USE SIMULATION TO STUDY THE FEASIBILITY OF AN AUTOMATIC GUIDED VEHICLE (AGV) SYSTEM

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1 INTRODUCTION

The growing competition from neighbouring countries and shortage of skillful labour force more and more manufacturing companies look into highly automated manufacturing systems. Although automation vendors must make sure the automation systems to install will meet the performance requirement, it is the manufacturing company's responsibility to achieve the overall target: the output, utilisation, work-in-process, and manufacturing cycle time.

An Electronics Manufacturing company in Singapore proposes to install an Automatic Guided Vehicle (AGV) for the material handling of an inspection operation. The proposed system is highly automated, complex in control logic, and capital intensive. To make sure the system would work after installation, field experiments were conducted to verify the inspection time, loading and unloading time, lot change over time, product conversion time, etc.. In addition, historical data such as lot size distribution, yield rate, machine breakdown, etc. were collected and analysed together with Planning, Quality and Engineering Departments. Forecast of the production volume and operational improvement were scrutinised.

However, several issues still remain uncertain. For example, what will be the probability when more than one machine are simultaneously sending request signals? how long will the AGV delay before it responds to a request signal? if the AGV's response time is too long, what will be the major cause and how can it be improved? To quantify the answers to these questions, the project team decided to adopt the computer simulation approach.

After a careful evaluation, WITNESS, the visual interactive simulation system developed by AT&T, was selected for this study. Visual interactive simulation models show the movement of the material handling system within the pre-defined system facility which enable users to identify the improvement.

2 SYSTEM DESCRIPTION

2.1 Operational Sequences

The operations of one inspection machine are illustrated in Figure 1. When a new lot starts, the following tasks will be performed:

i) A number of trays are fed onto the Input Stack "L" (see left hand side in Figure 1) by the AGV. The tray size (i.e. number of units per tray) is product dependent.
ii) The units in the trays are inspected by moving the trays through the inspection machine one by one (from left to right in Figure 1). The inspection time per tray is product dependent.
iii) When a tray approaches Output Stack "G", the reworkable units are picked up and placed to "R", and the reject units picked up and placed to "X".
iv) After the reworkable and reject units are picked away, the first tray of the lot with the remaining good units is transferred by AGV to Buffer "B".

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v) For subsequent trays, the tray is replenished by good units from Buffer "B". The inspected tray full of good units is placed at Output Stack "G".
vi) When the whole lot completes (i.e. the last tray moves to Output Stack "G"), the AGV is requested to take all the trays in "G", "B", "R" and "X" to the out-going station.

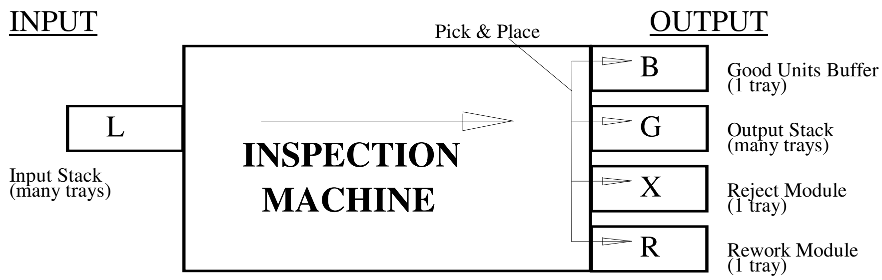

Fig. 1. The Operations of an Inspection Machine

2.2 AGV Movement Layout and Specification

The schematic layout of the AGV movement is shown in Figure 2. The AGV moves clockwise along the track. The following data was acquired from the AGV vendor:

- Normal AGV travelling speed
- Cornering time: time that the AGV turns around a corner
- Locating time: time that the AGV positions itself before loading and unloading
- Signal communication time: time that the AGV needs to receive a request signal at the in-coming station. It decides what tasks to undertake for the next trip
- Loading/unloading time: time that the AGV takes one or more trays to/from one position, e.g. unload all trays to Input Stack "L", load 1 tray from Rework Module "R"
- Battery-charge time and interval

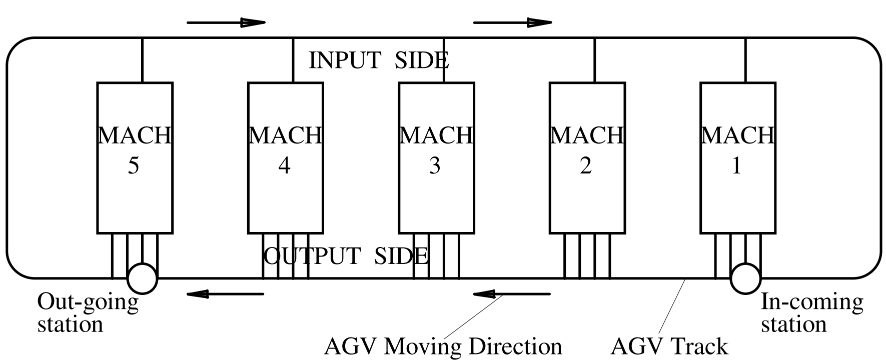

Fig. 2 The Schematic Layout of the AGV Movement

The request signals to the AGV are served on a First-Come-First-Serve basis. Signals from the same machine before the AGV receives a signal at the in-coming station are served in one trip. Any signal comes after the AGV's signal communications is not served in this trip. At any trip, only one machine is served.

The AGV can undertake battery-charge during signal communication, locating and loading at the in-coming station.

2.3 Types of Requests Signals for AGV

The machines send signals to request AGV's services when they require inputting or outputting trays. Initially, 8 types of request signals were identified:

Open Lot: when a new lot starts, the AGV takes a number of trays from the in-coming station to the Input Stack "L", one empty tray to "R" and another empty tray to "X".
Prepare B: after the first tray of a lot is inspected, the AGV transfers it to "B".
Remove G: when the number of trays in Output Stack "G" reaches its limit, the AGV will take all the trays to the out-going station.
Replenish L: when the last tray in the Input Stack moves into the inspection machine, the AGV will take a number of more trays of the same lot to "L".
Replenish B: when the good units at Buffer "B" are used up, the AGV will take a new tray of good units from the in-coming station to replace the empty tray.
Replace R: when the tray in Module "R" is full, the AGV will replace it with an empty tray.
Replace X: when the tray in Module "X" is full, the AGV will replace it with an empty tray.
Close Lot: when a lot completes, the AGV takes all the trays in "B", "G", "R", "X" to the out-going station. When the Close Lot signal is accepted, the AGV will no longer undertake tasks of other signals from the same machine, such as Replenish B, Replace R.

The request signals are sent from the machines at extreme conditions. For example, Replenish L is signalled when the last tray moves into the inspection machine; Replenish B is signalled when the last unit in the tray is picked away; Remove G is signalled when the number of trays in the Output Stack reaches the limit; Replacing R and Replace X is signalled when the R or X tray is full respectively.

2.4 Production Data

The production data included:

- Inspection time: they are collected by product types
- Tray size (number of units per tray) by product type
- The time of Pick & Place, jam and breakdown time of the inspection machines, operator efficiency are considered
- Product conversion time, i.e. the time required to do calibration on the inspection machine when the product is changed
- The limit of the number of trays in Input Stack "L" and Output Stack "G"
- The forecast of production volume for the next 4 years by product
- Lot size assumptions

3 PROJECT APPROACH

Figure 3 illustrates the approach proposed by the project team for analysing the simulation results and suggest improvements.

As shown in Table 1, 24 scenarios = 2 (factor I) x 3 (factor II) x 4 (factor III) were proposed for the initial simulation study. In each scenario, the forecast production volume of 6 quarters were simulated, this resulted in a total of ***144*** sets of simulation conditions.

Factor Level	I: Inspection Machines	II: Lot Size	III: Yield %
1	Machines combination A	1000	80
2	Machines combination B	2000	85
3		3000	90
4			95

Tab. 1. Factor Level for Initial Simulation Experiment (values are modified for confidentiality)

The step by step simulation and the first round of results were presented to the Automation, Production and Industrial Engineers for validation. For each simulation condition, dozens of duplications were run, and the a confidence interval of 95% was used for analysing the results.

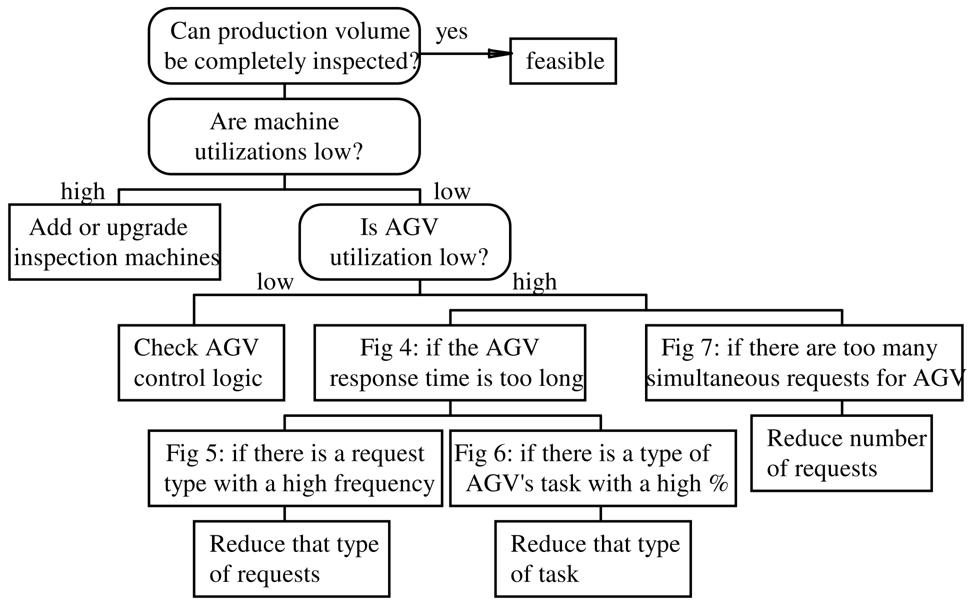

Fig. 3. Approach for Analysing the Simulation Results

Following the project approach for analysing the simulation results, general observations were made on the impact on production and AGV performance by the three factors and conclusions were drawn as follows:

a) The inspection operation can only meet the production requirement until the end of the year.
b) The highest utilization of the inspection machines from all the simulation results is about 76%, far below the target.
c) The utilizations of AGV are very high, between 87% and 97%.
d) The number of request signals to AGV is always higher for machines combination A than for machines combination B.
e) In the situation of low yield rate, the larger the lot size, the better the inspection machine utilizations. In the situation of high yield rate (i.e. 90% and 95%), there is no significant difference between the results from different lot sizes.
f) The higher the yield rate, the shorter the AGV response time.
g) Figure 4 shows that the AGV response time in the case of low yield rates is very long, with an average of 7 to 10 minutes. This caused a high percentage of machines' time spent on waiting for Open lot, loading, unloading and Close lot.

h) Figure 5 shows that the most number of requests sent out by machines is Replenish B.
i) Figure 6 shows the most time-consuming work for AGV is loading and unloading, which account for more than 40%.
j) Figure 7 shows that the probability of more than one machine simultaneously signals to request AGV is as high as 60% to 80%.

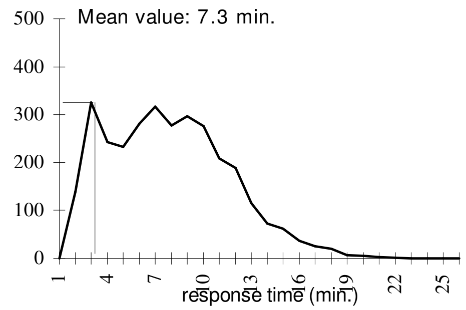

Fig. 4. AGV Response Time

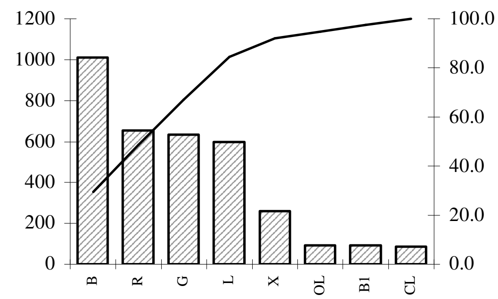

Fig. 5. Pareto Chart of Machine Signal Type

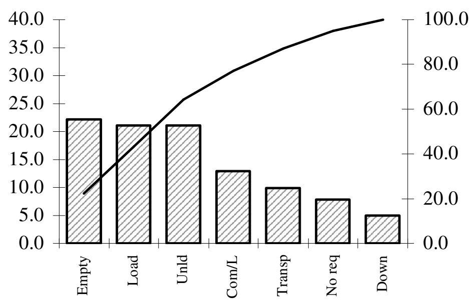

Fig. 6. Pareto Chart of AGV Task Time

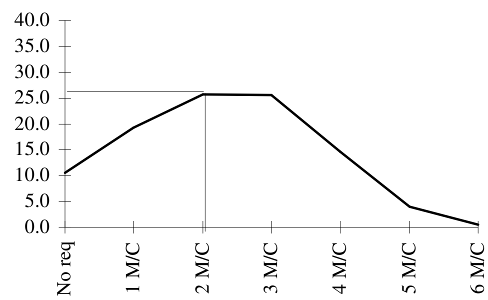

Fig. 7. Probability of Simultaneous Signal Requests

4 IMPROVEMENT SUGGESTIONS AND RESULTS

After detailed discussions between Automation, Production and Industrial Engineers, it was agreed that the long response time was caused by the high probability of simultaneous signal requests. The following improvement ideas were suggested:

Use Two-level Signal to Request AGV. The objective is to increase the number of tasks per AGV trip, thus reducing the simultaneous request signals from more than the machines. It is proposed that a second level signal, or warning signal, is sent before the extreme conditions. This signal will be served only if the AGV comes to serve this machine. Or else, the signal will stay in the signal queue. A first level signal, which is equivalent to the originally designed signal, is sent at extreme conditions. The first level signal must be served.

Many simulation experiments were conducted to identify the conditions for sending the warning signal, e.g. at the Output Stack, how many trays should be in "G" when the warning signal is sent to Remove G; and at the Rework Module and Reject Module, how many units should be in the tray when the warning signal is sent to Replace R and Replace X respectively.

Reduction of Loading and Unloading Time of AGV. It is achieved by a negotiation with the AGV Vendor. After a careful study, the vendor improved the mechanism which would improve the loading and unloading time per bundle by 10%. The revised AGV specification was used to conduct a complete set of simulation analysis.

Building a Stack at Buffer B to hold more trays. The objective is to reduce the number of signal requests to Replenish B. Due to the physical constraint of the inspection machines, building the stack at buffer B requires further investment.

The benefits derived from the improvement suggestions can be summarised as follows:

- The implementation of the two-level signal scheme alone would improve the machine utilization by around 6%.
- A significant improvement on AGV response time was achieved by reducing the loading and unloading time. The combination of the two-level signal scheme and the reduction of loading and unloading time would improve the machine utilization to 84%, the target.
- Building a stack at buffer B is most effective at low yield rates, with an improvement of machine utilization by 16%, and the AGV response time is improved by an average of 4 minutes per trip. At high yield rate, however, the improvement is not significant for either machine utilization or AGV response time.

5. CONCLUSIONS

Computer simulation plays a vital role in evaluating the performance of automation systems before the implementation. It safeguards the interests of the user by ensuring that the system to install will achieve the designed target. In this project, a total of more than 300 conditions were simulated. A wide range of scenarios, "what-if" analysis, and improvement suggestions were experimented before implementing the AGV system.

Detailed simulation results are excellent to help identify the bottlenecks. The improvement ideas in this project were all derived from the initial results, i.e. designing a two-level signal scheme to reduce the simultaneous request signals; reducing the loading and unloading time of AGV; and building a stack at buffer B to reduce the total number of request signals.

Simulation can further quantify the benefits of various improvement suggestions. By analysing the "what-ifs", the most cost-effective method can be identified. Significant improvement has been achieved from the original design without extra investment. Although building a stack at buffer B requires investment, the simulation results quantified the return on investment (ROI), and showed that it is the only solution when the production volume goes up and more machines need to be installed.

It is essential that the simulation team is either from in-house or its team members have extensive project experience in similar manufacturing environment. Not only will the simulation team understand the operational issues quicker, but also they can provide important advice and suggestions. In this project, the simulation team helped specify the performance measures for the AGV system (Figure 4 to Figure 7), and proposed the two-level signal scheme.

6 ACKNOWLEDGEMENTS

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