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SIMULATION OF A COMBINATION CARRIER AIR CARGO HUB

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ABSTRACT

The air cargo industry has witnessed impressive growth in recent years. The tight airline schedules, short connect times for shipments at airline hubs, the wide variation in shipment weights and sizes, and the inherent uncertainties of the airline environment make operations at the cargo hubs of combination carriers, such as American Airlines Cargo (AA Cargo), a complex and challenging task.

This paper illustrates the use of simulation for evaluation and analysis of air cargo operations by describing the development of a simulation model for the Dallas/Fort Worth Airport cargo hub of AA Cargo. The modeling approach, model inputs, and model output is described. The model was used to evaluate the effectiveness of existing operating procedures and resource allocations at the hub, and to quantify the impact of proposed modifications in layout, procedures and resource allocations. The simulation tool described can also be used to analyze the impact of future changes to operations such as new airline schedules and the implementation of automated material handling systems.

1 BACKGROUND

American Airlines Cargo (AA Cargo), a division of American Airlines, is classified as a combination cargo carrier. Combination cargo carriers are airlines that carry both passengers and cargo using the same aircraft. Being a combination carrier, AA Cargo faces challenges that are not experienced by dedicated cargo airlines. These challenges are precipitated by the schedules of aircraft at hubs, and the uncertainty of available cargo space caused by sharing its fleet with a passenger airline.

Airline schedules are devised primarily to facilitate connecting passengers through hubs. There are nearly 450 departures each day from American's hub at Dallas/Fort Worth. The aircraft arrive and depart in 12 complexes (groups of arriving or departing aircraft). Although this provides an enormous amount of lift, or outbound capacity, full utilization of the lift is complicated. Outbound cargo must be planned, staged and loaded for approximately 40 departing aircraft, 12 times per day. In addition, due to cargo sharing aircraft belly space passenger bags (with higher priority), the amount of space available for cargo is an uncertainty until time of departure.

2 AIRPORT CARGO OPERATIONS

Aircraft complexes, a group of arriving and departing aircraft, generally have a West to East or an East to West flow through American's DFW hub . The direction of this flow alternates from complex to complex over the course of a day. Because inbound cargo connecting through DFW requires sortation, it generally cannot be connected though the hub within the same connecting complex. As a result, the next opportunity to connect the cargo, due to the geographically alternating directions of complexes, is generally two complexes after the cargo arrives.

In order for this desired two complex connecting period to work, a number of activities must take place. First, cargo is unloaded from the aircraft and brought to the cargo terminal by cargo tractor drivers (called runners). After arrival at the cargo terminal, cargo must then be unloaded from it's inbound flight container, or ULD (Unit Load Device), and sorted into shipments terminating at the hub and those transferring to other destinations. The transferring shipments are then loaded into ULD's, which are

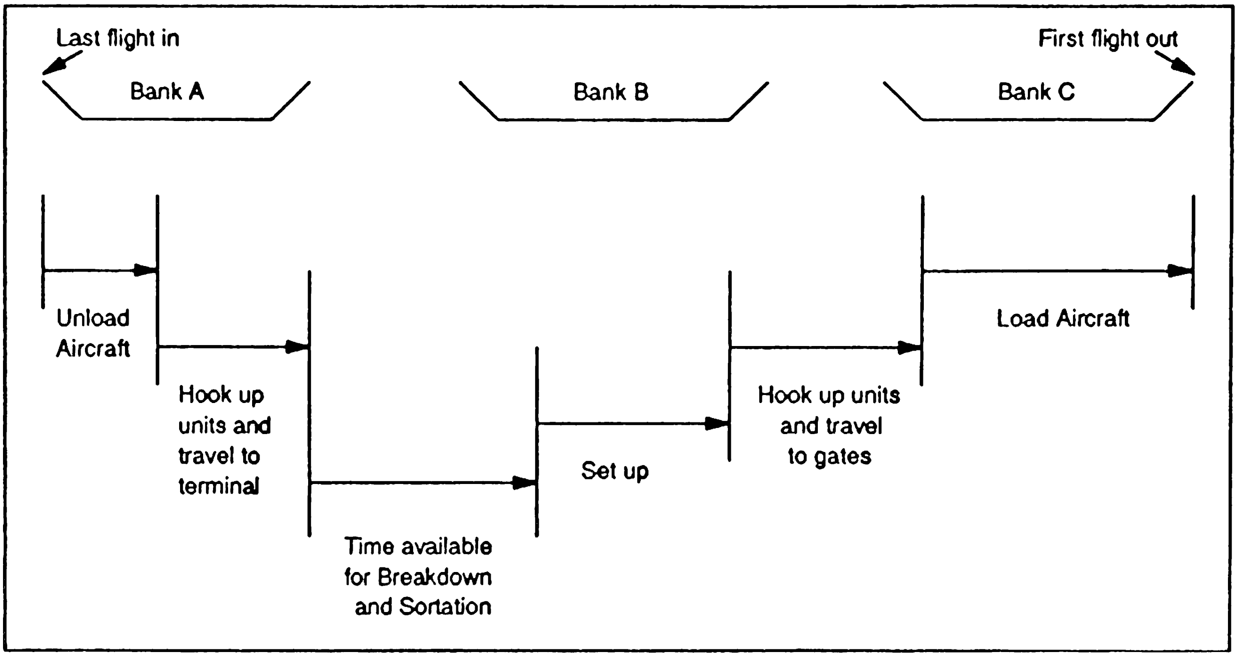

Figure 1: Flow of Transferring Cargo

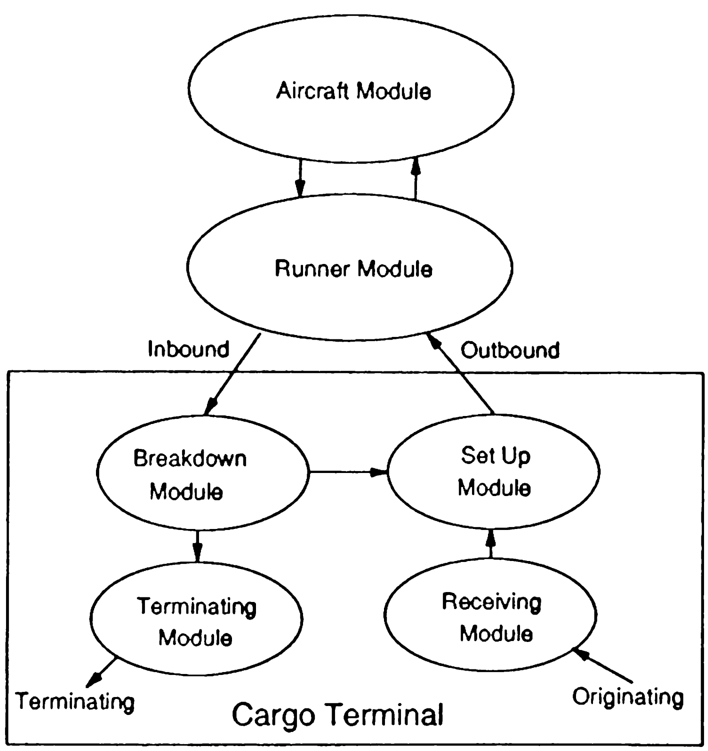

Figure 2: Simulation Model Schematic

dedicated to each outbound destination. These outbound ULD's are then planned for the next departing aircraft to the desired destination with available space. At the appropriate time, the outbound ULD's are weighed and set up on dollies, and are then delivered to the outbound gate by a cargo runner. The timing of this connecting process is shown in Figure 1. The inability to perform the required operations within two complexes is the motivation for the simulation studies.

3 SIMULATION MODEL

The focus of the simulation was to study the individual functional areas and the interrelationships between these areas. For this reason the simulation was designed in stand alone "modules" that are representative of each functional area (see Figure 2). These modules were individually verified and validated, and experiments were run. The modules were then combined and run together. The modeling approach of each is discussed. In addition, the methods of obtaining the large amount input data is described.

The simulation was coded using Systems Modeling's Siman/Cinema 4.0 and FORTRAN on an OS/2 platform. The original executable files provided by Systems Modeling were recompiled using Siman utilities, FORTRAN, and Macro Assembler, to allow all of the modules, which used a total of 20,000 entities at one time, to be run together.

3.1 Modeling

The aircraft module is designed to create arriving aircraft, generate inbound cargo, and dispose of outbound cargo. Aircraft entities are created according to a specified airline schedule. As the aircraft entities arrive, duplicate entities are created to represent inbound pieces of cargo. These pieces are assigned individual characteristics, such as piece weight, and then grouped into shipments. Shipments are then assigned an outbound destination from an historical distribution of connecting cities for inbound freight in that bank. Finally, shipments are grouped into ULD's that will serve as input for the runner module.

The runner module is used to analyze the two different strategies for retrieving and delivering ULD's to and from aircraft. Both strategies use cargo tractor drivers (called runners) to transport ULD's in trains of up to four (due to FAA regulations). The strategy in place at the time of the simulation divided the airport into five equal zones and dispatching three cargo runners to each zone regardless of the work load in each zone. Three additional runners were then assigned to the zones with the greatest load. The simulation was then used to evaluate a second strategy that used an optimization routine to determine the best allocation of runners to the workload, taking into account distances traveled, operational constraints, and the number of gates a runner is allowed to span. Simulation code of the current operation is accomplished using standard SIMAN routines, but in order to implement the optimization model a large FORTRAN code is called as a subroutine for each of the twelve complexes.

The breakdown and set up modules are the two main modules that constitute cargo terminal operations. Breakdown receives input, in the from of inbound ULD's, from the runner module. The ULD's are split into shipments and then pieces, sorted by destination, and then re-grouped to form pallets. These grouped pallet entities serve as inputs for the terminating dock and setup modules. The set up module checks an outbound schedule of flights for departures to the destination of each ULD. If there is a scheduled flight, that particular flight is checked for outbound capacity, and capacity permitting, the outbound gate for that flight is assigned to the unit entity. These entities serve as input for the outbound portion of the runner module.

The receiving dock module generates truck arrivals and uses forklift transporters to unload and process freight. Processing is accomplished in much the same way as transferring freight, with the exception of additional paperwork delays. Grouped pallet entities are then sent to the setup module.

3.2 Input Data

Finding accurate input data and analyzing this data is typically the most difficult task in a simulation project. This task becomes particularly challenging when modeling very large scale systems. The majority of input data for this simulation was obtained from flight and shipment databases that are populated from real-time information systems at American Airlines. Data unavailable through corporate databases was found through physical surveys.

The data requirements primarily fell into four categories: (a) aircraft characteristics, (b) shipment characteristics, (c) piece characteristics, and (d) truck arrival characteristics.

Pieces from cargo originating and transferring through the DFW hub were sampled to determine a piece-weight distribution. Piece weights were generated in the simulation by sampling the raw piece data as the data could not be used to fit any of the standard distributions. To better understand the arrival process an extensive survey of truck arrivals and shipment characteristics was performed at the receiving dock of the cargo terminal. Shipment characteristics such as the weight of a shipment and the number of pieces per shipment differed significantly based on the destination of the freight (international/domestic) and source of freight (company material/revenue customer), so individual distributions were developed for each of these categories.

The truck arrival process in the receiving dock module presented a unique challenge due to the erratic arrival pattern of customers to tender freight for shipment. The arrival rate is variant based on the time of day and type of customer, making a standard Poisson process inappropriate. Three distinct arrival patterns did emerge based on customer type. A recent article [Leemis,1991] outlines the use of raw data to create a non-homogenous Poisson process. The technique does not require any arbitrary parameters and generates arrivals based on the intensity of the arrivals in the raw data, while ensuring that the expected number of arrivals is equal to the average number of arrivals surveyed. The technique creates a piece-wise linear function, similar to a cumulative density function. The difference is that the cumulative inter-arrival time is along the Y-axis and the time of the arrival is on the X-axis. After a truck arrival is generated the number of shipments, the number of pieces, and the weight of each shipment is created based on the results of the survey.

Aircraft characteristics determined from flight databases at American Airlines included: (a) distributions of the total freight pounds on inbound domestic and international aircraft by aircraft type and arrival complex, and (b) the number of aircraft without any freight by aircraft type and arrival complex.

Data obtained from shipment databases included: (a) the percentage of weight flowing to different destinations by inbound complex, (b) the number of shipments on narrow-body aircraft by arrival complex, (c) the average weight of a shipment arriving on a narrow-body aircraft, (d) the percentage of shipments by product type, and (e) the distribution of the number of shipments per ULD and aircraft.

3.3 Validation

Validation of the simulation model was done by comparing model output to historical data, and by reviewing the output measures and animation with cargo terminal managers.

Difficulties in obtaining adequate data on cargo flow within the terminal resulted in validation being limited to historical data on the overall connect time for transferring cargo and outbound cargo flows from the hub. In the validation process, an actual past schedule and the corresponding inbound cargo volumes were input to the model. The outbound cargo flow in a bank and the overall cargo flow in a day were used as the output measures. Hypothesis tests indicated that the historical mean cargo flows in a bank were equal to the simulated mean cargo flows at the 95% confidence level. The simulated maximum and minimum cargo flows in a bank were also compared to the historical maxima and minima. The distribution of transfer cargo connect times obtained from the simulation also closely matched the distribution obtained from actual data for the day.

Face value validity of the model was confirmed by having organized, periodic reviews with cargo terminal managers. This involved examining output data from the model for measures, such as incremental processing times, that are not contained in the corporate databases. Additionally, the model animation used to validate operating procedures with the terminal managers.

4 ANALYSIS AND RESULTS

The air cargo hub simulation model was used to evaluate each functional area of the DFW Cargo operation. Data collected for these experiments typically included process times, work-in-process, resource utilizations, and the number of resources required. A base model of the existing operations was developed first. After studying output statistics, areas of concern were highlighted and experiments were run to test proposed solutions.

The inbound cargo breakdown function, a known problem before the simulation, was the first area to be investigated. The operation consists of a set of clerks unloading inbound ULD's and another set using forklifts to move and stage the cargo into outbound ULD's. The experiments focused on finding the best ratio of unload clerks to clerks driving forklifts. In addition, the effect of increasing the manpower allocation for breakdown was also investigated.

The results of the experiments are best summarized by Figure 3. It was found that the existing ratio of 2:1 was inadequate. By simply shifting more clerks to driving forklifts from ULD unloading without increasing manpower, the average process time in breakdown decreased by over 50% and resulted in the average total connection time decreasing by 15%. In another experiment, increasing the manpower in breakdown reduced the process time even further. However, due to the associated reduction in clerk utilization, the extra decrease in process time did not justify the increase in the manning level.

The outbound set up operation was also studied. Set up, which entails weighing and loading

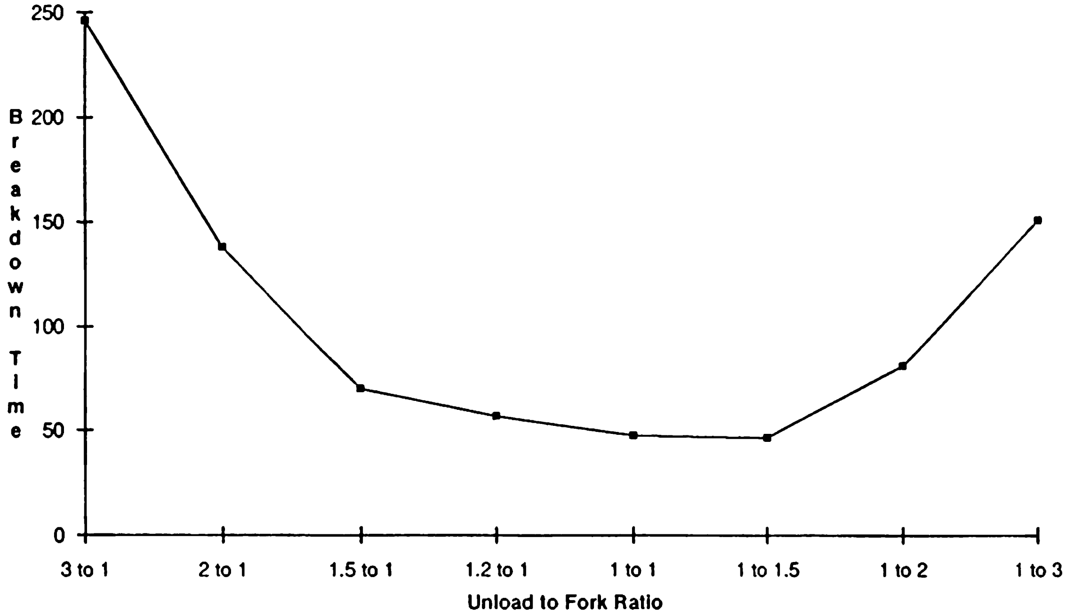

Figure 3: Breakdown Analysis - Breakdown Processing Time

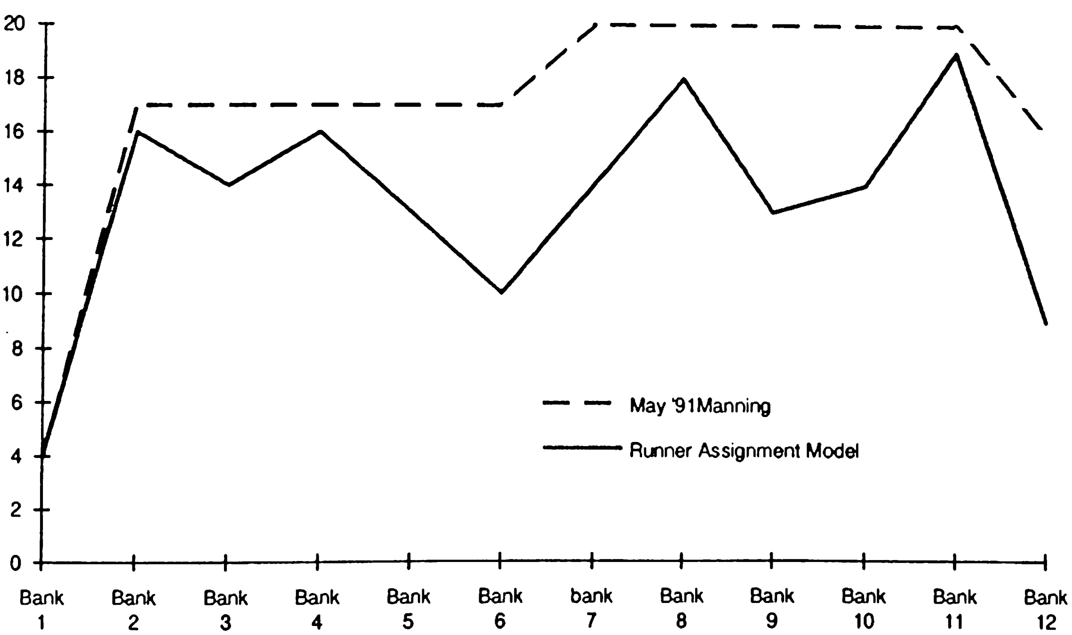

Figure 4: Runner Requirements

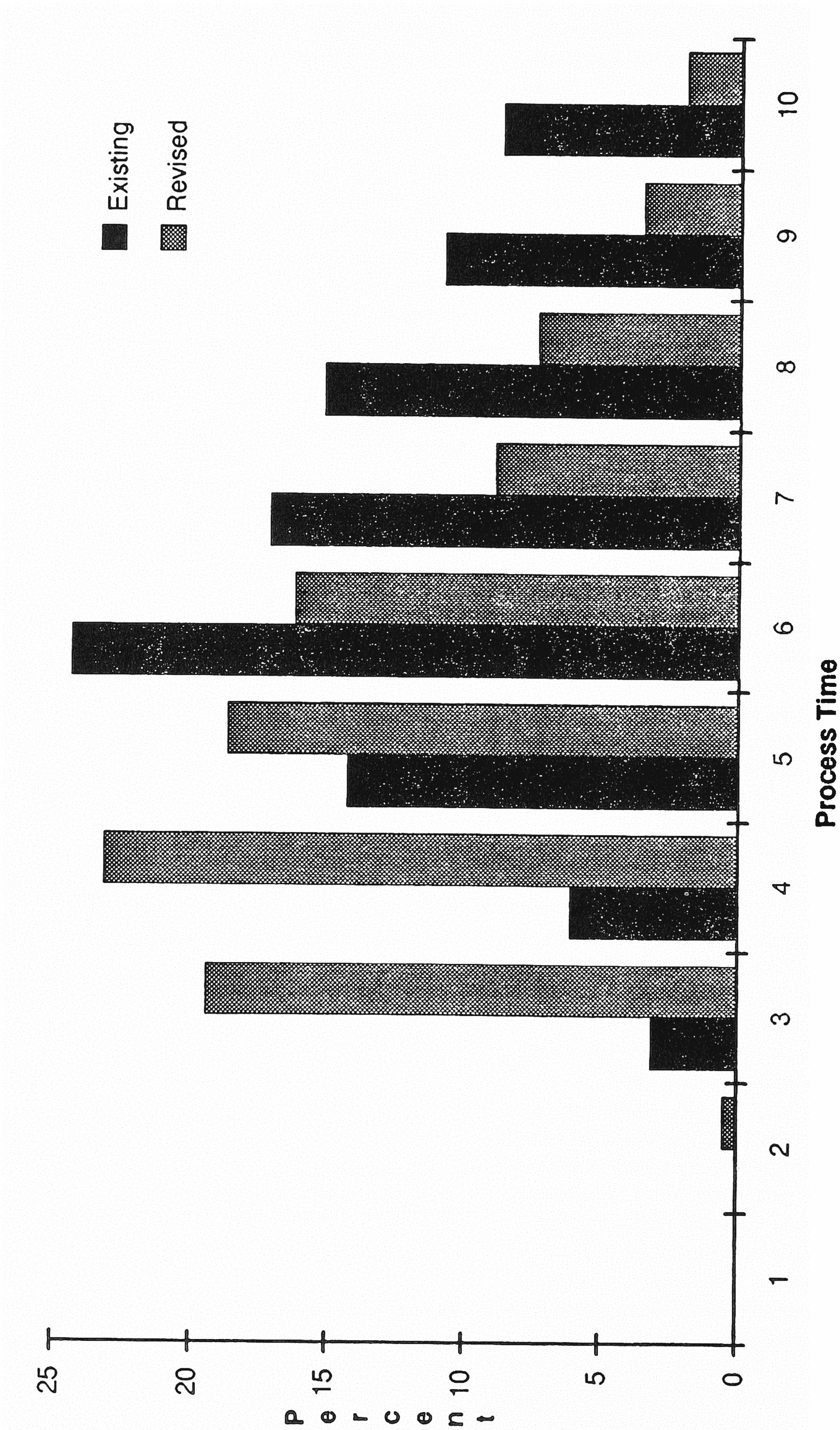

Figure 5: Effect of Combined Experiments

outbound ULD's onto dollies, begins two hours before the first departing flight for a complex. The experiments involved increasing set up resources, such as clerks, forklifts, and scales, in the hopes of delaying the start of set up. By delaying the start of setup, the amount of time allowed for breakdown and sortation could be increased, and thus more cargo could be connected within two banks. The experiments determined the impact of the delay. The results were somewhat surprising in that the impact of the delay was small. As later experiments would reveal, the delayed impact had a diminished effect due to the long process times in the existing inbound process.

The two strategies of retrieving and delivering ULD's to and from aircraft yielded significant results. Dramatic improvement in ULD retrieval time as well as a reduction in the amount of manpower required demonstrated the effectiveness of the optimization routine. Figure 4 shows a comparison of the number of runners required to retrieve and deliver ULD's to and from aircraft by complex.

Finally, experiments were conducted to determine the interaction effects of several of the proposed modifications. A two-level factorial design with three variables was used to study the effect of breakdown forklift allocations, setup resource allocations and runner assignment strategy. Ten replications of the simulation were performed for each run of the design. The effect of the three factors on processing time is shown in Figure 5.

5 FUTURE WORK

The hub simulation model is currently being modified for studies of other cargo hubs. These studies will include the analysis of facilities layout, new airline schedules, and proposed automated material handling systems.

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