\_\_\_\_

Title INTEGRATION OF AGVS ANALYSIS\_\_\_\_\_

Effective Completion Date 920430 (Performance) 920430 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	_____
Final Report of Inventions and/or Subcontracts	N	_____
Government Property Inventory & Related Certificate	N	_____
Classified Material Certificate	N	_____
Release and Assignment	N	_____
Other _____	N	_____

Comments\*\*PAID IN FULL; NO FINAL BILLING REQUIRED. \_\_\_\_\_

Subproject Under Main Project No. \_\_\_\_\_

Continues Project No. \_\_\_\_\_

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Management	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other _____	N
_____	N

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580  
SR

*May Wolfe*

B-10-693

**INTEGRATION OF AGVS ANALYSES**

A report to

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submitted by

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## Table of Contents

	page
1.0 BACKGROUND AND MOTIVATION	1
2.0 TASK ACCOMPLISHMENT	2
3.0 INTRODUCTION TO EWS	4
4.0 SIMULATION MODEL	8
4.1 System Schematic Diagram	8
4.2 Processes and Part Flows	10
4.3 Vehicle Movement	11
4.4 Input Data Requirements and Output Performances	12
4.5 Problem Limitations	14
5.0 INTEGRATION OF EWS WITH MANUPLAN	16
6.0 EXAMPLE	18
6.1 Input Data	18
6.2 Simulation Execution Procedure	18
6.3 Output Summary Report	21
6.4 Animation Execution Procedure	22
6.5 Interface Program Execution Procedure	27



## 1.0 BACKGROUND AND MOTIVATION

Georgia Tech, for the past two years, has been developing an interactive environment for designing automated guided vehicle system (AGVS) applications. This environment is based on the AutoCAD package, employs the AutoLISP programming language, and embodies an ASCII format neutral database. The environment referred to as the engineering workstation (EWS), incorporates analytic models for estimating the required number of vehicles, and interactive tools for manual design of the guidepath layout. However, AGVS design is a complicated process. Some of the factors which directly impact the design such as guidepath layout, load information, workstation information, and the vehicle information, interact with each other so that each cannot be considered separately but all must be considered simultaneously. Thus, simulation seems to be the main method for obtaining a detailed and accurate estimate of performance for a proposed system.

A project for SIEMENS RTL addresses development and demonstration for a restricted class of applications of an "automatic simulation" capability for the EWS. Also included as part of the scope of work is collaboration with SIEMENS RTL on the modeling of AGVS applications for various forms of analysis, and on the development of appropriate interfaces to support them, in an integrated way using AutoCAD as a control program, or shell.

This report summarizes the current result of this research project which consists of the implementation of a simulation code generator (SCG) in the EWS and the creation of an interface program for converting the neutral data files into a MANUPLAN format data file. A general description of the EWS is also presented. Finally an example is given to display the process of modeling AGVS using the EWS and running the simulation in SIMAN and animation in CINEMA.

## 2.0 TASK ACCOMPLISHMENT

The simulation code generator presented in this report is written in Quick BASIC version 4.5. It can retrieve data from the EWS neutral database to output a required program for simulation. The simulation code is in SIMAN (the simulation package from Systems Modeling, Inc.) and consists of a model frame and an experimental frame. The model frame defines the system logic. The experimental frame, on the other hand, defines the experimental conditions under which the model is run to generate the output. The whole procedure including the program generation and its execution is controlled by a batch command file, which is accessible within the EWS from a menu by using a mouse.

Once the simulation output is obtained, it is desirable to view the dynamic system behavior through the CINEMA, which is an animation software package designed to work with the SIMAN. A CINEMA animation consists of two kinds of objects, static objects and dynamic objects. Static objects form the layout background and present the portion of the layout that does not change during the animation. However, dynamic objects are superimposed on the static background and change size, shape, color, or location in correspondence with changes in the state of the system during the execution of a simulation. The System Modeling, Inc. provides a convert function which can transfer an AutoCAD drawing file to the CINEMA static layout background, but the dynamic objects have to be added to the layout step by step within CINEMA. As a result, automating the animation to the same degree as the simulation cannot be done yet.

Further, an interface program which can convert the system description defined in EWS database into a MANUPLAN format input data file also has been developed. MANUPLAN is a tool for designing and analyzing manufacturing systems. Outputs from MANUPLAN include part flow times, work-in-process levels, equipment utilizations, and production rates achieved. The integration of the EWS with MANUPLAN provides the user with output statistics from both manufacturing and

transportation systems. However, there are couple parameters used in MANUPLAN but not collected in the EWS. In addition, the part routes and operation times are assumed to be fixed in the EWS, but multiple routes and distributed operation times are allowable in MANUPLAN. Thus, there are some arbitrary limitations to the EWS/MANUPLAN interface. The detailed discussion of the limitations will be given in a latter section.

### 3.0 INTRODUCTION TO EWS

The engineering workstation is a modeling, analysis, design, and simulation tool for AGVS research. The main purpose of this workstation is to facilitate and improve the AGVS design process. The EWS is built around the neutral database. These neutral data files provide the link to the other system modules. Figure 1 gives a schematic view of the engineering workstation's structure. This figure shows input data coming from the CAD package and DIALOG programs. This data is then extracted from the neutral files and analyzed with a number of different routines. The user or designer is involved in the feedback mechanism. Output data from the analysis routines is presented to the user who makes changes to the current system design and returns the analysis. Thus, an iterative solution procedure that intimately involves the user is used.

The CAD package, AutoCAD version 10.0, serves as the graphical interface to the system. It is used to enter geometric information, such as block layout, guideway layout, and locations of pickup and deposit stations. A drawing post processor converts the geometrical data into logical records which can be stored in the neutral data files and accessed by other programs.

The DIALOG module is written in Quick BASIC version 4.5, based on a spread-sheet format. This module consists of several programs for collecting the remaining non-geometric information necessary for the complete description of the AGVS from the user. The input data from these programs includes:

- (1) Flow requirements concerns the flow rate data (or the from-to matrix). This matrix defines the transportation requirements for the AGV system.
- (2) Work area information concerns the information about the work areas such as workstation capacity, mean time to failure, and mean time to repair.
- (3) Part/process routes concerns the specifications of the part characteristics and the deterministic route including the interarrival distributions and operation times. The part routes will be translated

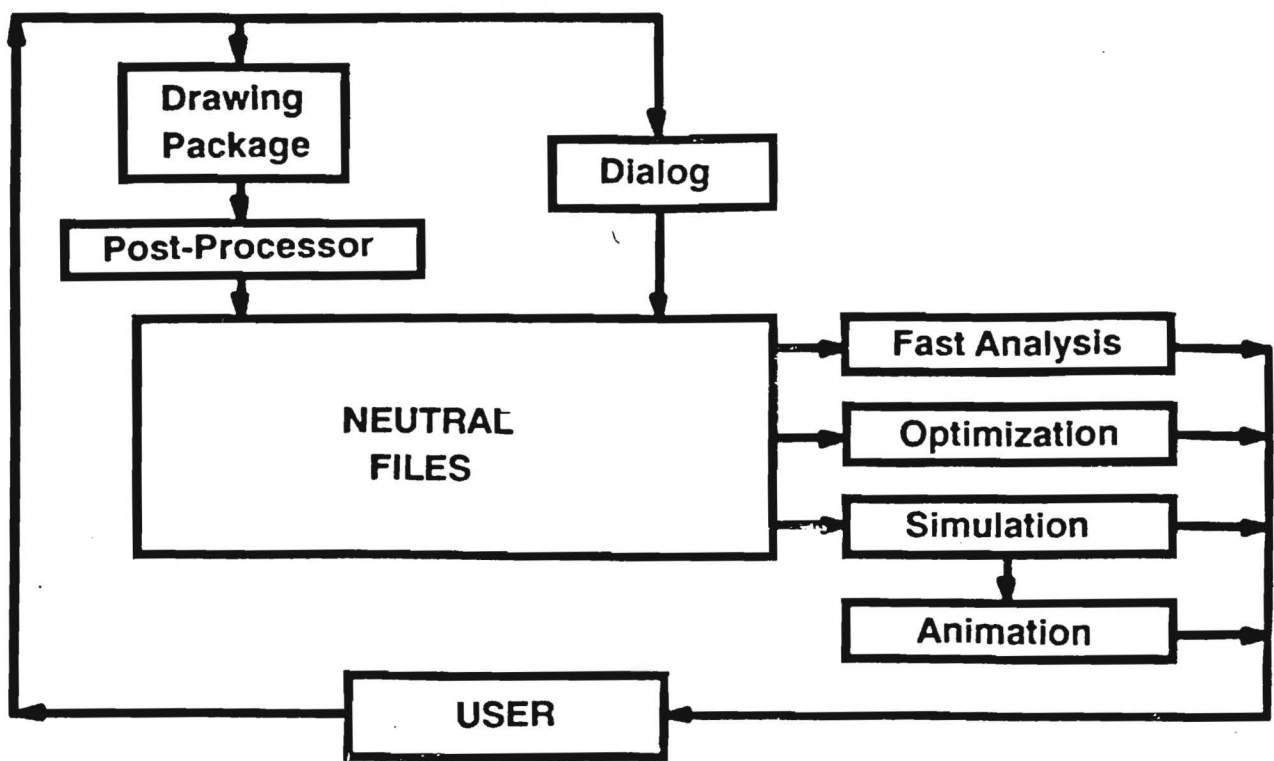


Figure 1 Engineering workstation structure

into flow requirements automatically by using the mean values of the interarrival time distributions of the parts.

(4) Vehicle specification concerns the specifications for the vehicles (speed, fleet size, and the load/unload time) which will be used in the system.

(5) Profile concerns the project profile for the currently active project which includes the project name, user name, date, analytical time span, and etc.

However, the core of the EWS is the neutral database. It contains all of the data necessary to specify the AGVS design. Each of the other modules must interface with these files to obtain input data and to store output data. The neutral data files are currently flat ASCII files with a prescribed format but not specified to any module format and therefore accessible by any of the programs.

Further, the analysis routines consists of three basic types. Fast analysis tools perform quick analytical studies on the design. They allow the user to estimate the vehicle requirements for a unit-load transportation system. A generic framework has been developed to provide an absolute lower bound and a reasonable upper bound on the number of vehicles required. In addition, statistical models of several different routing and dispatching rules such as the minimum travel, the worst dispatching, first-come-first-serve, and the round trip are developed and implemented for performance evaluation.

Second, optimization models are applied to portions of the design problem. the optimization models and heuristics allow the user to effectively design flow paths and wiring configuration for active frequency-based routing. The underlying model for the flow path design uses a network flow problem formulation. Effective heuristics are implemented to quickly generate feasible flow path, and the user is provided with graphical tools and performance measures to improve the design. Furthermore, the wiring problem for active frequency-based routing is formulated as an optimization (matching) problem, and the wiring configuration that uses the least amount of floor space can be found and

displayed.

The last is the simulation/animation module which provides a detailed performance evaluation of the AGV system. The simulation can be time consuming and, as a result, is usually only used to consider a limited number of alternatives. Therefore, it is recommended that the user go through several of the fast analyses and collect the results from each iteration. Based on these fast analysis results, a narrower range of values for a simulation parameter will usually be indicated. This narrowed-down range reduces the number of simulation alternatives which must be considered. Consequently, the time to make comparisons among alternatives, and to devise an appropriate AGVS design is also reduced.

## 4.0 SIMULATION MODEL

An FMS with automated guided vehicles moving along a uni-directional guidepath network through workstations is the system being modelled. In this system, the new part is assumed to be inducted according to a given interarrival distribution. After a part is processed on a machine, a vehicle is requested to transport it to another workstation where its next operation will be performed. For convenience, an example system schematic diagram is given in the next section as shown in Figure 2.

### 4.1 System Schematic Diagram

The system in Figure 2 consists of three workstations and an AGVS guidepath network which contains 22 segments and 19 control points. The AGVS uses vehicles traveling on a uni-directional guidepath network. A unique named location, STAGING, is included for parking idle vehicles. Different workstations may contain different machine types, but within a workstation there is only one type of machine. Each machine is capable of processing only one part at a time. In addition, all vehicles are assumed to be identical with a capacity of one unit load. Each workstation is connected to the guidepath network with two points, a pickup point and a deposit point. The pickup point represents the location of the workstation output buffer from where parts are removed and loaded onto vehicles. The deposit point represents the workstation input buffer location where parts are unloaded from vehicles. In general, each workstation must have its own P/D (pickup/deposit) points. It may have a combined P/D point serving the functions of both the input and the output buffers, or a pair of points with one pickup and one deposit. These points indicate locations of buffers. The sizes of buffers are arbitrary.



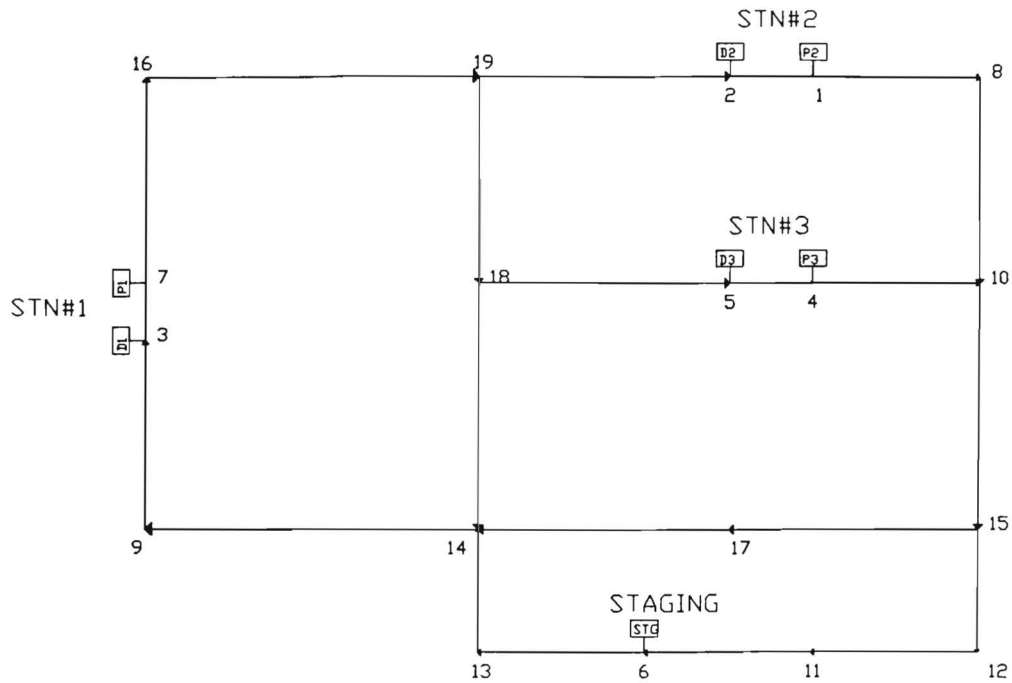


Figure 2 A system schematic diagram

## 4.2 Processes and Part Flows



Six interarrival time distributions are used to model introduction of new parts into the system. These selections are (1) Deterministic, (2) Exponential, (3) Normal, (4) Triangular, (5) Uniform, and (6) Gamma.

Each part type is assumed to have a fixed process route. The workstation where new parts enter the system can be common for all part types. New parts can also be introduced into the system at different points depending on their particular routes. No matter where the new part comes into the system if the input buffer is full, this new part is rejected by the system. However, this limitation can be overcome by adjusting the size of the input buffer and/or modifying the original interarrival distribution.

After a part is inducted successfully, or after it reaches an input buffer, it is put in a queue to wait for an available machine. The available machine is assigned to the part according to the FCFS rule. The part is then delayed for a period of time, representing processing. If there are additional processing operations required by the part, it must occupy a position in the output buffer before it releases the machine. Otherwise, once it finishes all operations it disappears from the system. After the part enters an output buffer, it must "reserve" a position of the input buffer of the next station before it can be transported (i.e., the next input buffer must be available). If the part successfully reserves the next input buffer, then it requests transportation (i.e., creating a service request). When a vehicle is available, it travels from its current location to the location of the part to be moved.

The above part operating sequence can be illustrated by an example given as below (refer to Figure 2). Assume that there is a part with its first operation in workstation STN#1 and the second in workstation STN#2. First, a new part is introduced into the system and stored in D1, the input buffer of STN#1. This part continuously stays in D1 until there is an available machine. After a delay to

represent the processing time it occupies a position in the input buffer of STN#1 and then releases the machine. After a position in D2 the input buffer of STN#2 is reserved a service request is created (i.e., an idle vehicle can be assigned to deliver this part from P1 to D2). After the vehicle arrives at D2, a message indicating completion of the request is released. A machine in STN#2 is requested to process its next operation. Since the last operation is performed in STN#2, the part is set to disappear immediately after finishing this process.

### **4.3 Vehicle Movement**

The path along which a vehicle travels between any two locations is predefined, based on a shortest path analysis. When the vehicle arrives at the workstation, the part is unloaded and the vehicle becomes free. If there are no other transportation requests, the vehicle returns to the staging area. There is a policy to assign idle vehicles to requests. If there is a request (say locating at the output buffer of STN#2) released from the workstation (say STN#2) where a vehicle just unloaded a part, this request has the highest priority to get the vehicle; otherwise, this idle vehicle is assigned to the oldest request or returns to the staging area. However, if all idle vehicles stay at the staging area, FCFS is used by requests to allocate vehicles.

Traffic congestion, in our model, occurs when two or more vehicles try to pass the same control point on the guideway network at the same time as shown in Figure 3(a). The vehicle which doesn't get the right-of-the-way is blocked until the traffic is clear. Figure 3(b) shows another congestion scenario which happens when a vehicle is blocked by another vehicle in the front of it. In this case, we also interpret this blocked vehicle as trying to pass a control point which is occupied by other vehicle. When a control point is occupied, the track segment(s) following this point is (are) automatically claimed as illustrated in Figure 3(c). In a traffic congestion area, FCFS is the only rule used to release the traffic. Since vehicles travel on the predefined shortest path, no alternative paths are considered even during traffic congestion. Hence, blocked vehicles remain at their current locations until the

traffic is released.

#### **4.4 Input Data Requirements and Output Measurements**

Basically, the input data must describe the characteristics of a system which can be modelled by the simulation code generator. The system information is classified in five major fields. They are (1) guidepath layout, (2) part information, (3) workstation information, (4) the vehicle information, and (5) the control logic.

The guidepath layout defines the system configuration which includes the control point location, segment type, length, and the location, as well as the direction of the path. The control point is defined as the place where the vehicle can stop during its travel for the purpose of load/unload, communication, traffic blocking, or else. Furthermore, the linkage of two control points forms a segment. The segment type can be either curve or straight line. A path is a set of segments with the same direction. Further, the part information involves arrival patterns, part routes, and part processing times. As mentioned, the new part comes in the system follows a distribution and each part type is assumed to have a fixed route.

In addition, the workstation capacity, buffer sizes, locations of P/D points, and machine down times are covered in the workstation information field. The physical locations of buffers are defined as same as the locations of P/D points. The buffer capacity can be specified as arbitrary number. However, the vehicle information contains the velocity including the acceleration and deceleration, load/unload time, the load capacity, and the number of vehicles in the system.

Finally, the fifth field concerns the vehicle dispatching and the traffic congestion releasing strategies. The vehicle dispatching rule is usually applied at one of three occasions. The first is to assign an available vehicle to one request in the waiting list (i.e., more than one requests are created

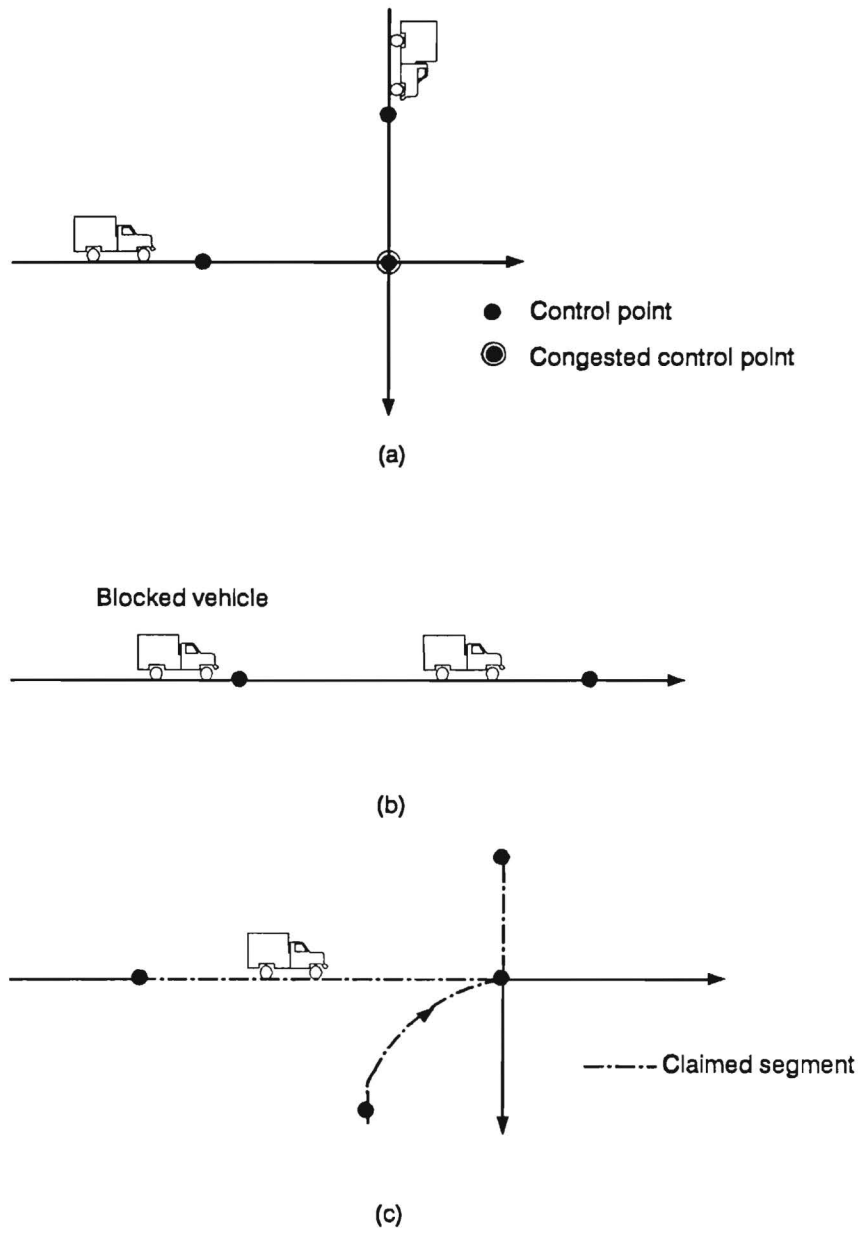


Figure 3 Traffic congestion cases and the claimed segments

before a vehicle becomes available). The second is to select one of the available vehicles and assign it to a just created request when no request is already in the list. Third, when the waiting list is empty, an available vehicle can be dispatched to some place and set to idle. The traffic congestion releasing strategy addresses the relief of congestion when it occurred. Currently only some fixed control strategies are implemented in the SCG. However, it is possible to extend and modify the software to allow more control rules to be added. Besides the above five fields, the simulation environment information such as the simulation time must be defined too.

Obviously, the output measurements should provide enough information to evaluate the system performance and to select a proper design. These measurements include the throughput and the average flow time of each part type. workstation utilization, buffer utilization consisting of the average and the maximum queue length, individual and the aggregate vehicle utilization, the loaded and unloaded travel time covering the average, minimum, and the maximum values, as well as the utilization of each control point which can be, transparently, used to point out the heavy traffic region.

#### 4.5 Problem Limitations

The detailed descriptions of the system model and the control logic have been presented in previous sections. In this section, the size of the problem (the framework), for example: how many control points are allowed, is discussed. In other words, the simulation code generator creates feasible simulation programs that have to meet the following restrictions.

Capacity:

- (1) Max. number of workstations = 50.
- (2) Max. number of control points = 100.
- (3) Max. number of vehicles = 20.
- (4) Number of vehicle types = 1.
- (5) Max. number of part types = 20.

- (6) Max. number of operations for a part type = 20.
- (7) Part induction interarrival distributions = 6.

Control logic:

- (1) If a part arrives when the system input buffer is full, the part balks, i.e., immediately leaves the system.
- (2) Queue removal rule is FCFS.
- (3) Vehicle must claim the next segment on its way before continuing travel.
- (4) The idle vehicle is sent back to the staging location when no more requests exist. Otherwise, the just idle vehicle is assigned to a request.

## 5.0 INTEGRATION OF EWS WITH MANUPLAN

MANUPLAN is an analytical software package based on network-of-queues and reliability modeling concepts. It is a tool for designing and analyzing manufacturing systems but does not explicitly model the transportation system. In order to provide the user with an evaluation of both manufacturing and transportation systems MANUPLAN has been integrated with the EWS. As shown in Figure 4, an interface program (named SIEFACE.EXE) provides the bridge connecting the EWS and MANUPLAN. By means of this interface program, the neutral data files created in EWS which must contain the input to the simulation code generator are then converted to a MANUPLAN format data file (named SIEMENS.PRN). This data file, therefore, contains the manufacturing system description required by the MANUPLAN processor and LOTUS 1-2-3.

However, as noted before, there are several parameters used in MANUPLAN are not collected in EWS, including the machine utilization limit, the variability in operation times, and lot size, as well as machine setup and speed factors. Therefore, in the interface program, fixed values are assigned to them for demonstration purposes. They are 95%, 30%, 1, 1, and 1 respectively. Furthermore, MANUPLAN allows a part to have multiple routes, but in the EWS the part is always assumed to have a fixed route only. The temporary solution to this limitation of the EWS is to substitute several "dummy" products for a single product having multiple routes. For instance, a part type has the demand 100 with a proposed multi-route as processing on machine 1 first, then 40% to machine 2 and 60% to machine 3 for the second operation. In MANUPLAN this situation is easy to model. In EWS this part type is replaced by one new part type with the demand 40 working on machines 1 and 2, and another new part type with the demand 60 working on machine 1 and 3.



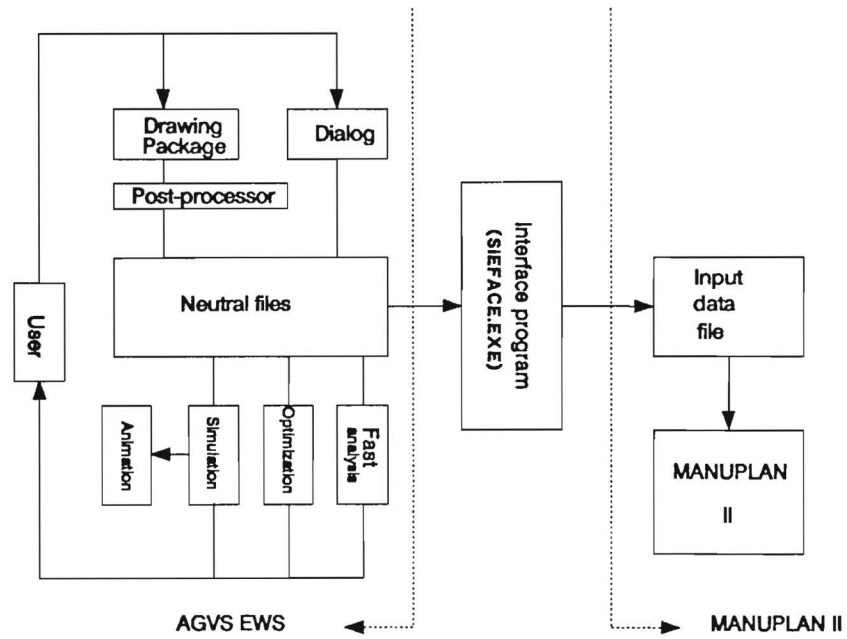


Figure 4 Integration of MANUPLAN and the EWS

## **6.0 EXAMPLE**

In this section, a numerical example is presented. This example demonstrates the input data requirement of the simulation code generator, the program generation and execution procedure, and the output summary. Furthermore, the steps for running the CINEMA animation and generating the MANUPLAN format data file from EWS neutral database are also discussed. It is assumed that all the required files and executable codes, listed in Appendix A, are available.

### **6.1 Input Data**

The system configuration for this example is shown in Figure 2. This system consists of three workstations and one staging area. Three part types are produced in this system and seven vehicles serve as transportation. Table 1 displays the workstation information including workstation label, capacity, and buffer information. In Table 2, the part induction distributions are presented. However, the part routes and processing times are given in Table 3. Table 4 shows the vehicle specification. Finally, the simulation environment information such as the simulation length, time unit, date, project title, and the analyst name is illustrated in Table 5. Note that these tables present the required data which are capable of describing a system but in a different format than that processed by SCG. The formal procedure to input data and then to generate a neutral database is demonstrated in the EWS user's manual.

### **6.2 Simulation Execution Procedure**

The SCG fetches the required data from the neutral database and generates a simulation program. Then this program is executed and output is obtained. A procedure for generating a simulation program and executing it is provided as below.

Table 1 Workstation information

Workstation		Input buffer		Output buffer		Combined buffer	
<u>label</u>	<u>capacity</u>	<u>label</u>	<u>capacity</u>	<u>label</u>	<u>capacity</u>	<u>label</u>	<u>capacity</u>
STN1	2	ST1D	10	ST1P	10		
STN2	3	ST2D	5	ST2P	5		
STN3	1	ST3D	3	ST3P	3		
STAGING	20					STG	20

Table 2 Part induction distributions

<u>Part type</u>	<u>Interarrival distribution</u>	<u>Parameters (min)</u>
Part 1	Exponential	8
Part 2	Uniform	(5.0, 10.0)
Part 3	Deterministic	10

Table 3 Part routes and processing times

<u>Part type</u>	<u>op1 proc time</u>		<u>Part route</u>		<u>op3 proc time</u>	
			<u>op2</u>	<u>proc time</u>		
Part 1	STN1	4.0	STN3	4.0	STN2	5.0
Part 2	STN2	4.0	STN1	5.0		
Part 3	STN1	4.0	STN2	4.0		

Note that two consecutive operations cannot be processed on the same workstation.

Table 4 Vehicle specification

<u>No. of veh in system</u>	<u>Speed (ft/min)</u>	<u>Load/unload time (min)</u>
7	100	0.25

Note that vehicles travel among control points in a constant speed. Vehicles are labeled as VEH101, VEH102, ..., and so on.

Table 5 Profile

<u>Simulation time length</u>	<u>Time unit</u>	<u>Date</u>	<u>Project title</u>	<u>Analyst name</u>
480	min	6-9-1989	Demo	Tester

1. Generate the model and experimental frames by typing

SCG

The simulation program generated from SCG.EXE doesn't model the machine breakdown situation.

2. Compile the model frame by typing

MODEL AGVS.MOD AGVS.M

The model processor (MODEL.EXE) reads the model frame (AGVS.MOD) and outputs the compiled code to AGVS.M.

3. Compile the experimental frame by typing

EXPMT AGVS.EXP AGVS.E

The experiment processor (EXPMT.EXE) generates a file AGVS.E from the input file AGVS.EXP.

4. Link the two frames (model and experimental) and save them in AGVS.P by typing

LINKER AGVS.M AGVS.E AGVS.P

5. Execute the simulation by typing

SIMAN AGVS.P

The whole procedure is controlled by a batch command file which can be accessed from a menu within the EWS. A summary report will be displayed on the screen after the program file is run by the run processor (SIMAN.EXE). In addition, if a "greater than" sign and an output filename are typed following the AGVS.P, then the final result will be saved in this given file instead of being shown on the screen.

### **6.3 Output Summary Report**

The SIMAN summary report for this example is shown in Table 6. It includes a title and two subreports (the tally variables and the discrete change variables subreports) display statistics for part flow time, vehicle utilization, and workstation utilization. As can be seen from the tally variables

subreport, the average unloaded travel time is 5.13 minutes and the average loaded travel time is 3.64 minutes. There were 76 type 1 parts processed during 480 minutes. The average processing time for part type 1 was 32.1 minutes. Similarly, statistics are given for part types 2 and 3. In the discrete change variables subreport, the first row shows an average of 5.67 vehicles busy, which corresponds to a utilization of 81%. The utilizations of individual workstations and their buffers are drawn from the data beneath the first row. The "AGV REQST QUEUE" displays an average length of 0.098 parts per minute in the line waiting to request an available vehicle. However, in this example, no parts were required to wait for a buffer space. Therefore, the "WAIT4 BUFF QUEUE" shows zeros statistics. At the next, the individual vehicle utilization is given. Furthermore, the control points occupancy utilizations are displayed at the end. These utilizations point out the more congested locations. For instance, control points 3, 9, 10, 14, 15,16, and 19 are the top seven congested points and all have the utilization above 35%. Explicitly, the segments which connected by these points from 14 to 9, 9 to 3, 16 to 19, and 10 to 15 denote the high utilized paths.

#### 6.4 Animation Execution Procedure

A general procedure for using CINEMA animation is given below:

1. Build a SIMAN model to represent the system being animated. This step includes the process required to get the AGVS.P file.

2. Construct symbols representing dynamic objects by typing

CINEMA AGVS.ENT      for entities

CINEMA AGVS.RES      for resources

CINEMA AGVS.TRA      for transporters

3. Construct the static objects of the animation layout by typing

CINEMA AGVS.LAY

and using a set of drawing functions provided by CINEMA, or by converting AutoCAD drawing from Data Exchange File (DXF) format to the CINEMA layout format.

Run Number 1 of 1

Project: DEMO  
 Analyst: TESTER  
 Date : 6/ 9/1988

Run ended at time .4800E+03

Tally Variables  
 -----

Number	Identifier	Average	Standard Deviation	Minimum Value	Maximum Value	Number of Obs.
1	UNLOADED TRAV TM	5.13928	2.34010	.14000	11.19995	507
2	LOADED TRAV TM	3.64462	1.51244	1.89999	6.63590	268
3	PART1 FLOW TM	32.12341	3.06050	24.14252	40.66551	76
4	PART2 FLOW TM	19.03686	1.54827	17.01170	23.11115	62
5	PART3 FLOW TM	13.99726	1.95979	11.06194	19.05891	47

Discrete Change Variables  
 -----

Number	Identifier	Average	Standard Deviation	Minimum Value	Maximum Value	Time Period
1	AGGR AGV UT	5.67806	1.33320	.00000	7.00000	480.00
2	STN1 UT	1.72957	.52128	.00000	2.00000	480.00
3	STN2 UT	1.72452	.88081	.00000	3.00000	480.00
4	STN3 UT	.67243	.46933	.00000	1.00000	480.00
5	ST1D UT	.63582	.79133	.00000	4.00000	480.00
6	ST2D UT	.02758	.16452	.00000	2.00000	480.00
7	ST3D UT	.22140	.42865	.00000	2.00000	480.00
8	ST1P UT	.76059	.66766	.00000	3.00000	480.00
9	ST2P UT	.58038	.49816	.00000	2.00000	480.00
10	ST3P UT	.84335	.59920	.00000	2.00000	480.00
11	AGV REQST QUEUE	.09855	.33106	.00000	3.00000	480.00
12	WAIT4 BUFF QUEUE	.00000	.00000	.00000	.00000	480.00
13	VEH101 STATUS	.84258	.36420	.00000	1.00000	480.00
14	VEH102 STATUS	.82610	.37902	.00000	1.00000	480.00
15	VEH103 STATUS	.80060	.39955	.00000	1.00000	480.00
16	VEH104 STATUS	.82665	.37855	.00000	1.00000	480.00
17	VEH105 STATUS	.81759	.38619	.00000	1.00000	480.00
18	VEH106 STATUS	.78895	.40805	.00000	1.00000	480.00
19	VEH107 STATUS	.77559	.41719	.00000	1.00000	480.00
20	CTRL PT 1 UT	.09834	.29777	.00000	1.00000	480.00
21	CTRL PT 2 UT	.29589	.45644	.00000	1.00000	480.00
22	CTRL PT 3 UT	.38046	.48550	.00000	1.00000	480.00
23	CTRL PT 4 UT	.06583	.24799	.00000	1.00000	480.00
24	CTRL PT 5 UT	.19750	.39811	.00000	1.00000	480.00
25	CTRL PT 6 UT	.22664	.41866	.00000	1.00000	480.00
26	CTRL PT 7 UT	.11580	.31998	.00000	1.00000	480.00

27	CTRL	PT	8	UT	.19666	.39748	.00000	1.00000	480.00
28	CTRL	PT	9	UT	.66318	.47262	.00000	1.00000	480.00
29	CTRL	PT	10	UT	.37750	.48476	.00000	1.00000	480.00
30	CTRL	PT	11	UT	.19990	.39993	.00000	1.00000	480.00
31	CTRL	PT	12	UT	.14812	.35522	.00000	1.00000	480.00
32	CTRL	PT	13	UT	.26018	.43873	.00000	1.00000	480.00
33	CTRL	PT	14	UT	.48141	.49965	.00000	1.00000	480.00
34	CTRL	PT	15	UT	.49245	.49994	.00000	1.00000	480.00
35	CTRL	PT	16	UT	.41277	.49233	.00000	1.00000	480.00
36	CTRL	PT	17	UT	.22707	.41894	.00000	1.00000	480.00
37	CTRL	PT	18	UT	.16458	.37080	.00000	1.00000	480.00
38	CTRL	PT	19	UT	.65922	.47397	.00000	1.00000	480.00

Run Time : 46 Second(s)

Stop - Program terminated.



4. In CINEMA, superimpose status variables, just built dynamic objects, or other objects representing the guidepath on the static layout.

5. Run animation by typing

CSIMAN AGVS.P AGVS.LAY

An animation shot at time 70.2 is shown as Figure 5.

The user may retrieve some dynamic objects which represent, for example, parts, vehicles, or machines from predefined files. However, other objects such as control points and guidepath segments have to be added to the layout step by step within CINEMA. This is because dynamic objects in CINEMA have to be numbered to match a corresponding number in the SIMAN model. For instance, in CINEMA, a queue symbol is used to display the entities that reside in a file associated with a SIMAN queue block. Then, the queue symbol has to be specified with a file number consistent with the number used in SIMAN model. Again, numbers representing the control points locating on the guidepath must match the corresponding numbers specified in SIMAN.

Unfortunately, these numbers corresponding to the geometric locations on the drawing picture are not explicitly. To resolve this difficulty, we have created a program (named DXF.EXE) which can combine the information of an existing DXF format drawing file with coordinates of control points and workstations to output a new DXF file. This new DXF file not only maintains the original drawing information but includes the geometric locations of control numbers and workstation numbers. By means of a convert program (named DXF2LAY.EXE) provided by System Modeling, Inc, this new DXF file is translated to a CINEMA static layout and then can be used as a scrap sheet to assist in locating dynamic objects in the CINEMA display. The steps regarding this conversion are presented as following:

1. Output a DXF file from a drawing file in AutoCAD by typing

DXFOUT

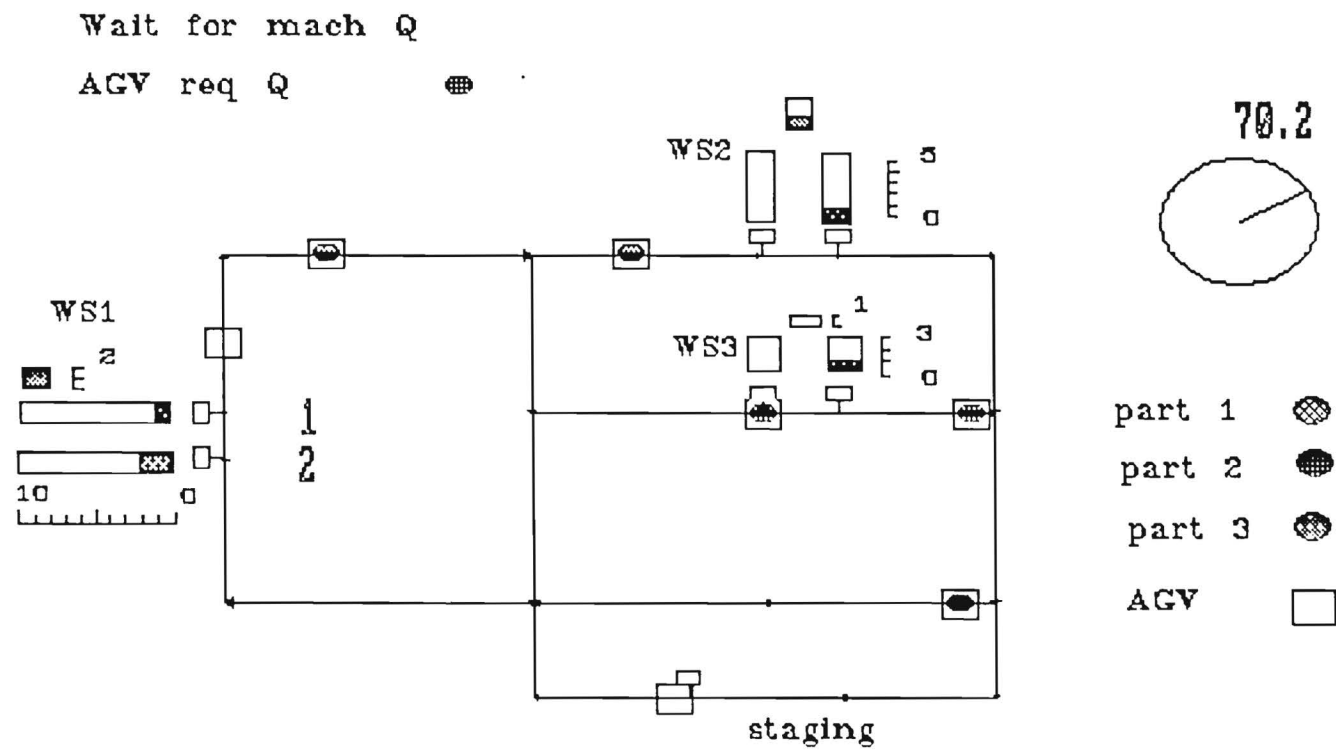


Figure 5 An animation shot

A filename without the extension name (which is defaulted as "DXF") will be asked to store this DXF file. Assume that "TEMPA" is chosen.

2. Create a new DXF file under DOS (i.e., outside AutoCAD) by typing

DXF

Questions asking the input and output filenames will show on the screen. Assume that they are TEMPA.DXF and TEMPB.DXF.

3. Convert this new DXF file to a CINEMA static layout by typing

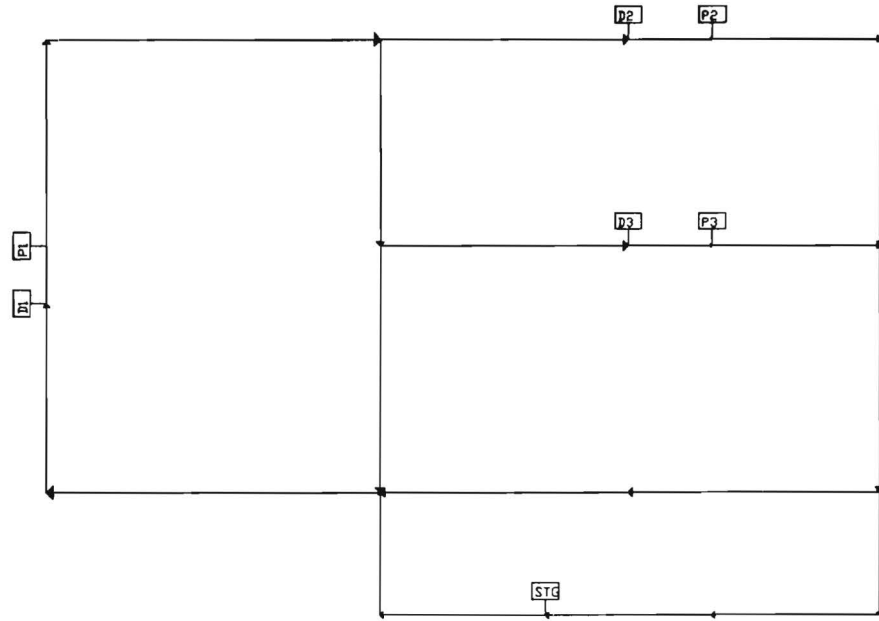
DXF2LAY

The screen will prompt the user to enter the name of the DXF file to be converted which is TEMPB.DXF in this example and a CINEMA layout will be generated with the name TEMPB.LAY.

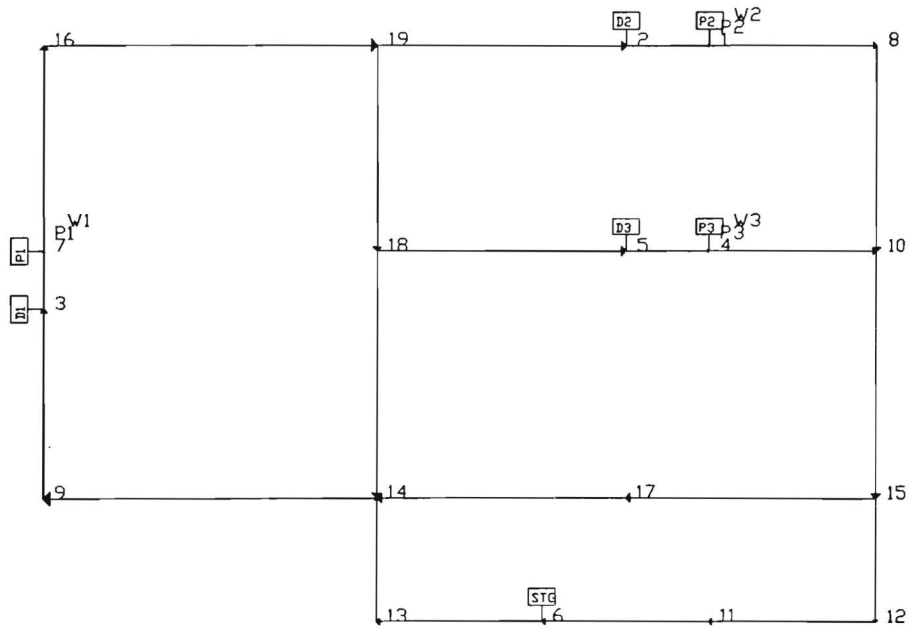
Figure 6(a) presents a primary drawing file example. After Step two, a new drawing file corresponding to TEMPB.DXF with geometric locations of 19 control points (noted by numbers 1 through 19), 3 workstations (noted by w1, w2, and w3), and the pickup points associated with these workstations is given in Figure 6(b).

### **6.5 Interface Program Execution Procedure**

SIEFACE.EXE is the only program needed to convert the EWS neutral data files into a MANUPLAN format file. Just typing "SIEFACE", all the "current" neutral data files will be searched and used to generate a file with the fixed name, SIEMENS.PRN. Then, according to the steps defined in MANUPLAN manual the user can view the statistics of manufacturing system aspect by playing around SIEMENS.PRN. Notice is that the current neutral data files are specified in a profile whose name is stored in a file called "FLAG".



(a)



(b)

Figure 6 (a) The primary drawing file (b) The modified drawing file

## Appendix A

The required files and executable codes are listed as below:

- (1) EWS related programs,
- (2) the simulation code generator (SCG.EXE),
- (3) the EWS/MANUPLAN interface program (SIEFACE.EXE),
- (4) DXF.EXE, and
- (5) a demonstration data set for running simulation and animation.

B 04-693

**INTEGRATED CAPACITY ANALYSIS**

**April 29, 1992**

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## 1 INTRODUCTION

Automatic Guided Vehicle Systems (AGVS) are a widely used automated material handling technology in modern manufacturing. Due to high capital costs, the design and analysis of these system are crucial for the successful use of AGVS. The Engineering Work Station for AGVS (AGVS-EWS), developed at the Material Handling Research Center (MHRC), is aimed at assisting the engineers in designing AGVS applications. AGVS-EWS provides a graphical interface and a set of analysis tools for the layout design and performance analysis.

Initially, the primary focus of the AGVS-EWS was on the material handling system. It provides a good graphical interface for the layout of the guide path and the location of pickup and deposit (P/D) stations. In reality, however, material handling systems are an integral part of the overall manufacturing system. Therefore, a good AGVS-EWS should also facilitate the design of these processing stations. The objective of this project is to create an integrated environment for the design and analysis of material handling systems and processing stations simultaneously. A second objective of this project is to investigate the new analytical tools that can provide more accurate estimates of system capacity measures.

## 2 STRUCTURE OF PREVIOUS AGVS-EWS

Since the addition of a graphical interface for the design of processing stations should leave the others AGVS-EWS' modules untouched, we first evaluated the current AGVS-EWS architecture carefully. After some study, we found that as long as we carefully implement any changes to the neutral database structure, these could be easily incorporated to the current AGVS-EWS.

There are basically four interrelated modules in the AGVS-EWS:

### 1. Setup environment.

In the Setup environment module, a logo program is first executed and an AutoCAD based graphical user interface environment is set.

## 2. Design system.

In the Design system module, a user can specify the guidepath layout, the location of the P/D stations and W/S stations from within AutoCAD. The AutoCAD menus were customized and blocks were added specifically for these tasks. As shown in Figure 1, the LAYOUT menu is used to obtain all the pertinent geometrical information from the layout:

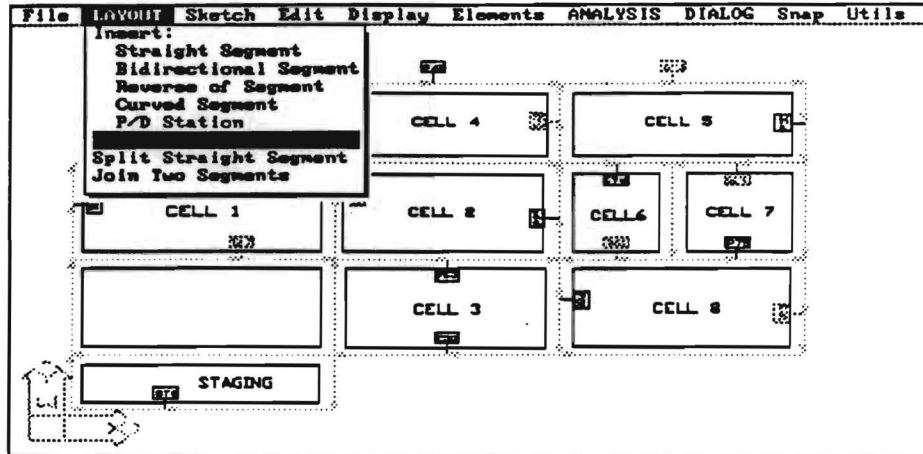


Figure 1. The LAYOUT menu in the previous AGVS-EWS.

## 3. Build Neutral Database

In the Build Neutral Database module, the user can provide information such as:

- Vehicle characteristics
- Workstation area
- Part processing
- Part routing

This module is implemented under the DIALOG menu. The user input in this module is either in a spreadsheet format or interactive dialog format. DIALOG functions are designed to obtain non-geometrical information. Both geometrical and non-geometrical information are processed and used to build the neutral database files. These are ASCII files with a prescribed format. Implicit key structures are assumed for the neutral database. Any application program,



developed in any language can then access the data. Since the information required to specify a manufacturing system is extensive, a well structured database is necessary. The neutral data base provides an open architecture for the AGVS-EWS. Figure 2 shows the way in which the information related to processing stations was entered in the AGVS-EWS:

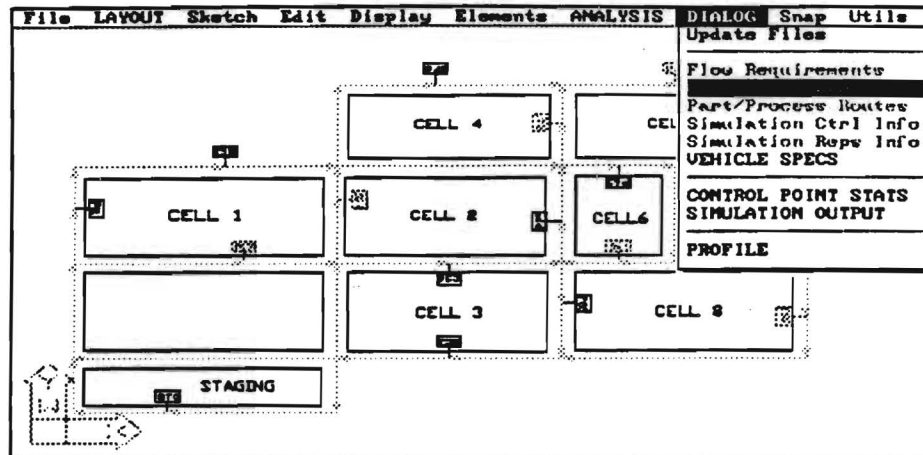


Figure 2. The DIALOG menu in the previous AGVS-EWS.

#### 4. System Analysis

In the System analysis module, there are many interface routines written in a variety of languages. Each routine interfaces with the neutral data base files to extract the information needed and to store output results. New routines can be added without affecting the performance of the existing routines. Different heuristic algorithms are employed to determine the flowpath and to compute the number of vehicles required. MANUPLAN, a specialized software package, was chosen as the rough cut analysis tool to be used in the AGVS-EWS. The simulation and animation analysis were developed in SIMAN with CINEMA to provide more detailed analysis.

### 3 NEW EWS-AGVS

The first decision in the addition of processing station blocks under the DIALOG menu is to determine their classification. We decided to categorize three types of processing stations, namely:

- Robots
- Machines
- Storage

Previously, the design of AGVS was done through the LAYOUT menu as shown in Figure 1. However, the specification of processing station attributes was done through the DIALOG menu as shown in Figure 2. This means that the user had to enter the information using different modules, leaving room for confusion and errors. Hence, it was considered appropriate to integrate the design of both AGVS and processing stations into one graphical module. This was done by replacing the WORKAREA submenu under DIALOG by the WORKSTATION submenu shown in Figure 3 under LAYOUT.

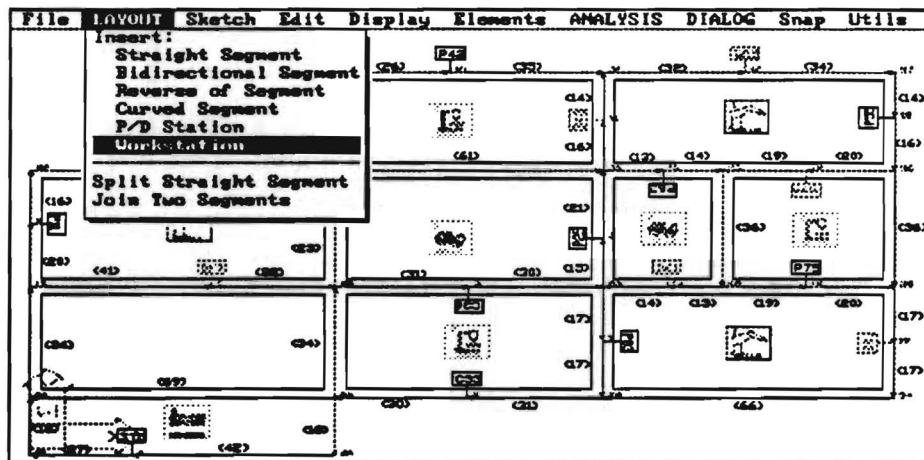


Figure 3. Current LAYOUT menu, with WORKSTATION submenu

The new DIALOG menu is shown in Figure 4:

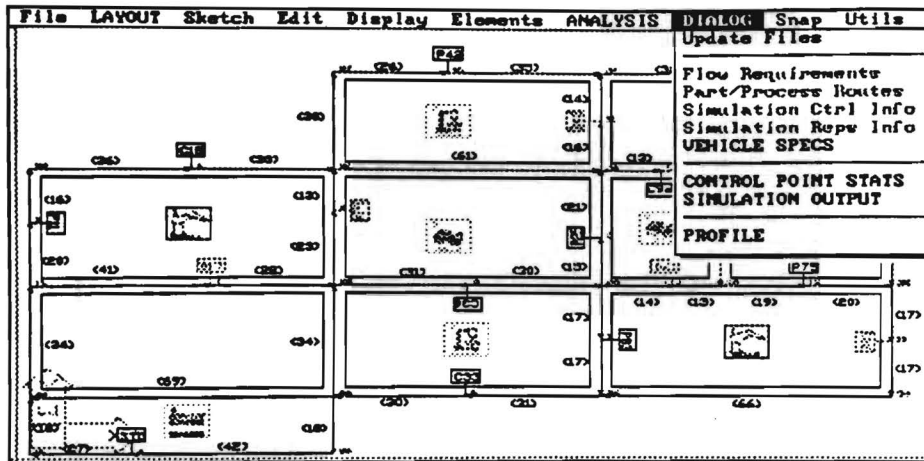


Figure 4. Modified DIALOG menu without WORKAREA information

Now workstations can be inserted into a user specified location and the menus will prompt for the appropriate information:

- Unique workstation Id.
- Number of workstations.
- MTTF (Mean Time to Failure).
- MTTR (Mean Time to Repair).
- Workstation capacity.

The following defaults are provided for these attributes and can be defined when creating the AutoCAD blocks:

	ROBOT	MACHINE	STORAGE
Unique W/S Id	CELL1	CELL2	CELL3
Number of W/S	1	2	3
MTTF	11,000	12,000	13,000
MTTR	10	20	30
W/S Capacity	1	1	1

The attributes can be made visible or invisible to the user. We chose to make visible the first two, Unique W/S Id and Number of W/S, but it is possible to customize this property when creating the attributes of each individual block.

The AutoCAD slides library has been updated to incorporate the different workstation slides that have been created. This step was needed to allow the use of AutoCAD's icon menus for the selection of the workstation type in a user-friendly way.

The Neutral Database structure was modified to allow this change and to correct some existing inconsistencies in the way the information related to workstations was being treated. The new structure is compatible with the existing tools.

The W/S information is being stored in the WSC file of the Neutral Database. This is the file format:

<b>Format</b>	A8	I3	F8.1	F6.1	I2	F8.1	F8.1
<b>Data</b>	Label	Capac.	MTTF	MTTR	Number	XCoor	YCoor
<b>Label</b>	STNLABEL	BUFFER	MTTF	MTTR	NUMBER	XCOORD	YCOORD

The FORMAT row, specifies the field type and length of each W/S attribute being stored in the WSC file. An "A" stands for alphanumeric, "F" for real numbers and "I" for integers. The DATA row is a short explanation of what the attribute is. The LABEL row lists the information recorded in the GEOBASE.TXT file. This file's purpose is explained later on in this document.

Once manufacturing stations were incorporated, it was important to extend the EWS-AGVS reporting capabilities to these new elements. That led us to the implementation of a new option under the ELEMENTS menu as shown in Figure 5:

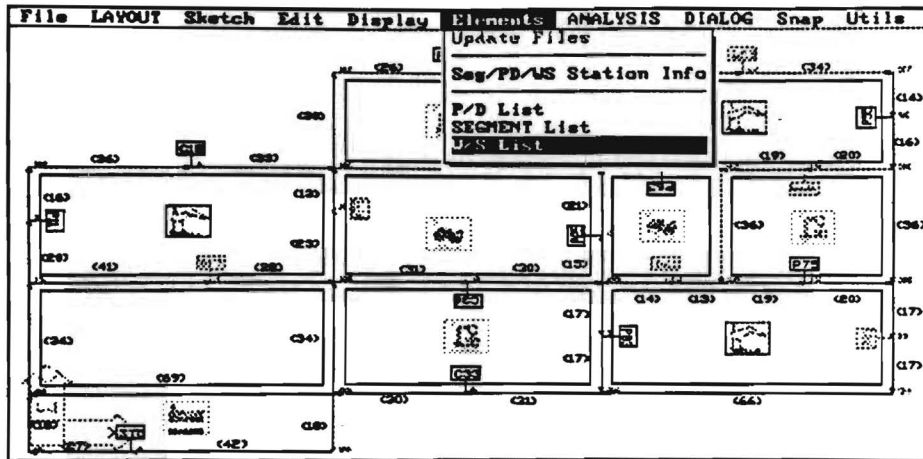


Figure 5. Modified ELEMENTS menu with the WORKSTATIONS LIST information

This menu option executes an external program which allows the user to list the W/S currently in the drawing with their respective attributes. It also allows to print this information to either a file or a printer and to sort the list by one of five possible attributes.

The process by which the AGVS-EWS' geometrical information is obtained has been changed so that the workstation attributes are now available to any external program through the WSC file of the Neutral Database as mentioned before. The format used to write this information to an ASCII file, was previously recorded in a file that will be called here, GEOBASE.TXT. The old GEOBASE.TXT file instructed the AGVS-EWS to record the following information from the AutoCAD drawing:

- Block name.
- X and Y coordinates.
- Orientation.
- Related workstation ID.
- Identifier.
- P/D station buffer.
- Workstation capacity.

Now, it will also take the attributes that follow:

- MTTF (Mean Time to Failure).

- **MTTR (Mean Time to Repair).**
- **Workstation number.**

The geometrical information from the drawing is written to an ASCII file. We will call it here PROJECT.TXT. The previous EWS-AGVS wrote 79 columns to this file, and that format has been kept in the new EWS-AGVS to avoid compatibility problems.

After the appropriate information has been extracted, the AGVS-EWS performs a series of simple tests whose objective is to verify that the different heuristics and algorithms are provided with the right input. These tests are performed by an external program. We will call it here, CONVERT.

The CONVERT program has been modified so that it now accepts workstation elements. These new elements, or blocks in AutoCAD jargon, are being checked for the following properties:

- **Check W/S labels.** So that later on typing mistakes will not affect different modules of the EWS-AGVS.
- **Check W/S uniqueness.** Duplicated W/S labels are not allowed.
- **Check physical presence.** All W/S associated to any P/D station must be physically present in the layout.
- **Check logical consistency.** If a processing station can be entered by a part, there must be at least a deposit station associated with it, and if a processing station can have a part leaving it, there must be at least a pickup station associated with it. This statement is summarized by the following expression:

```

IF ( # of Combined P/D) > 0 THEN
    Fine
ELSE
    ( IF (# of Pickup P/D) * (# of Deposit P/D) > 0 THEN
        Fine
    ELSE
        (Report an error))

```

#### 4 INTEGRATED ANALYSIS WITH MANUPLAN

Since the manufacturing decision-making process is usually very complicated, simulation is often the only tool available to achieve more accurate estimates. An automatic simulation, Simulation Code Generator (SCG), has been developed in MHRC under a different project. Although simulation models can be made accurate and life-like, however, simulation has its own disadvantages (especially in the early stages of planning):

- Simulation models require an enormous amount of information;
- Information collecting also requires large investments of labor;
- Running simulation is very time-consuming.

One way to reduce possible simulation efforts is to eliminate the number of inferior decision alternatives before actually running simulation. Analytical tools have been proved to be useful in eliminating inferior decision alternatives in the early stages of planning, and can then be used to overcome disadvantages associated with simulation. A software package, MANUPLAN, is incorporated as the current analytical tool of the AGVS-EWS for the purpose of overcoming those simulation disadvantages.

MANUPLAN, a commercial software package which is developed by Network Dynamics, Inc., is the analytical tool incorporated in the AGVS-EWS for the design and analysis of the overall manufacturing system. The analysis procedure of MANUPLAN is as follows. First, based on user input, MANUPLAN constructs a model (which is called MANUPLAN model) of manufacturing system as a network of queues, where workstations and their processing operations are represented as queueing nodes (which are called equipments in MANUPLAN) and services (which are called operations in MANUPLAN), respectively. Then, MANUPLAN uses queueing network methodology, along with reliability theory, to analyze the resulting queueing network model. System performance measures, such as the average flow times of parts, average work-in-process levels, and utilizations of workstations, can then be calculated. Although MANUPLAN is already introduced into the AGVS-EWS for the purpose of designing and analyzing the overall manufacturing system, its usage can be improved by modifying the model of the system.

In current applications of MANUPLAN, the results obtained by using MANUPLAN are quite different from the results obtained by using simulation. Hence, one of the objectives of this project is to investigate that, either

- the current MANUPLAN applications can be improved, or
- an alternative analytical tool is needed to replace the role of MANUPLAN.

#### 4.1 Previous MANUPLAN Model

In the AGVS-EWS, the applications of MANUPLAN is described as follows. The current approach uses MANUPLAN to construct a MANUPLAN model of the overall manufacturing system as shown in Figure 6. In the figure, cells are modeled as individual queueing nodes.

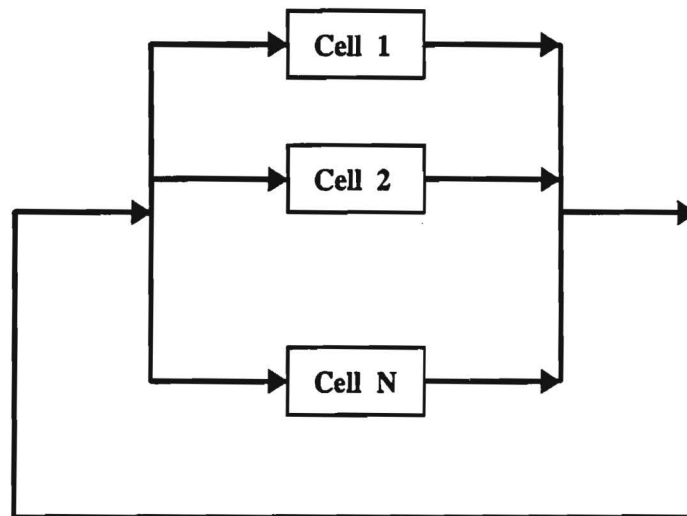


Figure 6. Original MANUPLAN Model



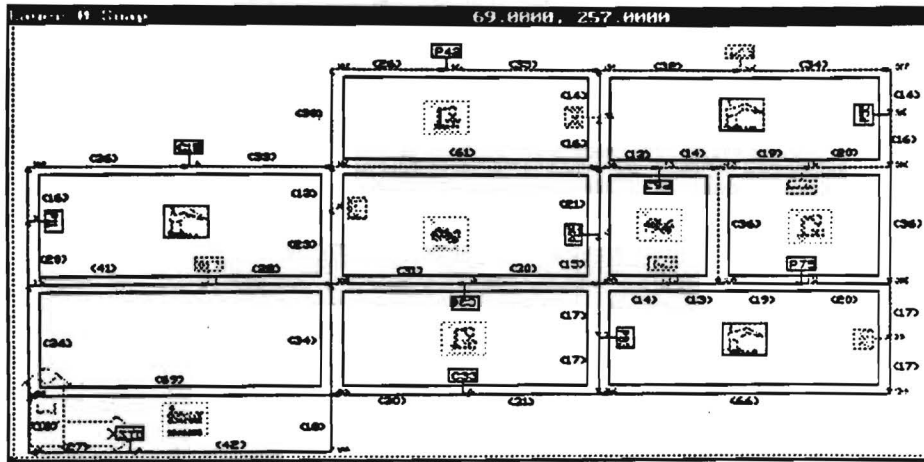


Figure 7. Layout of Examples

	Simulation	MANUPLAN
<b>Production Rate:</b>		
Part 1	19	20
Part 2	43	45
Part 3	35	35
<b>Flowtime:</b>		
Part 1	26.2	15.6
Part 2	34.9	25.9
Part 3	52.3	37.0
<b>Utilization:</b>		
Cell 1	28	26
Cell 2	61	42
Cell 3	47	37
Cell 4	45	46
Cell 5	17	33
Cell 6	31	44
Cell 7	20	41
Cell 8	19	43

Table 1. Numerical results of Example 1

The AGVs are ignored in the MANUPLAN model. The advantage of the current approach is the simplification of the resulting MANUPLAN model. But this simplification may also be the disadvantage. It is apparent that the current approach will be inappropriate if transfer operations of the AGVs play an important role in the overall manufacturing system. For example, the average flow times

of parts obtained by the current approach will be smaller because transportation times of the AGVs transfer operations are omitted. Fig 7 shows the layout of manufacturing system of Example 1, and the numerical results is given as in Table 1. In the table, columns 1 and 2 are the results of the MANUPLAN model of the current approach and simulation model respectively.

As we can see, the flow times of parts of the current approach are all underestimated compared with the simulation results. The reason of underestimating the flow times, as stated above, is mainly due to ignoring the effects of transfer operations of the AGVs in the current MANUPLAN model.

As shown in Table 1, since transfer operations of the AGVs may play an important role in determining the flow times of each part type, better results can be expected if the AGVs are included in the MANUPLAN model. The issue then becomes how to develop an alternative approach which can incorporate the modelling of the AGVs in the MANUPLAN model.

#### 4.2 New Approach to MANUPLAN Model

Generally, in queueing network models there are two different ways for modelling material handling devices of manufacturing system: one is the central server model, and the other is the non-central server model. In the central server model, material handling devices are treated as a single queueing node in which the number of servers in the node is equal to the number of material handling devices available. All servers are conceptually the same. Transfer operations of material handling devices are treated as the services which are provided by servers of the queueing node. The service discipline of the node may depend on the types of servers, e.g., the characteristics of material handling devices being modeled. The advantage of the central server model is the simplification of the resulting queueing network model if most material handling devices are of the same characteristics. The disadvantage is that this simplification may cause inaccuracy if servers have significantly different characteristics.

In the non-central server model, each of material handling devices are treated as separate queueing nodes, that is, the number of queueing nodes is equal to the number and the types of material handling devices available. In contrast to the central server model, the advantage of the non-central

server model is that, since each of material handling devices is treated as separate queueing nodes, the resulting queueing network model can then represent the system more accurately. However, the disadvantage is that the model becomes more complicated.

Considering the model complexity and the capability of MANUPLAN, we propose that the central server model is a good alternative. The reason is that, in most cases, the AGVs used in a manufacturing system are usually of the same or similar characteristics. Hence, the simpler central server model should be used. As a matter of fact, the central server model is the one that is used to model material handling devices in most research work. Thus, in the proposed approach, the AGVs will be modeled as a single central server node. The concept of the modified MANUPLAN model of manufacturing system with material handling devices is applied to the same layout shown in Figure 8. Note that, in the figure, the additional queueing node called AGVs is the central server node. In the modified MANUPLAN model, all parts finish processing operations in one workstation will now be transferred to the next workstation by one of the available servers of the central server node AGVs. (In terms of MANUPLAN terminology, the AGVs and transfer operations are modeled as equipments and operations in the MANUPLAN model respectively.)

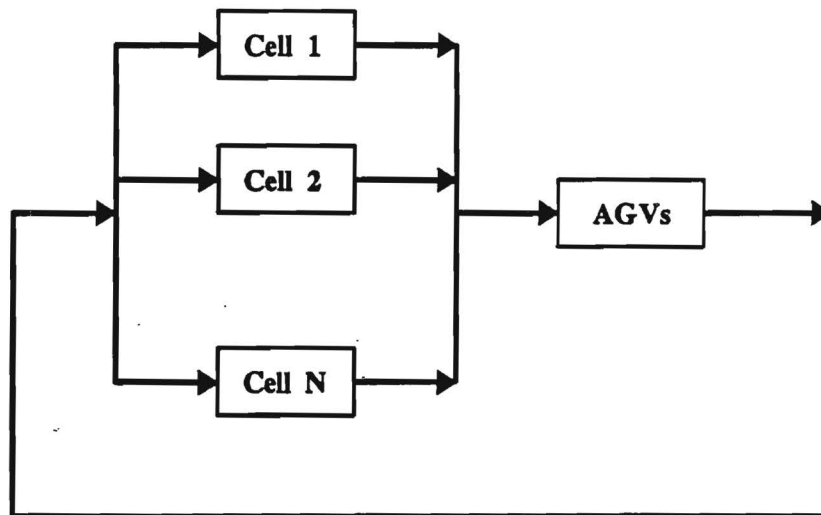


Figure 8. Modified MANUPLAN Model

In order to implement the proposed approach, we need to estimate the average travel time of the AGVs. This average travel time will be used as the mean operation time of the AGVs equipment in the MANUPLAN model. The derivation of the average travel time of the AGVs is shown as follows.

Let the AGVs central server node be denoted by workstation 0, and also let

$D_{0j}$  travel distance from workstation 0 to workstation j,

$D_{ij}$  travel distance from workstation i to workstation j,

$N_{0j}$  parts flow from workstation 0 to workstation j,

$N_{ij}$  parts flow from workstation i to workstation j,

$T_{0j}$  travel time from workstation 0 to workstation j

$T_{ij}$  travel time from workstation i to workstation j

$V$  mean travel velocity of the AGVs,

$T_{load}$  average load time of the AGVs.

$T_{unload}$  average unload time of the AGVs.

$T_{avg}$  average travel time of the AGVs.

Then we have

$$T_{0j} = \frac{D_{0j}}{V} \quad \text{and} \quad T_{ij} = \frac{D_{ij}}{V} \quad \text{for all } (i,j).$$

and average travel time  $T_{avg}$  can be calculated as

$$T_{avg} = \frac{\text{Total unloaded travel time}}{\text{Total number of unloaded travels}} + \text{AGVs load time} \\ + \frac{\text{Total loaded travel time}}{\text{Total number of loaded travels}} + \text{AGVs unload time.}$$

Since  $\sum_{(0,j)} N_{0j}$  and  $\sum_{(i,j)} N_{ij}$  are the total number of unloaded travels and the total number of loaded travels respectively, and  $\sum_{(0,j)} (N_{0j} * T_{0j})$  and  $\sum_{(i,j)} (N_{ij} * T_{ij})$  are the total unloaded travel time

and the total loaded travel time respectively, therefore

$$T_{avg} = \frac{\sum_{(0,i)} (N_{0j} * T_{0j})}{\sum_{(0,j)} N_{0j}} + T_{load} + \frac{\sum_{(i,j)} (N_{ij} * T_{ij})}{\sum_{(i,j)} N_{ij}} + T_{unload} . \quad (3.1)$$

### 4.3 Numerical Results

In this Section, several numerical examples are given to show that the proposed approach indeed gives better results than the current approach (the results are compared with that of simulation model). For clarity, the models of the current approach and the proposed approach will be noted as the original MANUPLAN model and the modified MANUPLAN model respectively.

The layout for Example 2 is the same as Figure 7 without Cell 4, and the numerical results is given as in Table 2. The average travel time of the AGVs calculated by using (3.1) is 2.4. Column 1 shows the results of simulation, columns 2 and 3 are the results of the original MANUPLAN model and the modified MANUPLAN model respectively. Note that, all the flow times of each part type are underestimated in the original MANUPLAN model. The flow times of the modified MANUPLAN model does give better estimation than the original MANUPLAN model.

As shown in the numerical example, it is clear that the modified MANUPLAN model is better than the original MANUPLAN model because it takes into consideration of transfer operations of the AGVs. In the remaining of the section, we make a simple experiment to investigate the effect of variation of the AGVs average travel time. In order to show the effect of variation of the AGVs average

travel time on the flow times estimation, we change the value of the AGVs average travel time and recalculate the flow times. The layout for Example 3 is the same as Figure 7 without Cell 1, and the numerical results is given as in Table 3.

	Simulation	MANUPLAN	MANUPLAN (AGVs)
<b>Production Rate:</b>			
Part 1	26	26	26
Part 2	55	55	55
Part 3	36	36	36
<b>Flowtime:</b>			
Part 1	25.0	16.6	23.2
Part 2	30.1	21.2	28.9
Part 3	39.9	32.1	41.4
<b>Utilization:</b>			
Cell 1	29	28	28
Cell 2	67	48	48
Cell 3	46	42	42
Cell 5	19	41	41
Cell 6	28	47	47
Cell 7	26	45	45
Cell 8	27	52	52

Table 2. Numerical results of Example 2

In Example 3, the average travel time of the AGVs calculated by using (3.1) is 2.4.. Note that there are two more columns in the table, i.e., columns 4 and 5, which are the results of the modified MANUPLAN model with different average travel times of 2.0 and 3.0, respectively. The results of these two columns are to show the effects of variation of the AGVs average travel time on the flow times estimation. As we can see in the table, the flow times of the modified MANUPLAN model (with the average travel time of 2.4) still gives better estimation. From columns 4 and 5, the results show that the effects of variation of the average travel time on the flow times estimation are not significant.

	Simulation	MANUPLAN	MANUPLAN (AGVs: 2.4)	MANUPLA N (AGVs: 2.0)	MANUPLA N (AGVs: 3.0)
<b>Production Rate:</b>					
Part 1	26	26	26	26	26
Part 2	55	55	55	55	55
Part 3	36	36	36	36	36
<b>Flowtime:</b>					
Part 1	25.0	16.6	23.9	22.7	25.8
Part 2	30.1	21.2	28.6	27.3	30.5
Part 3	39.9	32.1	41.9	40.3	44.5
<b>Utilization:</b>					
Cell 2	29	28	28	28	28
Cell 3	67	48	48	48	48
Cell 4	46	42	42	42	42
Cell 5	19	41	41	41	41
Cell 6	28	47	47	47	47
Cell 7	26	45	45	45	45
Cell 8	27	52	52	52	52

Table 3. Numerical results of Example 3

Hence, we may conclude that the proposed approach, adding an AGVs central server node in the modified MANUPLAN model, gives better estimation than the original MANUPLAN model.

Furthermore, the average travel time calculated by (3.1) is quite robust in the flow times estimation.

## 5 CONCLUSIONS AND FUTURE RESEARCH

This research has demonstrated the feasibility of a graphical user interface, based on AutoCAD, that provides access to powerful analytic procedures for joint evaluation of material handling and process equipment. Specifically, the AGVS-EWS has been extended by adding icons for processing operations which can be placed in the CAD drawing in the same way as AGVS P/D stations. The software has been modified to provide an automated use of MANUPLAN for analyzing the production operations. In addition the queuing network model of the system has been modified to include a material handling node.

As shown in Section 3, the inclusion of the AGVs central server node of the proposed approach gives better results than the current approach. To implement the proposed approach, the following tasks

need to be done: (i) develop a computational procedure to calculate the AGVs average travel time  $T_{avg}$  and (ii) modify the current programs to incorporate the addition of the AGVs central server node in the MANUPLAN model.

Besides developing the proposed approach using MANUPLAN, we also investigate other analytical tools including Zulma's algorithm and QNET. Zulma's algorithm is a heuristic method, as stated by the developer, it is developed to analyze specifically manufacturing systems with automatic storage/retrieval system (AS/RS). QNET, a software package developed by Harrison et al., is based on heavy traffic theorem and diffusion approximation (more specifically, Brownian motion approximation). A special feature of QNET is that it takes into consideration of variations in manufacturing systems, therefore it can be used to treat more general problems. However, computational difficulties still need to be resolved. (Furthermore, blocking is a quite common situation in most manufacturing systems. Unfortunately, most available software packages are not able to handle blocking situations. More theoretical work need to be done in this area.)