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ANIMATED SIMULATION OF A FLEXIBLE MANUFACTURING SYSTEM

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ABSTRACT

A flexible manufacturing system requires computer control of a variety of machines, complicated product routings and mixing, and costly installation. To reduce potential design errors and associated financial risk, simulation techniques must be employed. This paper applies animated simulation to a flexible robotic inspection cell, a flexible wave soldering cell, and an automated guided vehicle system (AGVS) in one of Intel's integrated circuit assembly plants in Arizona. The flexible robotic inspection cell consists of two inspection stations, two robots, a programmable conveyor system, and input/output mechanisms. The simulation identifies the units per hour (UPH) of the cell, and operator's utilization which gives clues to multiple cell handling. The flexible wave soldering cell includes a wave soldering machine, a loader, and an unloader. The simulation provides insights to critical design parameters of the loader/unloader and the number of operators that are necessary to maintain smooth operation of the cell. In the AGVS, one automated guided vehicle (AGV) and 21 docks are used. The AGV picks up or drops off a tote of materials on each dock. Excessive raw material delivered to each dock increases manufacturing cost; however, too little will increase the number of AGV. The simulation is used to identify the optimal quantity of material in a tote.

1. INTRODUCTION

The semiconductor industry is highly competitive; the ever-ending demand for smaller, faster, cheaper integrated circuits renders a state-of-the-art product quickly obsolete. To adapt to this volatile market and rapidly bring products to customers, manufacturing processes must be flexible. Flexible manufacturing system (FMS) which employs robots, automated guided vehicle system (AGVS), intelligent machines, and computer control (Ranky 1983) suits the needs.

FMS is superior to conventional hard automation in the following aspects (Browne and Rathmill, 1983 and Hegland, 1984):

1. Product mixing is allowed.
2. Change of product type can be easily adapted.
3. Machine utilization can be maximized.
4. Throughput time can be significantly reduced.
5. Future system upgrading or expansion can be easily adapted.

However, FMS requires tight computer control of a number of machines, complicated part routing sequences, and costly installation; a design error is likely to cause disastrous financial consequence. To ensure design integrity and minimize the associated financial risk, simulation must be performed (Dey, Rangswami, and Wang, 1986). Animation technique is an excellent aid to simulation; for instance, debugging is much easier and completion time of programming is much sooner. In addition, the simulation results are better perceived and accepted by management (Wang, 1985).

In this paper, two simulation languages with animation feature were used; SIMAN (Pegden, 1985) was applied to the design of a flexible robotic inspection cell and a flexible wave soldering cell, and PCModel (White, 1985) was used in the design of an automated guided vehicle system (AGVS) in one of Intel's assembly plants in Arizona.

2. FLEXIBLE ROBOTIC INSPECTION CELL

The flexible robotic inspection cell is a stand-alone station; its application is to inspect the coplanarity, tweezing, and footprint properties of the plastic leadless chip carrier (PLCC) package. It is designed such that when an operator loads a number of tubes which contain PLCC parts in the input port of the cell, parts will be transported, inspected, categorized, and inserted into a tube in of the output ports automatically.

This flexible robotic inspection cell has two inspection stations: one for coplanarity and the other for tweezing/footprint inspection, see Figure 1. Each station employs several cameras to take pictures of a part from different angles; images of the part are digitized and sent to a computer for analysis. At each station, there is a robot which presents a part to the cameras of the station, and places the inspected part on selected locations depending on the inspection outcome. The programmable conveyor system consists of five branches, designated as #1,#2,#3,#4, #5, and #6. It links each station and input/output ports.

The operation of the cell is as follows: an operator picks up a number of tubes from the incoming lot and loads them in the input port where one part at a time will be placed on the branch #1 of the programmable conveyor system; the part is then transported to the first robot. When detecting the presence of a part, the robot picks up and places it under the cameras of the first station (tweezing/footprint). If satisfying the inspection criteria, the part is picked up by the robot and placed on branch #2 to continue its journey; if failing the test, it is transferred to the port labeled "BAD" by the robot and through branch #3. Before reaching the second station, the good part is flipped over so its bottom is exposed. Then it is picked up by the second robot, and presented to the cameras of the second station (coplanarity). Based on the inspection results, it is transferred to a tube in one of the output ports labeled "BAD", "MARGINAL", and "GOOD" by the robot and through branch #4,#5, or #6. When each output port is full of tubes, the operator unloads and brings them to the outgoing lot.

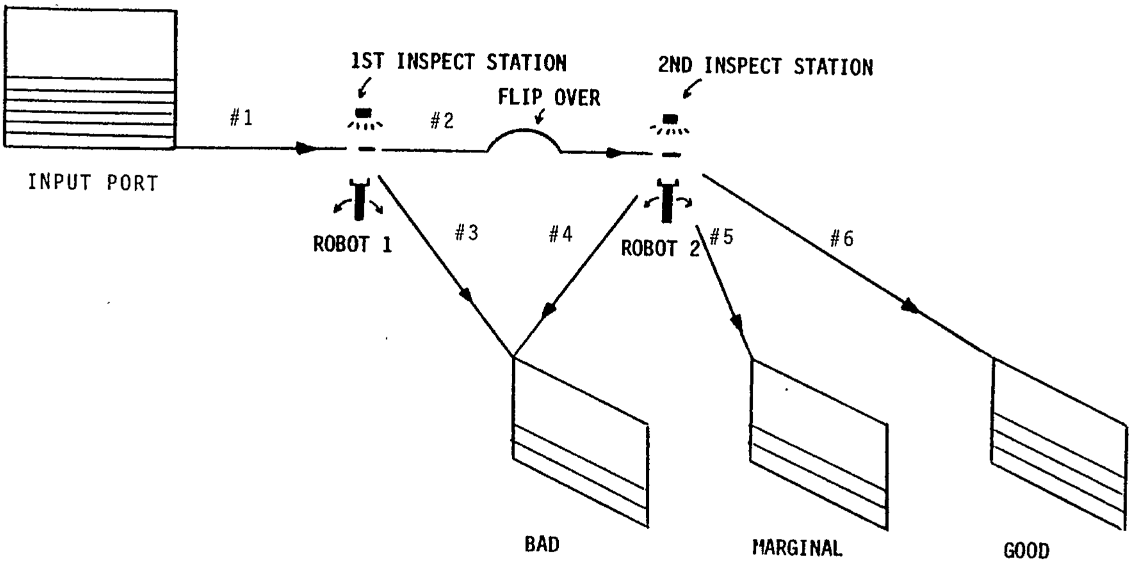


Figure 1: Flexible Robotic Inspection Cell

The assumptions used in the simulation were:

1. Operator loading or unloading time (per four tubes) = 10 seconds
2. Robot loading or unloading time = 1 second
3. Part transport time in each branch:
   Branch #1 = 1 second
   Branch #2 = 3 seconds
   Branch #3 = 1 second
   Branch #4 = 1 second
   Branch #5 = 1 second
   Branch #6 = 1 second
4. Coplanarity inspection time = 2 seconds
5. Tweezing/footprint inspection time = 9 seconds
6. Capacity of input or output ports = 10 tubes
7. # of parts per tube = 8
8. Probability (uniform distribution) of test at each station:
   First station: 98% good, 2% bad, 0% marginal
   Second station: 96.04% good, 1.96% bad, 2% marginal

Based on the above assumptions, the following results were obtained after one hour simulation.

UPH of Good parts = 343
UPH of Bad parts = 11
UPH of Marginal parts = 9
Operator utilization = 7%

From the simulation results, we find the UPH is quite low (343). This result is not unexpected since long inspection time at each station (9 and 2 seconds respectively) is required. Since the utilization of operator is low (7%), one operator can handle several cells simultaneouly.

3. FLEXIBLE WAVE SOLDERING CELL

Solder coating is a necessary process for many packages, especially surface mounted packages such as plastic leadless chip carrier (PLCC) (Rowland, 1985). The solder coating serves two purposes: preventing leads of a package from corrosion and preparing the package for the solder reflow process during surface mounting (Walton, 1985). Wave soldering is one of the soldering techniques (Walton, 1985). Sigulated parts or lead frames which contain a number of parts are first loaded in a fixture which is placed on the conveyor of a wave soldering machine. The fixture is then carried through a tunnel and is periodically submerged in molten soldering material. Since the movement of the conveyor is slow, the soldering material has sufficient time to adhere to the lead surface completely.

The flexible wave soldering cell consists of a loader, an unloader, and a wave soldering machine, see Figure 2. The purpose of the loader is to load lead frames into a solder fixture automatically, and vice versa for the unloader. The operation of the cell is as follows: an operator picks up a magazine containing unsoldered lead frames from the incoming lot and loads it in the input port of the loader. He (or she) then loads an empty fixture at the output port of the loader. The loader indexes the magazine and the fixture simultaneously so a lead frame can be unloaded from the magazine, transported, and loaded in the fixture. When filled up, the fixture is picked up by the operator and loaded on the conveyor of the wave soldering machine. When the fixture exits the soldering machine, the operator picks up the fixture and loads it in the input port of the unloader. Similar to the loader, the unloader indexes the magazine/fixture, unloads, transports, and inserts a lead frame in a magazine in the output port of the unloader. When filled up, an operator picks up the magazine and moves it to the outgoing lot. As time progresses, empty magazines and fixtures are generated, therefore, the operator also needs to recycle empty fixtures or magazines.

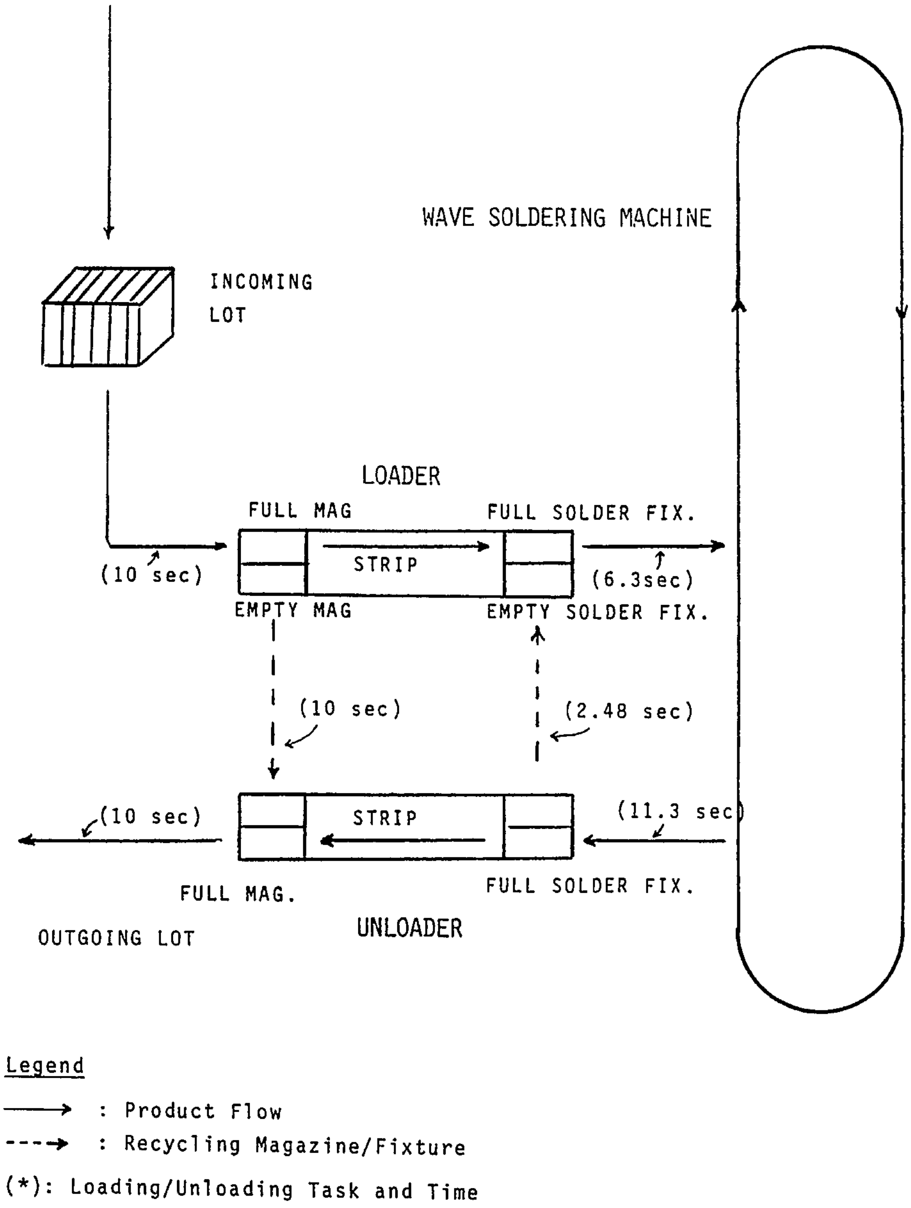


Figure 2: Flexible Wave Soldering Cell

Three critical parameters of loader/unloader are as follows: lead frame transport time, magazine/fixture indexing time, and queue size of input/output ports. The queue size is the number of magazines or fixtures that can be loaded or unloaded in the input/output ports of the loader/unloader. Suitable queue sizes significantly reduce the need for the operator to travel from one place to another. Also critical is the number of operators to operate the cell. These parameters can be explored by simulation.

The following assumptions were used in the simulation:

1. 1 Lot = 80 Lead Frames = 6 Magazines = 10 fixtures
2. One magazine contains 14 lead frames.
3. One fixture contains 8 lead frames.
4. Parameters of wave soldering machine:
   Length = 26 meters
   Speed = 0.025 meter/second
   Width of a slot for a fixture = 0.5 meter
5. Parameters of loader/unloader:
   5a. Lead frame traveling time = 1.5 second
   5b. Magazine/fixture indexing time = 0.5 second
   5c. Queue size of input/output port = 1
6. # of operators = 3
7. # of magazines simultaneouly loaded by operator = 6
8. # of fixtures simultaneouly loaded by operator = 1
9. Loading/unloading task and required time, and designated operator are listed in Table 1.

Table 1: Loading/Unloading Tasks, Time, and Designated Operator

Task	Operator	Loading/Unloading Time (second)	* Cycle Time (second)
Loading six full magazines to loader	#1	10	200
Loading one full fixture to solder	#2	6.3	20
Unloading one full fixture from solder	#3	11.3	20
Unloading six full magazines from unloader	#1	10	200
Recycle one empty solder fixture	#1	2.48	20
Recycle six empty magazines	#1	10	200

*: Time to call an operator for a loading/unloading service.

It is noted that the loading/unloading tasks can be classified into three categories: loading fixture on the wave soldering machine, unloading fixture from the wave soldering machine, and others. However, the unloading fixture from the wave soldering machine is the most critical task; as indicated in Table 1, every 20 seconds the operator must unload a fixture from the soldering machine. If not, the fixture will reenter the soldering machine and cause parts to be soldered twice. Hence, it is logical to assign one operator for loading the fixture on the wave soldering machine, one for unloading the fixture from soldering machine, and the third operator for the remaining tasks as stated in Table 1.

After two-hour simulation, the following data was obtained:

Utilization of operator #1 = 31%
Utilization of operator #2 = 32%
Utilization of operator #3 = 49%

From the above results, it is found that each operator has low utilization, therefore, it is possible to reduce the number of operators in this cell.

Case 1: one operator performs all loading and unloading tasks

From the simulation results, clearly, it is impossible to have one operator to do all loading/unloading tasks (if so, the operator's utilization will be 112%!).

Case 2: two operators performs all loading and unloading tasks

In this case, the operator utilization is 63% (31%+32%) and 49% respectively. Therefore, two operators can perform all loading/unloading tasks in this cell.

Based on the simulation assumptions and operator utilization, we conclude that:

Lead frame transport time = 1.5 second (assumption 5a)
Magazine/fixture indexing time = 0.5 second (assumption 5b)
queue size = 1 (assumption 5c)
Number of operators = 2

4. AUTOMATED GUIDED VEHICLE SYSTEM

The factory where the AGVS is being utilized has the following sequential processes: wafer sawing, die attaching, wire bonding, molding, laser mark, dejunk/trimming/forming (DTF), soldering, and packing/shipping. Wafer sawing, die attaching, and wire bonding are called front-of-line (FOL) processes; the rest are called end-of-line (EOL) processes.

Materials delivered to or from each process are contained in a tote and the material handling is performed by an automated guided vehicle (AGV). The AGV is unidirectional and has two shuttle mechanisms that can automatically pick up or drop off a tote on a dock. Two kind of docks are used; a pickup dock from which the AGV picks up a tote, and a dropoff dock on which the AGV drops off a tote. Under central computer control, the AGV transports materials from inventory to FOL/EOL areas, and vice versa (Wang, 1985). In addition, the AGV recycles fixtures from EOL to FOL. Of each dock, the type, associated process, and materials to be transported are listed in Table 2.

Table 2: Type, Associated Process and Material of Each Dock

Dock	Type	Process	Material
1	Dropoff	Die Attaching/ Wire Bonding	Wafers/Lead Frames
2	Dropoff	Die Attaching/ Wire Bonding	Wafers/Lead Frames
3	Dropoff	Die Attaching/ Wire Bonding	Wafers/Lead Frames
4	Pickup	Die Attaching/ Wire Bonding	Scrap
5	Dropoff	DTF	Indirect Material
6	Dropoff	Molding	Molding Compound
7	Dropoff	DTF	Indirect Material
8	Dropoff	Soldering	Tubes
9	Pickup	Recycling Fixtures to Dock #1	Fixtures
10	Dropoff	Molding	Molding Compound
11	Pickup	Molding	Scrap
12	Dropoff	Packing/Shipping	Boxes
13	Pickup	Packing/Shipping	Finishing Product
14	Dropoff	Inventory Inputs from Docks 4,11,13	
15	Pickup	Material for Dock 5,7,8	
16	Pickup	Material for Dock 10	
17	Pickup	Material for Dock 6	
18	Pickup	Material for Dock 3	
19	Pickup	Material for Dock 2	
20	Pickup	Material for Dock 1	
21	Pickup	Material for Dock 12	

FOL processes are located in clean room area in which air is continuously filtered and positive pressure compared to its surrounding area is maintained (Austin, 1970). Positive air in clean room is to prevent outside dirty air from infiltrating into the room, thus, potential particulate contamination can be eliminated. However, if the entrance is opened when the AGV is entering the FOL area, the positive pressure air may be completely lost and causes contamination problems. To retain positive air, the pressure lock room (Austin, 1970) is built as the entrance of FOL. The pressure lock room has interlocked double doors which cannot open simultaneously, hence, positive pressure in FOL can always be maintained. Inside the pressure lock room, air is also constantly filtered to remove particles brought in by the AGV. To enter FOL, the AGV opens the outside door first and stops temporarily in the pressure lock room; then the outside door closes and air in the room is filtered. After a period of time, the inside door opens to allow the AGV to enter the clean room. The AGV guidepath layout and dock locations are shown in Figure 3. The pressure lock room is located at the upper left corner of Figure 3.

Raw materials share a large percentage of manufacturing cost; therefore, if a small amount of materials can be just-in-time (JIT) delivered to a dock by the AGV, the cost of manufacturing can be reduced. Materials are contained in a tote, therefore, by decreasing the amount of materials in a tote the cycle time that a tote of material is used up is also decreased. As a result, the AGV needs to travel to the dock more frequently and more AGVs may be required. Hence, arbitrary reduction of raw materials in a tote may not justify the increased cost of using more AGVs. By the same token, arbitrary reduction AGVs may not justify the increased cost of raw materials either. Since materials (lead frame, wafer,...) used in assembly process are small compared to the size of a tote, we can always determine the cycle time of each dock by controlling the amount of materials in a tote. Hence, it is possible to use simulation to explore the relation between cycle time and the AGV utilization. The purpose of the simulation is to identify the optimal quantity of materials in a tote that the AGV delivers to (or picks up from) each dock.

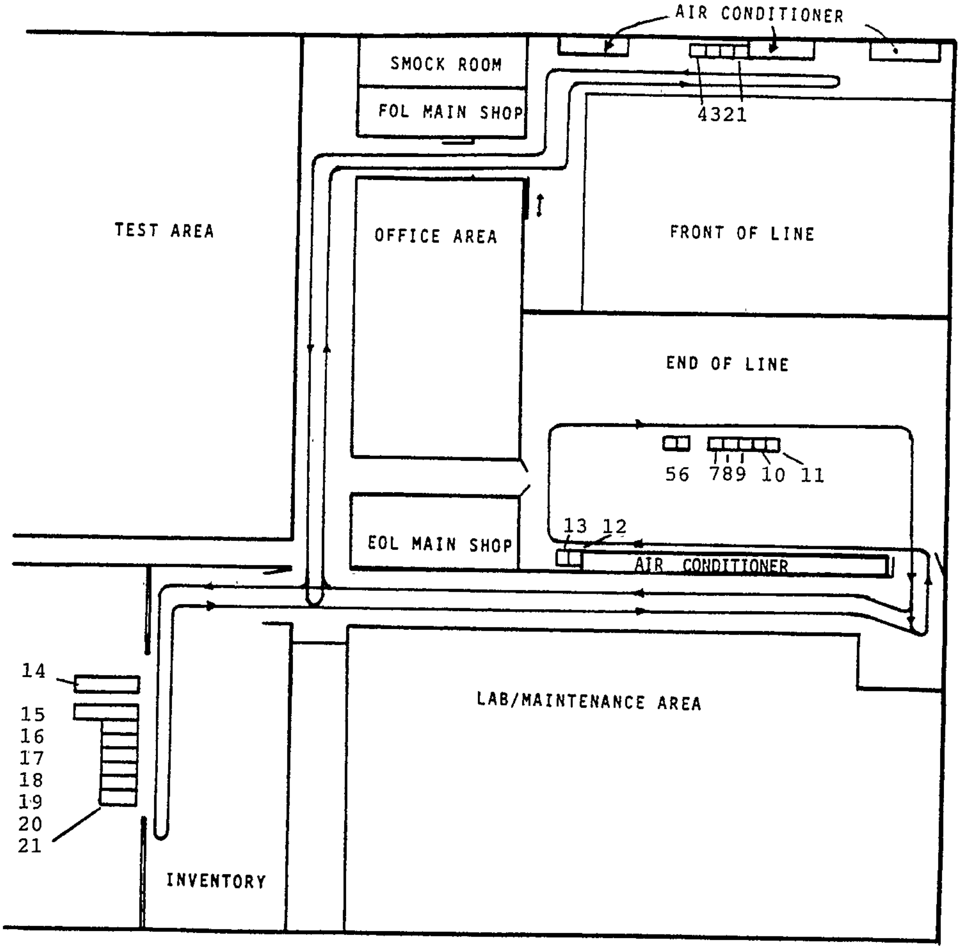


Figure 3 AGV Dock Location and Guidepath

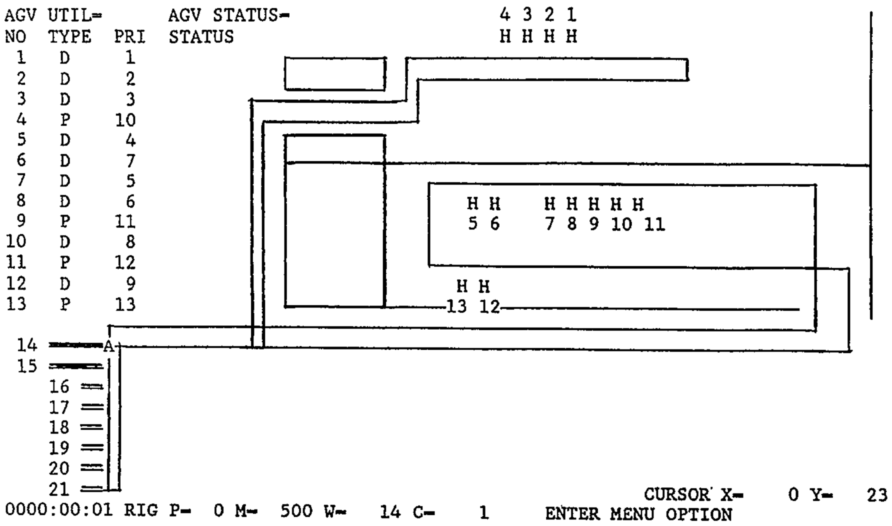
The screen display for animated simulation is shown in Figure 4. Parameters of interest such as number of totes AGV is carrying, AGV utilization, and accumulation/shortage/priority of each dock are shown at the upper left corner.

The assumptions used in the simulation were:

1. One AGV is used.
2. Loading/unloading a tote = 30 seconds
3. Speed of the AGV = 30 meters/minute
4. Temporary stop in pressure lock room = 45 seconds
5. The cycle time of pickup and dropoff dock is the same.

In addition, the AGV is programmed to stop randomly for 5 seconds, then restart to simulate frequent human interference. The cycle time (the time a tote of material is used up or created) is a uniformly distributed random variable with upper and lower limits obtained by increasing or decreasing 30% of the given value.

The results after an eight-hour simulation were shown in Table 3.



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AGV UTIL=        AGV STATUS-
NO  TYPE  PRI    STATUS
 1   D     1
 2   D     2
 3   D     3
 4   P    10
 5   D     4
 6   D     7
 7   D     5
 8   D     6
 9   P    11
10   D     8
11   P    12
12   D     9
13   P    13
14
15
  16
  17
  18
  19
  20
  21                                        CURSOR X-    0 Y-    23
0000:00:01 RIG P-   0 M-   500 W-    14 C-    1     ENTER MENU OPTION
```

Figure 4: Screen Display of AGVS

Table 3: Simulation Results

Cycle Time (Hour)	AGV Utilization	Remark
2	65%	No Material Shortage/ Accumumlation at Each Dock
1.75	76%	No Material Shortage/ Accumulation at Each Dock
1.5	82%	No Material Shortage/ Accumulation at Each Dock
1.25	95%	No Material Shortage/ Accumulation at Each Dock
1	97%	Occurance of Material Shortage/Accumulation at Dock 4,6,7

From the simulation results, we confirm that increasing cycle time of each dock decreases the AGV utilization, and vice versa. It is noted that when the cycle time of each dock is one hour, the utilization of the AGV is pushed to the limit (97%); as a result, material shortage/accumulation occurs at docks 4,6, and 7 which have the lowest priority, see Table 3 and Figure 4. When the cycle time is 2 hours, the utilization of the AGV drops to 65%. Although the AGV utilization is lowest at this cycle time, the amount of raw material delivered to each dock is the highest. If cycle time is 1.25 hour, the AGV utilization is still unacceptably high (95%) although no visible material shortage/accumulation occurs. Hence, the optimal cycle time should be 1.5 hour, when the AGV utilization is acceptable and the amount of raw material delivered to each dock is modest.

5. CONCLUSION

In this paper, we successfully applied animated simulation to design a flexible robotic cell, a flexible wave soldering cell, and an AGVS. The simulation identified (1) the UPH and operator's utilization of the flexible robotic cell (2) the lead frame transport time, magazine/fixture indexing time and queue size of loader/unloader, and the number of operators to operate the flexible wave soldering cell (3) the optimal amount of material in a tote delivered to each dock by the AGV in the AGVS. With the aid of animation, we avoided long programming time and presented the results to management in a more convincing manner.

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