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EVALUATION OF A DISTRIBUTION CENTER TOW-LINE MATERIAL HANDLING SYSTEM THROUGH SIMULATION MODELING

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ABSTRACT

Random House, one of the world's largest and most distinguished publishing houses, embarked on a mission to improve its tow-line material handling system at its main distribution center located in Westminster, Maryland. A mechanical tow-line system, while a rugged low-tech but reliable solution, still comes with complicated management and control issues which require a simulation to evaluate and understand. A three person team designed, developed, and implemented a simulation model of a proposed modification to the existing transport system. The results were then analyzed and presented to company management.

This paper discusses the processes and solutions of this simulation including how our team approach improved the model, how the model identified significant variables in the implementation and how the model results were used to help justify the capital expenditure.

1. INTRODUCTION

THE RANDOM HOUSE DISTRIBUTION CENTER RECEIVES AND SHIPS HIGH VOLUMES OF PALLETIZED BOOKS EACH DAY ....

Random House is one of the world's largest and most distinguished publishing houses. The main distribution center for Random House is located in Westminster, Maryland. Each day the facility receives from 500 to 1,200 pallet loads of books from binderies and ships from 350,000 to 600,000 books to retail stores and wholesale outlets. These outgoing shipments are also palletized but may consist of a mix of cases and single books that are consolidated into case lots.

The Westminster distribution center has grown in stages and consists of three buildings totaling over 762,000 square feet. The first building was opened in 1966. The second, located adjacent to the first, was constructed in 1972. The third addition was dedicated in 1983 and is connected to the other two warehouses via a 565 foot covered bridge.

THE MATERIAL HANDLING SYSTEM AT THE RANDOM HOUSE DISTRIBUTION CENTER WAS BEING PUSHED TO ITS LIMITS ....

As the Westminster facility grew, so had the mechanical tow-line system which is the primary means for transporting pallets of books throughout the three buildings. The tow-line system uses an in-floor continually moving chain to transport both loaded and empty carts. Although the path of the tow-line system was appropriate when each of these buildings were built, the design of the system no longer supports the current method and volume of operation and Random House's plans for future growth.

The existing tow-line system consists of three independent loops which (1) rely heavily on transfer connections between buildings and (2) have a path which weaves extensively within pallet rack aisles. These two factors have contributed to reducing the efficiency of the operation, increasing overall pallet transport time, and reducing the predictability of pallet transport time.

RANDOM HOUSE EMBARKED ON A MISSION TO IMPROVE THE MATERIAL HANDLING SYSTEM THROUGHPUT TO SUPPORT CURRENT AND FUTURE NEEDS ....

The goal of Random House was to design and implement a material handling system for pallet transport between buildings that achieved the following goals:

1. support an anticipated 25% increase in volume within the next five to ten years
2. support the current and future pallet movement patterns

3. increase the reliability and predictability of goods being transported between buildings
4. reduce material handling costs and improve the efficiency of the operation

TOW-LINE SYSTEMS ARE RELIABLE WORKHORSES BUT LACK THE GLAMOUR OF HIGH TECH MATERIAL HANDLING SYSTEMS....

Tow-line systems, for movement of cart loads of material, have been in use for decades in distribution centers, freight docks, newspaper production and manufacturing operations. Although overshadowed by higher technology Automated Guided Vehicle Systems in recent years, tow-line transportation remains a rugged, reliable and low cost means of automatically moving and routing heavy, sometimes awkward, loads(Young, 1991). Specialized cart design in combination with the ability to program cart movement creates an efficient system(Bradt, 1971)

Tow-line movement occurs by means of a continuously moving chain that is installed below floor level. The chain has pusher dogs at regularly spaced intervals which capture and pull a pin that is, in turn, attached to a transportation cart. The cart is custom tailored in size and shape to the load that it handles.

After evaluating several different methods of pallet transport, including Automated Guided Vehicle Systems, Random House made the decision to modify and upgrade the existing tow-line system. Although a mechanical tow-line system is not as glamorous as other higher tech systems, it is a untiring workhorse. The tow-line system is capable of delivering a large number of heavy pallet loads to various points throughout the facility. In addition, the existing tow-line system is mechanically sound and has experienced very little downtime for repairs over the past 30 years.

A MAJOR CHANGE TO THE CONVEYANCE LOGISTICS WAS PROPOSED TO IMPROVE DISTRIBUTION CENTER OPERATIONS ....

To achieve the project goals and improve the system performance, a major redesign of the tow-line system was studied. The system layout was reconfigured to (1) provide a path from any point of origin to any destination that is less dependent upon transfers, (2) eliminate excessive looping of the path within the pallet racking which currently causes congestion in the aisle ways and increases cart transport time, and (3) provide overflow spurs to reduce the number of carts that recirculate in the system.

The result of the study was a proposal to simplify the three loop system into a single loop which skirts the perimeter of the buildings. This was done quite easily by abandoning the internal portions of the loops and adding some new track.

2. THE SIMULATION MODEL DESIGN

BEFORE PROCEEDING WITH A MAJOR CAPITAL EXPENSE, SIMULATION MODELING WAS USED TO ANALYZE AND VALIDATE THE PROPOSED CHANGE ....

Although management at Random House believed the performance of the redesigned system would be an improvement over the current system, they wanted assurance that the system would achieve the desired goals and that the additional system enhancements would be beneficial. Some key questions to be answered were:

1. Is the new single loop system capable of transporting up to 2,000 pallet loads per day using a load profile whereby the majority of moves are generated on the first shift?
2. Is the average transport time for a pallet load from origin to destination less than 45 minutes and is delivery time fairly predictable?
3. Are the added overflow spurs in buildings 1 and 2 beneficial in reducing the number of carts that recirculate? And if so, what is the proper overflow capacity?
4. Should the tow-line shut down if an overflow spur fills?
5. Is a capacity of 6 carts sufficient for the new transfer in building 2?
6. How many carts are required in the system and how should they be managed?

After reviewing the complexity and volume of peak day pallet move data and taking into consideration system variables such as system downtime, spur service times, and time to unload carts, a decision was made to develop a simulation model. A simulation model was the best means of determining the expected performance benefits and would assist in evaluating design parameters.

Model animation was planned to be an important means to evaluate the logical operation of the model during testing and also provide credible evidence to the management of Random House that the model emulated real life system events.

THE SIMULATION MODEL HAD THREE GOALS ....

The primary goal of the model was to determine the predictability of the transport time for loaded carts and to recommend the number of carts for each of two operating modes:

1. shutdown tow-line when an overflow fills
2. recirculate normally if an overflow fills

Transport time is defined as the elapsed time from the dispatch of a loaded cart at the origin to the arrival of the load at the destination. Wait times at the origin for an empty cart, as well as load and unload times and wait times at the destination for service, were not included in the transport time.

For purposes of the model, the load was considered dispatched when an empty cart was loaded and a destination assigned. Arrival at a destination was defined as arrival of a cart at either the destination spur or the group overflow spur associated with the intended destination.

The secondary goal of the model was to ascertain the impact of each of four parameters on the transport time of loaded carts and on the number of recirculating carts.

1. capacity of transfers
2. capacity of overflow spurs
3. capacity of the empty cart pools
4. time to service spurs and unload carts

A third goal was to derive a recommended quantity for each of the four parameters that was consistent with the desired performance at the level of operation for the busiest historical day at the distribution center.

A TEAM JOINTLY DEVELOPED THE MODEL AND EVALUATED THE RESULTS ....

The authors worked as a team to develop and utilize the model to assess the performance of the proposed system changes. Kris Jacoby represented Random House; Joel Hoffner provided the tow-line experience; and Jay Bakst wrote the simulation model using SIMAN for modeling and ARENA for animation.

However, rather than each of the participants having an isolated assignment, a team approach was adopted. Each had areas of prime responsibility, but the help of team members was repeatedly accepted and sought out.

Although Joel developed the design document and Jay the model itself, each had a role in reviewing and improving the design and validating the model. But the cooperation went deeper than that. Sharing our knowledge of the tow-line, modeling techniques and the distribution process enabled us to make appropriate simplifying assumptions that allowed use of conveyor constructs extensively and still get results in a reasonable time. Had we not done this, free path constructs would have been used with far less reliability and accuracy.

The teamwork extended to Kris identifying situations that caused the model to develop a gridlock condition which affected 25-30% of the iterations. This led to a speedy repair of the model.

THE SYSTEM LAYOUT WAS STRAIGHTFORWARD BUT CHALLENGING ....

The perimeter tow-line system design consists of a loop segment within Buildings 1 and 2 approximately 2100 feet long with 38 spurs; a loop segment within Building 3 approximately 2100 feet long with 19 spurs; and a bridge approximately 500 feet in length connecting the buildings together. The total distance around the perimeter of the buildings and through the bridge is 5200 feet. (see diagram 1)

Carts are 48 inches long and are transported on 20 foot centers on the main tow-line and on 6 foot centers on the transfers. There are currently 350 carts available for use in the system. The system may dispatch as many as 2000 loads within a day with the majority of the loads moved during the first shift (0730 to 1600).

Tow-line speed is 60 feet per minute. Each spur may hold a different number of carts. Multiple spurs with the same identity were aggregated in the model.

The transfer capacity at the entrance to the bridge in Buildings 1 and 2 was estimated to be 6 carts. The final capacity of the transfer in Buildings 1 and 2 was determined with the aid of the model. The capacity of the transfer at the entrance to the tunnel in Building 3 was constrained to 3 carts as this was an existing transfer that would be retained in the proposed system.

RULES FOR EMPTY CART MANAGEMENT WERE ESTABLISHED ....

In order to manage empty carts in the system, Empty Cart Pools were created. An Empty Cart Pool reflects carts stored in the immediate vicinity of the point where a previously loaded cart was unloaded. A maximum of 25 pools were created and maintained. The pools were associated with a group of spurs that are in close proximity to each other. This allowed easy placement of the cart into the pool and equally easy retrieval of an empty cart when needed.

When a load is initiated at a spur, an empty cart is consumed. The primary source for empty carts is a series of empty cart pools. Each pool is associated with

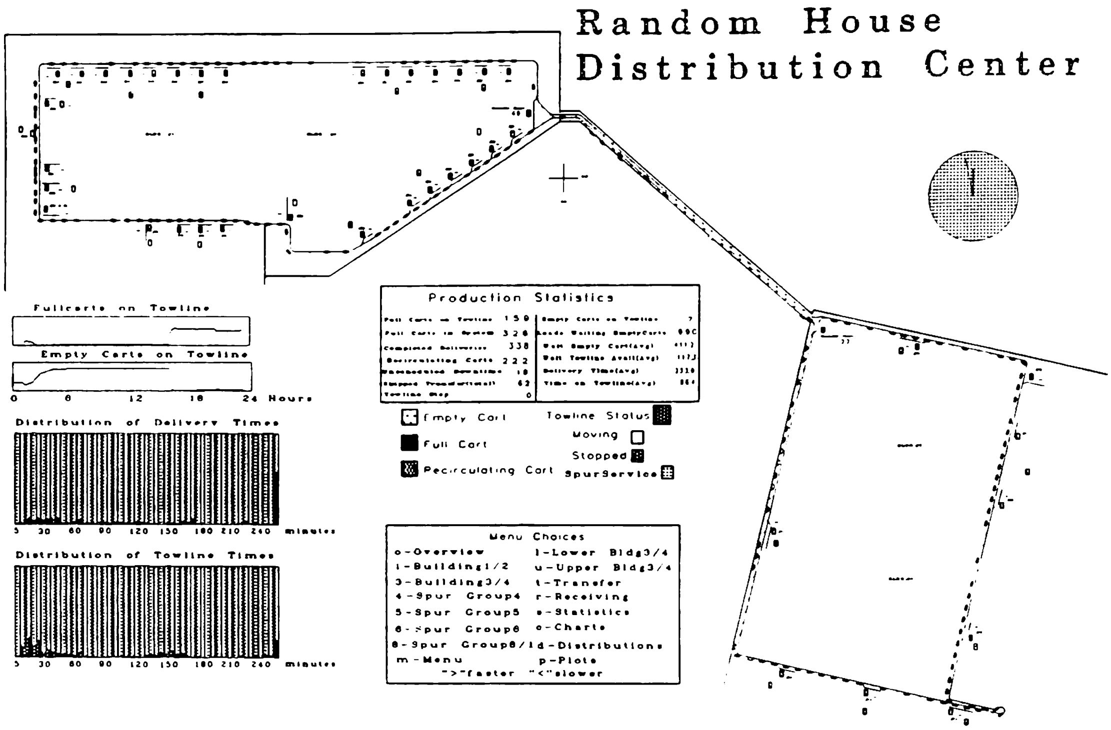


Diagram 1

Hit "m" for menu

a groups of spurs. If no carts are available from the empty cart pool, then the operator waits until an empty cart enters the spur area on the towline.

Empty cart pools were assigned a maximum number of carts and a reorder point. If the number of carts in the pool dropped below the reorder point and there was someone working in the area (initiating a load or servicing the spur), an empty cart was removed from the towline and stored in the empty cart pool. The limits for each pool were set via a menu entry prior to model execution.

SPUR AND EMPTY CART POOL DESIGN WAS CAREFULLY CONSIDERED ....

There are a total of 36 regular spurs in the model. In some cases, a number of these regular spurs, can have the same identity. In actual operation, a cart destined for this multiple spur configuration, will enter the first spur that has room. To simplify the model, these multiple spurs with the same identity were configured as a single spur with a capacity equal to the aggregate number carts in all the spurs. This reduced the complexity of the model with no loss of integrity or precision.

In addition to the 36 regular spurs, the new system design includes 5 group overflow spurs. The overflow spurs are associated with a series of spurs in the same general vicinity. The overflow spurs provide a second chance for a cart to arrive near its destination in a timely manner. This reduces the number of carts that recirculate in the system.

Empty cart pools are associated with sets of spurs in close proximity. The pools contain empty carts which are used to route a load from one of the spurs in the set to a remote destination. If no empty cart exists, the load must wait to be transported.

For ease of visual observation and ease of experimenting with various capacities, the spurs, transfers and empty cart pools were modeled as queues with menu selectable capacities. The spurs, transfers and empty cart pools appeared in the animation as small bar charts which showed the percentage full at a quick glance.

RULES FOR ENGAGING AND DISPATCHING LOADED CARTS WERE CONSTRUCTED ....

An activity file was provided by Random House with actual peak daily pallet move data. The file defined the point of origin, destination spur and the time of origin for each load. A load may originate at any spur. The destination for a load may be any spur except the origin. Loads must wait for an available empty cart before being initiated into the system.

Loaded carts are placed on the tow-line as the next empty 20 foot space passes the spur. Loaded carts move counter-clockwise around the tow-line system. Loaded carts take the shortest route to their destination unless a bypass transfer is full.

Loaded carts queue in a transfer if traffic on the main tow-line does not allow a merge from the transfer to occur. Loaded carts move from the main tow-line to the destination spur if room exists on the spur. If the spur is full, the cart bypasses the spur. If a loaded cart passes the destination spur, it will move into the overflow spur unless it is also full. If the overflow spur is full one of two actions can be chosen:

1. the loaded cart recirculates until the destination or overflow spur is able to accept the cart, or,
2. the tow-line stops until at least one cart is unloaded from the overflow spur

3. SIMULATION MODEL DEVELOPMENT

THE MODEL WAS DEVELOPED TO EMULATE THE SYSTEM CONSTRUCTION AND TO OBSERVE STATUS IN RELATION TO PERFORMANCE ....

The main path of the tow-line system weaves its way around the buildings. When the tow-line stops, it is necessary to stop all of the carts on the towline in their place and wait until the disturbance is over.

Second, the number of carts in a spur varies over a set range. When using the animation, the actual number of carts in a spur is less valuable than having an idea of the utilization of the spur.

Third, throughout the day, operators come to a spur to unload the carts and to "service" the zone. While they are in the area, several activities (taking off empty carts, loading the spur, emptying loaded carts) could take place.

The main line of the tow-line system was modeled as a non-accumulating conveyor. Push dog entities were placed on the conveyor and acted as carriers for empty and loaded carts. The spurs where the carts were diverted automatically were a combination of queues which stored the carts, and levels which displayed the current utilization of the spur. A similar construct was used for empty cart pools. Operator activity was displayed with global variables that changed with each change in the state of service activity.

The levels displaying the queue data and the global variables showing operator status provided a dynamic display which was extremely easy to understand. At all times while running the animation the relative number of carts in each of the spurs, the empty cart pools, and the overflow spurs was easily viewed.

MODEL INITIALIZATION, STARTUP AND STABILIZATION WAS EASED BY THE MODE OF OPERATION ....

During model development, concerns about initialization and stabilization were identified. A startup scenario was constructed to address these concerns. Empty carts were placed on the tow-line and in empty cart pools throughout the system. This was accomplished by running the conveyor at near infinite speed for the first few minutes and metering empty carts onto the tow-line from a single source spur. Likewise, empty cart pools were filled to their respective reorder points.

Fortunately, system activity in the initial hours of operation each day from midnight to approximately 7 AM is light. This allowed the system to reach equilibrium and emulate actual performance within the first hour of operation. Statistics were reset at one hour of model execution.

SYSTEM DOWNTIME WAS SCHEDULED TO REFLECT ACTUAL EVENTS ....

The tempo of operations in the Random House distribution center was often broken by scheduled operational break times and unscheduled tow-line shutdowns required for operating convenience.

For a model and project such as this, where dozens of different cases were evaluated, it was important to eliminate the effects of factors which are outside the bounds of the study. Modeling explicit breaks in operation by means of a fixed table of outage periods eliminated the possibility that random variations in these outage periods would inadvertently skew the results and therefore was more effective than randomly scheduled events. Actual historical downtime statistics were obtained and a file of outage periods was constructed.

MOVEMENT, LOADING AND UNLOADING TIMES FOR CARTS WERE BASED UPON ACTUAL HISTORICAL PERFORMANCE AND OPERATIONAL STATISTICS ....

Similarly, an activity file was developed and used as a basis for the workload in each of the runs. Scenarios for average and peak activity were developed. The transport time of the system and the number of cart recirculations were effected by the four major parameters listed earlier, each of which was modeled and specified individually.

Operator activities such as cart marshaling and servicing were developed by looking at dispatching logs and observation times. With these sources the servicing times represented realistic expectations.

MENU DRIVEN MODEL PARAMETER ENTRIES WERE DEFINED TO EASE MODEL EXECUTION....

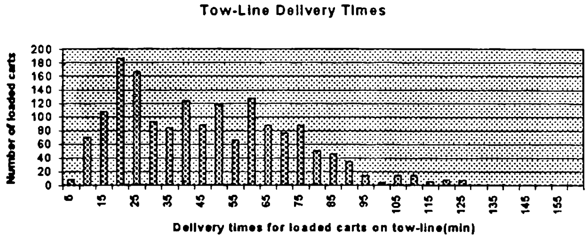
The SIMAN simulation language was used to develop the model and the ARENA product was used for animation purposes. This is in keeping with the concerns identified by M. Seppanen(1995) for modeling industrial strength systems. Animation on selected cases provided the validation of cart movement and insight to the activities occurring in the model.

The nature of the analysis encouraged parameterized data sets which made it easier to modify the data in an orderly fashion and to assure complete coverage of the options to be tested.

A menu-based variable entry system developed by Automation Associates provided a vital means of storing multiple data sets, tracking the multiple model run scenarios and enabling several parameter runs to be made consecutively. Finally, the SIMAN model without any constraints and/or delay from animation enabled us to run many different scenarios quickly. Iterations were batched and run overnight.

MODEL OUTPUTS WERE SELECTED TO EMPHASIZE THE PERFORMANCE CRITERIA TO BE INVESTIGATED ....

The primary purpose of the model was clear: to evaluate predictability of transport within the facility. With this in mind, specific outputs were selected. The model provided average, minimum and maximum transport (flow) times for the carts dispatched. A frequency distribution showing number of carts for various transport times was used to interpret the variance of transport times.



To aid in the validation and interpretation of the model results, statistics were displayed:

1. on the animation screen as the model was running
2. as end of run statistics
3. as graphics which tracked values over time and maintained a history throughout the run

The output processor was used to answer a few specific questions but comparing differences among many different runs was the main evaluation technique.

4. ANALYSIS

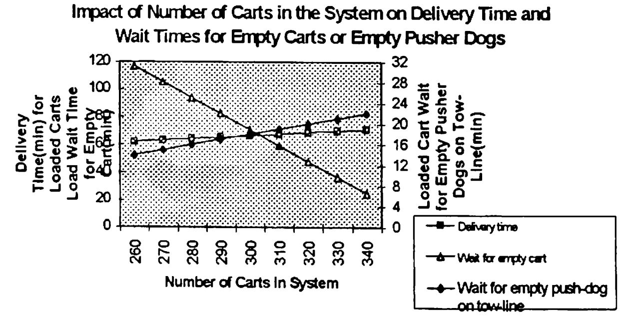
MODEL CASES WERE SELECTED TO PROVIDE A PARAMETRIC STUDY OF THE MOST SIGNIFICANT VARIABLES ....

We hypothesized that transport time was most significantly effected by a few variables. The test cases were designed to demonstrate the sensitivity of transport time to:

1. number of carts in the system
2. empty pool sizes
3. time to service a cart after arrival at the destination
4. overflow spur capacities
5. transfer capacities
6. shutdown versus recirculation upon spur overflow

MORE THAN 100 CASES WERE RUN AND THE RESULTS INTERPRETED ....

Numerous model runs were made by parametrically varying the variables that were selected as the most significant. Each series of runs varied one parameter over a representative range while holding the other parameters constant. The results were summarized on a spreadsheet for easy comparison and evaluation.



It was quickly determined that certain parameters, such as transfer capacity, even when varied over a wide range had very little impact on the dependent variable, transport time. For other parameters, such as number of carts in the system, transport time was shown to be highly sensitive to the parameter over a narrow range.

Interpretation of initial results guided the selection of additional runs for further evaluation. In other words, the design of the experiment was fluid and driven by results of each new case that was tested. The investigation converged on results in an iterative fashion with the analyst and the model working in a closed loop environment.

5. RESULTS AND CONCLUSIONS

MODEL RESULTS DEMONSTRATED THAT THROUGHPUT CAPACITY, TRANSPORT TIMES AND VARIANCE MET THE DESIGN CRITERIA ....

The capability of the tow-line system to deliver loads was found to be limited to approximately 2300 to 2500 loads per day using the load schedule profile provided by Random House wherein the highest concentration of loads occurred between 0700 and 1600 hours.

The system had no difficulty in handling the 1764 loads associated with the peak expected daily load assuming that spur service, cart loading, loaded cart placement on the tow-line and empty cart removal from the tow-line were as recommended.

The average transport time for a load was 45 minutes, once placed on the tow-line, and after eliminating abnormally long times for the few carts trapped on the line during a long scheduled shutdown at 0100 hours. This conclusion was based upon allowing carts to recirculate.

The average full delivery time which includes the wait for an empty pusher dog, was 53 minutes, also after eliminating abnormally long times for the few carts trapped on the line during the long scheduled shutdown at 0100 hours.

Substantial delays were incurred waiting for an empty dog after the cart is loaded. This condition was less significant as the number of loads scheduled per day decreases. This implied that personnel may be required to linger in an area after carts are loaded to wait for empty dogs to occur.

Approximately 90% of the carts were on the tow-line less than 80 minutes whereas the total delivery time was less than 95 minutes 90% of the time.

MODEL EXECUTION HIGHLIGHTED OPERATIONS CONSTRAINTS THAT WERE EXPECTED AND UNEXPECTED....

The model showed that the system ran more efficiently and delivered loads up to 10% faster if carts are allowed to recirculate when the overflow spurs fill as opposed to shutting down the tow-line. This was not in concert with the expectations of the team prior to modeling.

Increasing empty cart pools from the prescribed capacity was found to have no significant effect on system performance. Similarly, increasing transfer and overflow spur capacities from the design quantities had little effect on system performance. Recirculations due to a full transfer were minimal under all conditions of operation.

Decreasing the maximum service interval a moderate amount from 95 minutes to 60 minutes had no effect on system performance. Service times less than 60 minutes began to have a beneficial effect. This was expected.

THE MODEL BROUGHT A NEW LEVEL OF UNDERSTANDING TO THE DYNAMICS OF THE OPERATION IN RELATION TO THE NUMBER OF CARTS ....

The impact of the number of carts in the system and empty cart management was found to be profound. The total number of carts in the system must be carefully selected to optimize system performance. For the parameters in the model, 260 to 270 carts provided the best results. Too many carts caused gridlock in the system and deteriorated performance. Too few carts starved the system.

The system performance was highly impacted by empty cart management. The spurs downstream of the receiving area (spur 74) were frequently starved for empty carts. A strategy to deliver empties to those spurs must be developed. Increasing the empty cart pools in these areas provides initial relief, however, these larger pools have no impact after the system achieves steady state because empty carts are not available to replenish the pools.

USING SIMULATION PROVIDED THE MEANS TO QUANTIFY SIGNIFICANT RESULTS AND IDENTIFY MANAGEMENT ISSUES.

The results of the simulation showed that: (1) the size of the transfer lines played a distinct role in the model's usefulness and (2) the number of carts on the tow-line had a profound effect on performance.

The model also showed that the need to manage empty carts will be a substantial and difficult task. This has given management an important "heads up" in preparation of the new design implementation. With this forewarning, new empty cart strategies can be developed.

THE MODEL PAVED THE WAY FOR CAPITAL APPROPRIATION APPROVALS FOR THE SYSTEM MODIFICATIONS ....

Simulation answered significant questions as to the viability of the proposed design:

1. The new design would support the necessary number of pallet moves for current and future needs.
2. Standards for consistent delivery times could be developed.
3. The system should continue to run when an overflow spur is full.
4. A capacity of six(6) carts at the new transfer bypass system was sufficient to prevent loaded carts from traveling all the way around to other buildings.
5. Overflow spurs were beneficial in preventing carts from recirculating.
6. The system operated best within a range of 260-270 empty carts.

With these questions answered, the company approved the expenditure and is in the process of modifying the system. The system is expected to be completed in mid-1996.

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