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USING SIMULATION AS A TOOL FOR BUSINESS PROCESS INNOVATION

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ABSTRACT

Business Process Innovation (BPI) often involves dramatic changes in processes, human resource issues, machinery and computer systems. Such changes create a new system that bears little similarity to the current state and often involves significant risk due to the uncertainty involved with the new design. This paper outlines the steps taken to demonstrate the feasibility and quantify the benefits of an innovative use of an automated storage and retrieval system (AS/RS) and an automatic guided vehicle system (AGVS). These systems perform material handling tasks for fabrication, subassembly, assembly and packing by moving totes between these work areas. The complexity of this design prevented simple calculations of the costs, benefits and consequences. Simulation was required to determine the quantity and timing on tote transactions, enabling the project team to determine the peak level of tote transaction requests associated with various levels of production. After proving that the design was feasible, the project team used simulation to quantify the costs, benefits and consequences of the new design, as well as identify additional opportunities for improvement. The financial numbers generated from the model demonstrated the immense value of the new system and provided ample justification for corporate approval. Following corporate approval, the model has continued to provide benefits by supplying the material handling vendor with assumptions, constraints and expectations for the new system.

1.0 THE MANUFACTURING AND MATERIAL HANDLING ENVIRONMENT

The manufacturing and material handling environment represented by this work has many of the problems present in most factories. 6000 end items are assembled in a small area on four product dedicated assembly lines. Common parts used across a large multiple of end items are stored at the lines. The remainder of the parts are stored within the warehouse and are delivered as required. Two or three assembly parts will change (due to function or finish) when assembly of a new end item begins. Controlling these parts causes problems with material handling, setups, production, scheduling, and inventory control. Parts are transported many times during the fabrication and assembly cycles and can be misplaced or damaged. Obtaining accurate inventory estimates is difficult and parts are not always available when needed in subassembly and assembly. All of these problems force the production managers to become expediters and firefighters.

Given the above environment, the project team documented the current system to identify non-value added activities, categorize parts as A, B and C parts, and quantify material handling, assembly and subassembly labor. The documentation process included the support services provided by the Systems Department, Quality Control and Maintenance. The project team sought to identify opportunities to reduce cost, improve quality and reduce cycle and lead times.

The problem areas identified in the current system documentation were compared to similar areas in some of the best American companies. These companies were contacted and when possible, factory visits were scheduled. These visits enabled the project team to meet the key company personnel and to view and discuss specific factory operations. The project team documented the innovative methods and procedures observed during these visits, and determined if these methods could be integrated in the conceptual design.

The project team produced a conceptual design based on the information gathered during the current system and best practices phases. Some of the key changes in this design included flexible workers, reduced material handling and movement, cell assembly, shorter lead times and smaller lot sizes. This design did not include the AS/RS. Assembly workstations were dedicated to a particular product family. Product specific parts were stored near the appropriate workstation. The workers delivering the parts to the assembly area would also perform material handling functions in other areas of the plant. A simulation model demonstrated that the level of material handling was too high and that assembly workers would often have to wait for the delivery of parts. The model also demonstrated that the starvation of workers cannot be avoided without increasing the amount of inventory stored at the workstation or increasing the number of material handlers.

To address the concerns that surfaced during the initial simulation, the project team visited several material handling vendors and observed many different factory designs. The most applicable design placed the workstations next to the AS/RS and totes arrived 'through the wall' to the workstations. This layout would minimize the material handling and potential for part damage, as well as improve inventory accuracy. The team augmented this design by having the AS/RS handle finished goods and certain WIP also. The modified concept included these enhancements, thereby eliminating several material handlers, reducing part damage and increasing inventory accuracy.

Some of the material handling tasks could not be performed by the AS/RS. Automatic Guided Vehicles (AGV) were included in the design to move material from remote locations such as polishing to the AS/RS control station. The parts would be stored in totes and delivered using an AGV. By using customized totes, product damage is minimized and the parts can be easily input into the AS/RS through the control station.

The modified conceptual design was very attractive for the reasons discussed above, however, it was difficult to determine its feasibility. The AS/RS crane must satisfy several sources of requests: Fabrication centers requesting and loading parts into the system, raw material receipts, assembly workstations requesting parts from storage and sending finished goods to storage, workstation replenishments, and finished goods requests from packing. Some of these requests could be performed off-shift (replenishments and some fabrication transactions), but most of these transactions would occur on first shift.

Based on the factory layout, AGV travel and transfer speed, and the expected tote volume, the project team could determine the average AGV usage. Unfortunately, such a calculation cannot reflect or quantify the peak periods of AGV usage. Many of the processes in the subassembly and assembly areas require regular and punctual deliveries. Given the fluctuations in AGV transaction request for other areas within the design, it was difficult to determine the AGV's ability to serve time-sensitive areas.

2.0 MODEL DEVELOPMENT AND APPROACH

The conceptual design was developed in a two step process. The AS/RS process was modeled first to demonstrate the feasibility of the conceptual design. Then, a second model was constructed to model the complex requirements of the AGV system and to determine the number of AGVs required for various levels of production.

The scope of the AS/RS model included parts arriving from and delivered to the fabrication areas, full and partial part totes delivered to workstations, partial and empty part totes arriving from workstations, finished goods totes arriving from workstations, and finished goods totes delivered to and returned from the pack station. The model included the workers performing the subassembly, assembly and packing tasks. The flexible worker logic allows any worker to perform any of these three tasks. Another worker is designated to replenish the workstations with generic parts (delivered in totes by the AS/RS) and act as controller for totes entering and re-entering the AS/RS.

This model was designed to provide information in two specific areas. First, the project team needed to know how many flexible workers would be required to reach the current production level. The human resources sub-team provided historical worker utilization data. This data permitted the project team to compare utilizations generated by the model with the historical rates. Second, the AS/RS system had to be fast enough such that no assembly worker would wait for parts. The workstations were designed to handle a specific number of totes, allowing a queue of work to form at the workstation. The size of this queue needed to be minimized; any increase in this queue would increase the width of the work area, thereby dramatically increasing the total square-feet requirement.

This model was designed in an iterative fashion. The initial model was presented to members of the project team and production floor personnel. The input received from these meetings was used to revise and enhance the model. Each revision was presented to production personnel, and this process continued until all parties agreed that the model accurately represented the proposed design.

Some initial assumptions were made for the model development process.

- o Transaction requests from the assembly and subassembly areas are given highest priority. Requests from the packing station are given the next highest priority and requests from the fabrication areas are given the lowest priority. When two or more outstanding requests have the same priority, the AS/RS will process the oldest request.

- o The system has 100% inventory accuracy. If a workstation initiates a request for two totes of Part A, each containing 15 parts, the AS/RS will deliver two totes with exactly those contents.

- o All workstations have the same priority. If workstations 1 and 2 have outstanding requests for assemblers and one assembler is available, that worker will go to the workstation with the oldest request.

- o While the number of customer orders that arrive at a particular workstation in a given day is fixed, the size of any individual order can vary and is subject to a distribution derived from historical order data. The process of constructing these distributions is discussed later in this paper.

- o The AS/RS would be set up in a 'zone' fashion. Under this assumption, parts required exclusively by workstation 1 would be stored near the workstation to minimize crane travel.

The scope of the AGV model included tote transactions at Shipping/Receiving, Stamp/Polish, Robot Polishing, Paint Cells, Zinc Plating, Sub-Assembly, AS/RS Control Station and Hand Polishing. The arrival rates of totes into the system from areas such as plating could be determined by historical production records. Some of the areas processed parts in a 'batch' mode, creating peak periods of AGV transaction requests. This arrival data was included in the AGV model to determine maximum queue sizes and maximum wait times. The model was constructed to allow the user to manipulate the number of AGVs and to adjust the level of production.

Some initial assumptions were made for the model development process.

- o The AGV will operate on a 'bus stop' basis; the AGV will always take the same path. For example, the AGV will always go from Station A to Station B to Station C and back to Station A. Therefore, if the AGV picks up a tote at station A and needs to be delivered to station C, the AGV will first go to station B then proceed to station C.

- o The AGV can transport a maximum of two totes. Because of the path described above, the AGV may be carrying two totes and deliver the 'second' tote before the 'first' tote.

- o The AGV requires 5 minutes of recharging every 45 minutes of travel time. The AGV can recharge during idle periods.

The simulation model had to be flexible so that different scenarios could be run easily. The project team needed the ability to change production levels by product line, staffing, and tote capacity for each part. The model was constructed using ProModel's PMI interface to allow this flexibility without requiring the user to input any data. This interface allows the user to modify the parameters mentioned above, while providing default values. This simplification makes the model 'user-friendly', an important consideration since a complex model is only beneficial if people can use it easily. Many simulations are used to find the optimal combination of several factors. Using a simulation in this manner requires the user to operate in a iterative fashion: change one variable, rerun the model, examine the results and repeat until the desired results are achieved. The simplicity of the PMI interface make the iterative process relatively simple. The model development process consisted of the following steps:

Data Gathering
Physical Layout
Order Analysis
Operating Procedures and Rules Definition
Model Construction

2.1 DATA GATHERING

The data requirements for these models were significant. Fortunately, the work performed during the documentation of the current system provided much of the data needed to create the simulation model. The current labor requirements and the time standards for subassembly, assembly and packing were included in this documentation. Time standards for the AS/RS Crane and AGVs were obtained from the material handling vendors.

Each workstation is dedicated to a particular product family. While a particular product family may have several permutations, the model was constructed such that the assembly cycle time for any unit at a given workstation is constant. In most cases, the actual assembly times within a product family do not vary greatly. In situations where the cycle times did vary significantly, the estimated cycle represents an average of the actual cycle times, weighted to represent the current production mix.

Tote capacity was calculated for each part used in the assembly process. This data was needed to determine the number of transactions for any material movement into or out of the AS/RS. The tote capacity for all the parts delivered to the work are treated as variables and can be modified through the PMI interface.

2.2 FACTORY LAYOUT AND WORKSTATION DESIGN

The new conceptual design included a CAD layout of the factory. The graphical portion of the simulation model, shown in exhibit A, represents this layout. The physical dimensions of the work area, available from the CAD layout, were used in conjunction with the crane speeds and access times provided by the AS/RS vendor to determine the crane travel time between storage zones and pickup/delivery stations.

Each workstation was ergonomically designed to improve worker efficiency while minimizing the possibility of repetitive movement disorders. The project team was confident that these improvements would make many of the assembly tasks easier and reduced the time standards from current levels.

2.3 ORDER ANALYSIS

The MIS department provided the project team with a download of customer orders. Several months of customer orders were analyzed to determine average monthly volumes per product line. While customer order size varies dramatically, weekly production levels on high volume items were fairly predictable.

Within a product family, the order size can vary greatly. For some lines, the majority of orders consist of less than 10 units, while others are greater than 200 units. This variability, rather than an average, had to be incorporated into the model. The use of an 'average' order would severely distort the number and timing of tote transactions. An order size distribution was constructed for each product line and was incorporated into the model such that the variability seen in the current system would be represented in the model.

2.4 OPERATING PROCEDURES AND RULES DEFINITION

There are many procedures and practices that affect the rules built into the simulation model. The criteria for making decisions can change on a weekly or even daily basis. In these circumstances, decisions are made based on past experience or even an employee's intuition. Simulation models require the rules for specific situations, not intuition. Defining the specific situations and obtaining consensus on the actions to these situations was time consuming, but necessary to develop definitive procedures and operating rules. Several examples follow.

Workers will remain at a workstation until that day's production requirements have been met. This policy creates the potential for 'worker starvation'. Under this scenario, a worker will remain at a workstation and wait for the AS/RS to deliver parts rather than moving to another workstation where parts are available. Starvation would most likely occur when there are many small (<5 units) customer orders for a particular workstation. Since the queue size of three for incoming totes is small , it is possible that the assembler could complete the orders associated with those totes before the AS/RS could deliver the totes associated with the next order, creating worker inefficiencies.

Production requirements are determined on a daily basis. A worker at workstation 1 will only build the units required to meet today's production requirements. Once the worker has completed today's production, he can move to another assembly, subassembly or pack station.

The flexible workers will only work on first shift. Unfinished customer orders will be the first orders processed on the next business day. A controller will be available on first and second shift, and will replenish workstations and process totes during those two shifts.

2.5 MODEL CONSTRUCTION

The data collection and rules definition steps provided input for the model building stage. The model was constructed using ProModel from Production Modeling Corporation. This language was chosen as the simulation language for two main reasons:

- o ProModel is a PC based language which offers excellent graphics that can be used to animate the simulation. The graphics were important to demonstrate what the model was doing.

- o ProModel allows the modeler to create external Turbo Pascal subroutines and call these routines from the model. This feature significantly expanded the functionality of the model. These subroutines were used to determine the number of totes required for assembly of a given customer order and the number of finished goods totes associated with that order.

3.0 OPERATING THE MODEL

The model was constructed using ProModel's PMI interface. This interface allowed the project team to vary the number of workers, adjust the production levels and change tote capacities, without modifying the model. This interface also permitted the team to run several different scenarios at one time. This process was often done in a batch environment, without graphics, thereby increasing the execution speed. This interface allows several replications of each scenario by using a different random number stream.

4.0 RESULTS AND CONCLUSIONS

By examining the report file produced by the AS/RS model, the team was able to see the effects of staffing and production levels on worker utilization, crane utilization and total product cycle time. While several scenarios can be run consecutively with this model, a more iterative approach was generally taken. The user can examine the report and make the necessary changes to the setup file. For example, suppose the user has defined a production/staffing level that results in a fairly low worker utilization. The user can begin removing workers until a satisfactory worker utilization is obtained. The user can also see the effect of staffing reductions on total product cycle time.

The AGV model demonstrated the need for two AGVs for current production levels and that a third unit would enable the system to accommodate a 50% increase in production. This model also quantified the maximum queue sizes required for all of the AGV stations.

These simulation models provide the user with a means of examining production alternatives and the impacts of each in a few minutes. Without any capital investment, the user can analyze the effects of changes, make additional changes if necessary and observe the new results.

BIOGRAPHIES

Mr. Jones is a Manager in the Great Lakes Consulting Performance Improvement Group of Ernst & Young. He has experience in Systems Engineering with an emphasis on the use of computer systems in industrial design and manufacturing environments, and in the use of simulation and modeling tools. Tom earned a Bachelor's degree in Mathematics and Systems Analysis from Miami University and an M.B.A. degree from the University of Cincinnati with a concentration upon quantitative analysis.

Mr. Elliott is a Manager in the Industrial Engineering Department at Von Duprin, a subsidiary of Ingersoll Rand. He has experience in the design and implementation of material handling systems and in the use of simulation tools. Bob earned a Bachelor's degree in Industrial Engineering from Purdue University.

Mr. Ball is a Senior Engineer in the Industrial Engineering Department at Von Duprin. He has experience in various aspects of manufacturing including material handling, automation, product design and workstation design. David earned a Bachelor's degree in Industrial Engineering from Purdue University.

Dr. Hein is a Senior Manager in the Great Lakes Management Consulting Performance Improvement Group of Ernst & Young. He has a broad range of experience in systems engineering with an emphasis on the use of computer systems for solving industrial problems, automation, engineering economics, simulation and applied probability and statistics. Dr. Hein earned Master's and Ph.D. degrees in Systems Engineering from the University of Toledo through NASA fellowships. He also has Master of Science in Engineering and Bachelor of Science in Physics degrees. Dr. Hein did his post doctoral training at the Georgia Institute of Technology.