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MATERIAL HANDLING REQUIREMENTS FOR A DISTRIBUTION CENTER

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ABSTRACT

This paper describes a phased modeling approach used to evaluate material handling alternatives and operational changes for a high volume food packaging, warehousing and distribution plant. The goals of the project were to recommend methods for improving both throughput and storage capacity within the existing facility in order to accommodate anticipated increases in inventory and customer order volume. Detailed "micro" models were developed for the major material handling systems to examine different equipment configurations and operational procedures. Once the best alternatives were identified in each area of the facility, a "macro" model encompassing the entire distribution facility was developed. The macro model was used to evaluate throughput, material flow, material handling equipment utilization, and resource allocation.

1 INTRODUCTION

A large manufacturer of packaged food products recently upgraded one of their main manufacturing and distribution plants by adding semi-automated swing reach vehicle (SRV) systems in the finished goods, material stores, and work-in-process areas. Also implemented was an automated guided vehicle (AGV) system connecting the SRV storage facilities. The goal of the automation project was to increase throughput of customer orders and stock transfers from other facilities, to increase effective warehouse capacity, and to reduce manpower requirements during peak demand periods.

The expanded facility produces over 200 finished stock items from materials and stores totaling over 1400 SKU's. In addition to the manufacture of finished goods, the plant also supports the largest distribution center within the company accounting for 25% of the companies total customer service base. Distribution involves over 800 finished goods SKU's with an average level of 3.5 million cases. The additional 600 finished goods SKU's are stock transfers brought in from other manufacturing facilities. Figure 1 shows the primary material flow for the facility.

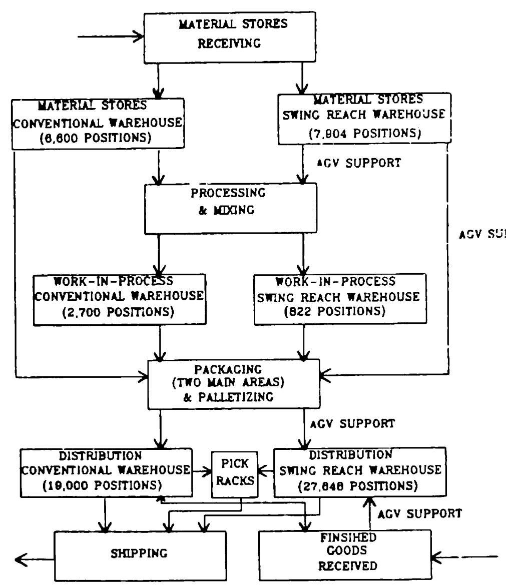

Figure 1: Primary Material Flow

Unfortunately, implementation of the computer system, AGVs and S/R warehouses did not produce the desired results. Throughput decreased from what was achieved using standard fork trucks, manpower requirements went up and storage utilization was poor. A consulting firm with expertise in distribution and warehousing was brought in to help determine why the system was performing well below expectations and to recommend solutions.

After several weeks of data gathering and investigation, the project team produced a five year plan with projected throughput and inventory requirements for the plant. From this plan, a list of possible alternative solutions was developed. Following is an abbreviated list of these alternatives:

1) Throughput Capacity in Swing Reach (S/R) Warehouse
   a) Switch throughput from S/R to conventional warehouse
   b) Increase S/R throughput capacity
2) Change system operations, management philosophies
   a) Spread material stores receiving across day to ease 1st shift burden
   b) Spread distribution receiving/shipping across day and load level
   c) Reduce order picking lead time window
   d) Pick case/tiers in advance and re-store as full pallets
   e) Reduce number of orders in-process at any one time
3) Storage Capacity
   a) Relocate case/tier picking
   b) Increase storage depths in swing reach (S/R) bays
   c) Reduce number of shipping docks and convert dock space to storage
4) Case/Tier Picking
   a) In conventional warehouse: evaluate pallet rack and flow rack with pick carts
   b) In S/R warehouse: evaluate using SRVs, flow rack, fork trucks
   c) Separate tier pick area using clamp trucks or vacuum lift gantry crane
5) Material Handling
   a) Lift trucks
   b) AGV (system had never been fully implemented and was not being used)
   c) Pallet conveyer
6) Control System Enhancements
   a) Expansion to include material stores and distribution warehouses
   b) Addition of AGV control, dual load and other features
   c) Increase response time
   d) Fix system "bugs"

The next phase of the analysis was to evaluate each alternative based on investment and operating costs, conduct economic and qualitative analyses, and identify the best plan(s). Simulation modeling was used during this process to help quantify the advantages and disadvantages of selected alternatives.

2 SIMULATION MODELS

To support the evaluation of design alternatives, detailed "micro" simulations of the S/R distribution warehouse and AGV system were developed. Our analysis showed that these areas presented the greatest opportunity for improvement. In addition to these two micro models, a comprehensive model was designed to encompass the entire finished goods warehouse and distribution material flow (the "macro" model).

This phased, bi-level modeling approach is an effective methodology for handling very large or complex simulation projects [Carpenter, Ward, 1990]. The first phase involves construction of accurate simulations of limited portions of the entire facility. These models can be quite complex and involve large data sets since they try to match the actual process as closely as possible. The second phase is to combine these models in an abstracted form to construct a macro model that encompasses all (or a larger portion) of the facility.

Abstraction of detailed models into less-detailed macro models involves sensitivity analyses to determine key variables. Micro models can be incorporated directly into a macro model with non-critical elements of the process deleted, they can be linked indirectly through a data file, or key output variables from the micro model can be converted to statistical distributions to be used in the macro model. Each of these abstraction methods involves tradeoffs. Incorporating one model into another offers the most accurate simulation but increases run time, model complexity and memory usage and can be difficult to implement because of the lack of modular constructs in simulation languages. Running the micro models separately and writing key variables (with time-stamp) to disk files is an effective way of driving the macro model if the number of data items is small and no feedback is required. Converting time-stamped data to an input distribution eliminates file input to the macro model reducing run time. This method works well if the data can be fit to a standard distribution or the number of samples is small (in which case a discrete distribution can be used).

The models were constructed using Siman [Pegden 1986], Cinema, and a set of Fortran routines. The decision to use Siman/Cinema was based on the following requirements: the models had to run on two different computer platforms (PC and Sun workstation); the language had to be extensible so that logic functions coded in Fortran could be used; and high-resolution animation to support management presentations and model verification. The models were originally developed to run under MSDOS on a PC, migrated to OS/2 as model size increased, then were ported to a Sun workstation for ongoing analysis at the customer's site.

2.1 AGV Model

A simulation model and high resolution animation were constructed to investigate a fully functional AGV system. Objectives of the model were:
- o Determine vehicle count required for peak activity
- o Examine alternative routing and staging strategies
- o Determine effective throughput under various loading conditions

In order to accomplish these goals, the model needed to use realistic production, distribution and material movement input data. A single data structure was designed to handle five separate AGV pickup activity rates. This structure consisted of the weekly volume for that activity, percent of weekly volume carried by AGV, percent per shift, schedule within each shift, number of pallets per load, and a discrete distribution for selecting AGV destination. A normal distribution was used to derive daily volume and an exponential to generate arrivals within a shift.

From a five-year business projection, peak and average weekly volumes from each target year were selected. Then for each weekly data set, three different scenarios were run; the entire warehouse, distribution only, and raw material movements disabled. The procedure for each simulation run was to select an AGV count that resulted in an AGV utilization of approximately 85% (with no break downs) and a production queue no longer than 4 pallets. AGV break downs were disabled during this series of runs so as not to skew maximum queue size results.

Once the number of vehicles required for each scenario was established, a second series of runs was made with AGV break downs included. The focus of these runs was to evaluate travel times, material flow, bottle necks and throughput. The animation was used extensively during this phase to identify traffic dead-locks and other vehicle routing anomalies.

2.2 Swing Reach Distribution Warehouse Model

A separate model of the S/R distribution warehouse was deemed necessary due to the projected increase in distribution volume and low current utilization. The warehouse was originally designed to be dual ended with AGVs delivering pallets to the rear and fork trucks retrieving pallets from the front for delivery to the docks. Because the AGVs were never fully implemented, the system was currently being loaded by fork truck from the center aisle causing a hazard for S/R trucks operating in the aisles. One of the primary objectives of the S/R model was to examine single ended operation (all pulls and stows from the front) as a method for improving throughput.

In designing this model, enough flexibility was designed into the data structures to allow stows to be directed to the rear, center or front of the aisles. The store and retrieve algorithms, aisle change rules, and pick priorities were modeled as accurately as possible using Fortran routines. Accurate work schedules, vehicle dynamics, and storage capacity were modeled. The input data driver developed for the AGV model was modified to add customer orders which were released in batches. The schedule of batch releases, the number of orders per batch, and the composition of orders are all inputs to the driver.

To validate the model, actual data from a recent production week was used as model input. The model was configured with the same number of vehicles per shift, the same resource schedules and the same pull/stow logic (with stows picked up in the center and pulls dropped off at the front). The animation was used in conjunction with statistical results to verify that the vehicles were performing operations in the correct sequence and priority. The average times to complete pulls and stows were compared against measured values. Minor adjustments were made to the vehicle delay times until these values correlated. Validation runs were then made with a run length of one week to match the period of the production data.

Results of these runs showed that the production level was achieved with vehicle utilization below the estimated range, store and pull queue sizes stayed within the expected limits, and inventory capacity was never exceeded. Once the base model was validated, it was then ready to be used to evaluate various design alternatives. Among the alternatives simulated were:
- o Single ended vs dual-ended
- o Modified single-ended with case/tier replenishment in center aisle
- o Relocate case/tier picking into S/R aisle
- o Spread distribution receiving/shipping across day and load level

Various low, medium, and high volume weeks were selected and run through each of the single-ended and dual-ended versions of the model. For a run to be deemed acceptable, the maximum time for any pallet to remain in the stow or pull queues had to be less than 280 minutes, the number of stows balked (input racks full or inventory at capacity) had to be at or very near 0 indicating that the SRVs were keeping up with the flow of incoming pallets, and the utilization of SRVs had to be as high as possible without violating the other conditions.

One of the interesting results of the S/R model runs and analysis was the discovery that the throughput of the finished goods S/R warehouse was more dependent on the schedule of order release than single versus dual-ended operation. Using a balanced order release schedule, we concluded that the higher the activity volume, the greater the benefit achieved by the single-ended system.

2.3 Macro Model

The goal of the macro model was to provide a comprehensive tool to be used by warehouse planners to analyze throughput capacity, truck scheduling, SRV usage, fork trucks, order release schedules, and manpower requirements under various operating conditions. The model needed to track all material flow in and out of the finished goods warehouse which included the following activities:

Inputs:
1. Production (to S/R and conventional storage)
2. Stock transfers (from dock to S/R and conventional)
3. Case picked pallets (from S/R center aisle back into S/R or to tier pick area in conventional warehouse)
4. Case and tier picked modules (from tier staging area to docks)

Outputs:
1. Customer orders (from S/R and conventional to docks)
2. Stock transfers (from S/R and conventional to docks)
3. Case pick replenishment (from S/R to S/R case pick aisles)
4. Tier pick replenishment (from S/R to tier pick area)

The macro model was constructed by building on top of the S/R model, incorporating conclusions and assumptions from the AGV model, and adding additional layers of code and data to simulate fork truck activity, dock activity, and truck scheduling. Much of the detail of the S/R model was maintained as it was critical to the operation of the warehouse. Only the outputs of the AGV model were used. These included the arrival rate and distribution of pallets arriving at the S/R input queue and stock transfer queues. No specific AGV routing was included in the macro model. The resulting size of the macro model necessitated a migration from MSDOS to OS/2.

Modeling fork truck activity correctly was an important part of the model since our earlier analysis showed that fork truck traffic was a throughput bottleneck. To limit travel overlap and quantify resource requirements, fork trucks were assigned to one of four pools with a set of material movements assigned to each pool. The fork truck pools were:
1. Truck load/unload
2. Dock stow - storage of inbound stock transfers and backup for load/unload pool
3. Conventional - movements in and out of conventional warehouse
4. Swing reach - movements in and out of S/R warehouse

Material move requests entered queues to seize (allocate) fork truck resources (Siman transporters). The queues were ranked by material move priority (customer orders and replenish requests had higher priority). The highest priority item in the work queue seized the closest available fork truck (using the Siman shortest distance selection rule).

The general logic for fork truck moves was to pick up one or two pallets from source location(s), deliver them to their destination(s) then attempt to perform opportunity moves enroute to the staging area. An algorithm was devised for selecting fork truck activity which placed a priority on dual-pallet loads and dual-cycle operation. Dual-cycle means that fork trucks look for opportunity moves as close as possible to their drop-off destinations to reduce deadheading time. Figure 2 shows the fork truck opportunity matrix that encodes the relative priorities of fork truck material movements. The matrix was applied while searching the pickup queues, the pending operation with the highest relative weight was selected.

Customer orders were scheduled on a wave release basis. The number of waves per shift, the schedule of wave release, the number of orders per wave, and the composition of orders were all driven by data structures derived from weekly volumes.

The procedure for releasing an order (customer order or stock transfer) involved first allocating a dock space to accumulate the order. Trucks were scheduled to arrive a variable number of hours (4 to 10) after wave release. Statistics in the model recorded time waiting for docks, time from wave release to dock staging complete, and late orders. The priority of an order was raised within a variable time window (normally 1 hr) of the truck arrival time.

	WT																		
SOURCE																			
SAME LOCATION	20	20	20	20	20	20	20	0	0	0	0	0	0	0	0	0	0	0	0
SAME ZONE	11	0	0	0	0	0	0	11	11	0	0	11	11	11	11	0	0	0	0
DIFF. ZONES	8	0	0	0	0	0	0	0	0	8	8	0	0	0	0	8	8	8	8
DESTINATION																			
SAME DOCK	15	15	15	0	0	0	0	15	15	15	15	0	0	0	0	0	0	0	0
SAME ZONE	10	0	0	10	10	0	0	0	0	0	0	10	10	0	0	10	10	0	0
DIFF. ZONES	8	0	0	0	0	8	0	0	0	0	0	0	0	8	8	0	0	8	8
MATERIAL																			
SAME TYPE	2	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0
DIFF. TYPE	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
RELATIVE WEIGHT		37	36	32	31	30	29	28	27	25	24	23	22	21	20	20	19	18	17

Figure 2: Fork Truck Opportunity Decision Matrix

Modeling the order release process and material flow to this level of detail allowed us to make accurate analysis of order picking lead times, order release schedules, and other operational issues.

2.3.1 Macro Model Simulation Runs and Analysis

Each of five years worth of data forecasts were broken into thirds. The first part of the year contained the least activity, the second part had an average throughput volume, and the last part of the year had the highest volume. The later forecasts showed some improvement in smoothing these activity variations, but the overall trend still existed.

Simulation runs were made using the median week for each period of the year to determine the proper manning and equipment requirements. The plant normally begins the year with its smallest staff and hire as necessary until staffing was sufficient to handle an average week. Additional temporary employees were brought in to handle periods of peak activity. In this manner, a manning level was established for every level of activity in the plant for the next five years.

In addition to the aforementioned scenarios, the highest throughput week of each year was run to determine peak manning, dock, and capital requirements. If necessary, the work week was expanded up to seven days to meet peak requirements. The objective during this phase of analysis was to determine the minimum resources required to meet the throughput. The effects of certain operating procedures were evaluated including: smoothing the work flow evenly over the day; enabling fork truck opportunity moves; and varying the number and assignment of docks.

The primary variables in each model run were the number of resources in each work "pool" (the pools were the four fork truck pools described earlier plus the swing reach vehicles). Each portion of the entire operation was broken down in the summary report so the analyst could quickly determine which resource pool to adjust if a run was not successful. Key items in determining a successful run were:

- Maximum time in and S/R pull/stow queue is less than or equal to 4 hrs
- Number of late orders is at or near zero
- Maximum time to complete an order from release to truck loaded is less than 8 hrs
- Maximum number of modules in the I/O rack at end of S/R aisle does not exceed 12
- The utilization of all resources is as high as possible without violating any of the conditions above

Once all the runs for the five year forecasts had been completed and summarized, one of the selected weeks was chosen for sensitivity analysis. This consisted of:

- Increasing volume by 20%
- Decreasing manning by 20% with volume kept constant (overtime required?)
- Decrease volume by 20% and determine necessary manning

Simulation results were summarized and presented to management in the form shown in Figure 3.

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         RUN      91                        RUN STATUS:  ACCEPTABLE
        WEEK       8
        YEAR    1993

MANNING PER DAY:                            DAYS PER WEEK    5

S/R VEHICLES        =   9             MAX S/R PULL QUEUE(MIN) 135
LT LOAD/UNLOAD      =   9             AVG S/R PULL QUEUE(MIN)  24
FLT DOCK            =   9
FLT CONV WHSE       =   6             S/R STOW BALKS           0
FLT S/R SUPPORT     =   9
CASE & TIER         =   7             CUSTOMER ORDER TRUCKS/DAY    20
UTILITY             =  10             STOCK TRANS IN TRUCKS/DAY    20
TOTAL/DAY              59             STOCK TRANS OUT TRUCKS/DAY    4

UTILIZATION(AVAILABLE TIME)
                                      LATE ORDER OCCURRENCES  0
S/R VEHICLES        =  88%
FLT LOAD/UNLOAD     =  65%                                     AVG  MAX
FLT DOCK            =  85%            LATE ORDER DELAY (MIN)     0    0
FLT CONV WHSE       =  56%            ORDER STAGING TIME "      72  170
FLT S/R SUPPORT     =  61%            ORDER COMPLETION   "     306  451

VOLUME INPUTS                                                  AVG AGV MAX
                    WEEKLY   DAILY    S/R I/O RACK STATUS        2    10
PRODUCTION           2882     576
INBOUND ST           4400     880                              AVG  MAX
CUST ORDERS          4400     714     DOCK USAGE OUTBOUND        6   13
OUTBOUND ST           844     169     DOCK USAGE INBOUND         4

FORK LIFT DUAL CYCLE PERCENTAGE       AGV SPUR QUEUE S/R      0.17    5
                                      AGV SPUR QUEUE CONV     0.11    6
DOCK                25%
CONVENTIONAL        12%
S/R SUPPORT         39%

TOTAL               26%
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Figure 3: Simulation Results

3 CONCLUDING REMARKS

From the total list of design alternatives, the best alternatives were simulated. Separate simulation models were developed for two material handling systems, AGV and S/R warehouse. These micro models allowed detailed analysis of picking strategies, priority rules, vehicle routing and scheduling. A macro model was built by combining the S/R model with results from the AGV model and adding additional resources, routes, activity drivers and animation.

There were many benefits to using a phased approach to modeling a large distribution facility. By focusing first on key material handling subsystems, we were able to tune the subsystems for maximum throughput. Combining these results into a more comprehensive model allowed us to evaluate material flow for the entire distribution area and predict resource requirements for different operating conditions.

The final phase of the simulation study was to present the results to management along with an implementation plan. Some of the results presented in the report were:

- Smoothing of the production schedules during the year to eliminate peak periods and improve overall throughput.
- Conversion of the S/R warehouse to single-ended operation with fork trucks picking up and dropping off at the front (dock) end.
- Full implementation of the AGV system with an expanded staging area near the output from production.
- Addition of an automated pallet stacking device at the AGV pickup in production to accommodate two pallets per AGV move.
- Separation of case and tier picking operations. Relocation of case picking into S/R aisles.
- Specification of projected staffing levels and vehicles (by shift) required through the five-year business plan.
- Recommended expansion of warehouse control system to include AGV control, support for dual fork truck loads, modified S/R work assignment logic and other operational issues.

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