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MODELING HIGH VOLUME CONVEYOR SORTING SYSTEMS

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ABSTRACT

This paper discusses alternative approaches to modeling high volume conveyor systems. After a brief review of various options, advantages and disadvantages of each approach are discussed. Several key issues, such as computer memory, run time, and model accuracy were evaluated for each modeling approach. An application is used to illustrate how one of the modeling options was implemented successfully.

1. INTRODUCTION

Most manufacturing and distribution facilities contain some type of material handling system for transporting material between and within areas of the facility. This paper presents a specific application of conveyors within a high volume sorting system for a Federal Express distribution facility.

The system modeled consists of approximately five miles of conveyors on which packages are moved from input areas to final sort buffers. An input area is where packages are first introduced into the conveyor system. Here the packages are manually placed onto the conveyors and begin their journey through a maze of conveyors. From an input area, packages have a "primary" routing on various conveyor segments. The primary routings define the path a package will take given that there are no conveyor failures or overflows.

Conveyor failures and overflows are considered in the simulation model for all conveyor segments. Conveyor failures are temporary breakdowns which prevent material movement along the particular conveyor segment. Overflows can occur when one or more conveyor segment(s), with specified capacities, merge onto another conveyor segment, whose capacity is less than the total capacity of the source conveyor(s). These conditions cause diverters, located at the beginning of each conveyor segment, to redirect packages to a "secondary" routing.

The objective of the study was to evaluate various package routings to maximize the flow of packages through the conveyor system in a given time period. Failures in the physical system cause immediate action by supervisors to reroute the packages to an acceptable "secondary" routing. The physical system moves many hundreds of thousands of packages each night so that experimenting with new routings using the actual facility at peak times was not an acceptable option. The simulation model is a valuable tool for evaluating the secondary routings under a given failure scenario.

This paper presents alternative approaches for modeling high volume conveyor systems and for analyzing the various problems faced by such complex facilities. Advantages and disadvantages of various modeling approaches are also discussed. A case study is presented to illustrate the successful application of discrete event simulation in this area.

2. CONVEYOR CHARACTERISTICS

Conveyors are a broad classification of automated material handling equipment. In general, conveyors work as follows. Objects wait at defined entry points for a specified amount of clearance space on a conveyor. Once an object gains access to the conveyor, it moves along a predefined path and eventually arrives at a transfer point where it exits the conveyor.

Conveyors can have many different characteristics, each of which requires a different type of control logic. For example, the control associated with an accumulating conveyor is different than that of a non-accumulating conveyor. Conveyors can be viewed as a number of linked "cells," all of equal length, which move in unison along a defined path. The cells can be considered either occupied or unoccupied. An object waiting to get onto a conveyor must wait until the required number of unoccupied, contiguous cells are available at the object's entry point. At this time, the conveyor is stopped, the object is placed onto the conveyor, the status of the required conveyor cells becomes 'occupied', and the conveyor continues to move.

For the purposes of modeling, conveyors are divided into cells. Each cell is of equal length and represents a section of the conveyor. Objects being transferred on the conveyor may require one or more individual cells. The overall length and speed of the conveyor must also be defined. The most basic conveyors allow only one object to occupy any given cell.

High volume conveyors are unique in that many objects may occupy a given conveyor cell. Examples of products which use high volume conveyors include: mail, packages, garments, sand and coal. The cells on this type of conveyor are not viewed as simply occupied or unoccupied. Each cell has a maximum capacity and waiting objects can be placed on an occupied cell if there is remaining capacity. For example, a Post Office distribution center may contain a high volume conveyor system which transfers mail from point to point. The conveyors may have a maximum capacity of 100 letters per foot. A foot of the conveyor which has only 40 letters is occupied but has a remaining capacity of 60 letters. Waiting letters can therefore be added to that one foot of conveyor on top of the existing 40 letters.

These types of conveyor systems are analogous to a rainwater pipeline draining system. Water enters street drains, flows down a series of pipelines and eventually drains into a reservoir. The key consideration in designing the pipeline system is to make the feeder pipelines large enough to handle the flow of water without overflowing the street drains during rain storms.

3. MODELING CONVEYORS

The most basic type of conveyors are easily modeled using conveyor constructs which many state-of-the-art simulation languages provide. The simulation language internally tracks whether cells are occupied or not and allows an object to enter the conveyor when the appropriate number of unoccupied cells arrives at the object's entry point. Simulation language constructs work well in the case where only one object can occupy any given conveyor cell. However, high volume conveyors are not easily modeled using these constructs and the analyst must use the simulation language creatively to capture the detail necessary for this type of conveyor.

Conveyors with a few, large cells are most efficient from a computational standpoint. Relatively few cells decrease the internal "accounting" necessary within the simulation language. Less computer memory and faster run times are associated with the reduced calculations. Large cells, however, can result in an inaccurate conveyor representation. See [Pegden et al. 1990] for discussion of cell size.

The modeler, in analyzing various modeling alternatives, must evaluate the tradeoffs between model accuracy, memory requirements and computer run time.

4. MODELING HIGH VOLUME CONVEYOR SYSTEMS

There are a number of modeling options available for modeling high volume conveyors. Some options are discussed below with the advantages and disadvantages noted. In addition, the modeling approach which was chosen for the case study is discussed in detail.

In evaluating the options, the following model considerations were examined:

1. Model size and complexity
2. Conveyor failures
3. Conveyor utilization statistics
4. Computer memory requirements
5. Simulation run time
6. Accurate representation of physical system

4.1 Option 1

Define the conveyor cells small enough so that *one* object (i.e. one letter) will occupy *one* cell. The post office example requires that each cell be only .01 foot long (i.e. 1 foot / 100 letters = .01 feet per letter). A 100 foot long conveyor will have 10,000 cells.

Advantages:

1) Each object is modeled individually and specific control of each object is obtained.

2) Each conveyor cell holds only one object allowing existing conveyor constructs to be used.

3) Conveyor utilization statistics can be easily obtained.

4) Conveyor failures can easily be modeled.

Disadvantages:

1) The large number of conveyor cells and objects drastically increases memory requirements.

2) For large conveyor systems, the number of objects which must be represented causes increased simulation run times.

4.2 Option 2

Existing conveyor constructs are used and a representative object moves on a conveyor. The representative object may be a group of packages, a bundle of letters or a pound of sand. For example, the representative object from our post office example can be defined as 100 letters. Each cell on the conveyor will be defined as 1 foot long and all letters will be grouped into bundles of 100 letters before they try to access the conveyor. The representative bundle is conveyed to a discharge point where the individual letters are regenerated. The 100 letters per bundle in our example is an arbitrary number and can be set to 50 letters per bundle when a conveyor cell is defined as 0.5 feet.

Advantages:

1) Existing conveyor constructs can be used.

2) Utilization of the conveyor can be easily obtained.

3) Some simulation languages allow grouping of objects without destroying the individual members of the group. The individual objects can then be split with their original characteristics after the representative object exits the conveyor.

4) Conveyor failures can easily be modeled.

Disadvantages:

1) Grouping of objects may cause the simulated system to perform differently than the actual system. For example, the 1st object will be delayed on the conveyor until the total group arrives at the destination point.

2) The execution speed may be slow depending on the size of the conveyor cell.

3) Since individual objects (i.e. letters) are modeled separately, memory requirements may be substantial.

4.3. Option 3

Existing conveyor constructs are used. Each conveyor cell contains a "cell object" which represents any items on that cell of the conveyor. The "cell object" has a single attribute which defines the number of physical objects that the cell currently contains. In the mail example, each foot of the conveyor has one "cell object", with an attribute representing the number of letters the one foot area contains. This attribute may have a value from zero (no letters) to one hundred (maximum number allowed). When the "cell object" reaches the end of the conveyor, the number of physical objects represented by the "cell object" can be recreated.

Advantages:

1) Existing conveyor constructs can be used.

2) Conveyor failures can easily be modeled.

3) Flow of product on the conveyors is accurately represented.

4) May have much smaller memory requirements

Disadvantages:

1) Utilization of the conveyor may be difficult to obtain because each conveyor cell always has an object. The modeler must then devise a technique to capture the number of occupied conveyor cells (using the "cell object" number of objects on the conveyor cell). This may be accomplished within the simulation language or with an external FORTRAN or C routine.

2) Grouping of objects may cause the simulated system to perform differently than the actual system. For example, the 1st object will be delayed on the conveyor until the total group arrives at the destination point.

3) The execution speed may be slow, depending on the size of the conveyor cell. The existence of a "cell object" on each conveyor cell (even those with zero physical objects) will also increase the execution speed.

4) Characteristics of the individual objects are lost when "generic" objects are used.

4.4 Option 4

Existing conveyor constructs are ignored and each object is simply delayed for an estimated amount of time required to be conveyed to its destination. For example, if the conveyor is 100 feet in length, operating at 50 feet/minute, then the object is delayed for 2 minutes, which represents the time necessary to traverse the 100 foot length.

Advantages:

1) Conveyor constructs are not modeled, which simplifies the modeling phase and decreases model size.

2) Execution speed is quick because the amount of model code required is relatively small.

Disadvantages:

1) The capacity of the conveyor is ignored, thus there is no contention for conveyor cells which may cause more objects to occupy the non-existing conveyor cells than physically possible.

2) Conveyor failures cannot be accurately modeled.

3) Conveyor utilization statistics cannot be directly obtained and may not accurately represent the actual system utilization.

4.5 Option 5

The modelers can write their own conveyor constructs. A constrained resource may be used to represent the capacity at the entry point of the conveyor, in conjunction with a delay for the object to arrive at the destination point. For example, if the capacity of the conveyor is 100 letters per foot, then once a single letter gains control of the entry resource at the start of the conveyor, the resource is retained for the amount of time until the next letter can enter the conveyor. Thus, the amount of time a letter controls the entry resource determines the rate at which the letters can enter the conveyor.

Advantages:

1) The exact control necessary for the specific conveyor being modeled can be captured.

2) Conveyor constructs are not used, simplifying the modeling effort.

3) Flow of objects on the conveyors is accurately represented.

4) The execution time of the model may be decreased due to the absence of the internal "accounting" necessary when using conveyor constructs.

Disadvantages:

1) Modeling effort is time consuming to accurately capture the details required to control the conveyors.

2) Methods for capturing conveyor utilization statistics must be developed by the analyst.

3) Detailed conveyor failures cannot be easily modeled.

5. FEDERAL EXPRESS CONVEYOR SYSTEM

High volume conveyor systems are commonly used in the package and letter sorting industry. This section describes a Federal Express facility devoted to high volume sorting.

The conveyor system at this facility can be defined as follows:

1) All conveyors are high volume conveyors.

2) Each conveyor has a single entry point and a single exit point.

3) Approximately five miles of conveyors are used.

4) A conveyor entry point is fed by a buffer which is fed by one or more conveyor exit points. This buffer is used, in conjunction with a first cell constraining resource, to control the input rate onto a conveyor. The buffer is monitored for conveyor capacity overflows.

5) Packages are considered 'generic,' with no individual package information required.

6) Once a package enters a conveyor, it is conveyed all the way to the end of the conveyor and immediately exits.

7) Diverters are located at the end of each conveyor section to allow packages to move to their next "primary conveyor" buffer or to a "secondary conveyor" buffer.

8) Random conveyor failures will occur.

9) Conveyor failures also occur when a conveyor overflows.

After evaluating all of the alternatives for modeling this system, options 1, 2 and 3 were eliminated because of the extreme length of the conveyors and the number of cells that would have been required. Many thousands of cells would be necessary if existing conveyor constructs are used. Even if one of these options had been chosen, run time would have been sacrificed because of the conveyor constructs. Option 4 was eliminated because conveyor capacities and failures must be considered and contention for the conveyor space could not be ignored.

Option 5 was chosen to best capture the level of detail required for the system described above. Because of the volume of packages estimated to be in the system at any particular time, simulation run time was a concern. By eliminating conveyor constructs, this option combined minimal run length with model accuracy. Although capturing conveyor failures and utilization statistics required additional modeling techniques, the application demanded that the model be accurate and run relatively quickly.

Designing the conveyor constructs required that control which exists in the physical system be replicated in the simulation model. The following are the key control considerations and assumptions used in developing the simulation model.

1) The capacity of the conveyor was controlled by a constrained resource at the beginning of the conveyor.

2) The time duration to traverse the conveyor was calculated to accurately represent the object arrival to the subsequent conveyor buffer.

3) When a conveyor failure occurs, packages currently on the conveyor continue to the end of the conveyor section. This assumption was made because the conveyor sections are relatively short. Packages cannot

enter a conveyor which is failed, but must be diverted to another conveyor section.

The Federal Express packages being sent through the conveyor system are represented by fixed size package groups. Packages are grouped together in lots of 10 and travel through the system in this manner. Object movement and statistics are based on the group package size of 10 packages.

To determine the package size which would most accurately represent the actual flow of packages, many simulation runs were tested. Packages had to be represented by package groups because of the volume of material present in the system at any one time. When representing packages individually in the system, the run time increased significantly. Runs were made with package groups of 5, 10, 15, 20, and 30 to determine the sensitivity of package group size. Conveyor utilization statistics and final buffer area sizes were carefully analyzed to determine the smallest group size which had a relatively fast run time. Model accuracy was a concern with group sizes of 20 and 30, because of the response time to final buffer areas being full. The group size of 10 was chosen after extensive sensitivity analysis was performed on key performance measures.

Figure 1 illustrates the method for modeling the conveyors. The constrained resource shown in Figure 1 represents the first cell of the conveyor. Objects (package groups) gain control of the resource and delay its release for an amount of time equal to the time necessary to traverse the first conveyor cell. The first conveyor cell can hold only one package group; therefore, there is only one resource to control each conveyor entry point.

Package groups which cannot get control of the first cell resource wait in the preceding buffer. This buffer will hold package groups arriving from preceding conveyors. For example, packages may merge from two conveyors onto one conveyor. The buffer at the beginning of the receiving conveyor will hold the packages which cannot immediately enter the conveyor. Packages will only reside in the buffers if the flow of material from the preceding conveyors is greater than the capacity of the receiving conveyor. The buffer at the beginning of each conveyor was not an accumulating portion of conveyor in the actual system, but used to control the capacity of the conveyor in the simulation model.

Once on the conveyor, the package group moves to the end of the conveyor. The diverter at the beginning of the next conveyor controls the group destination. The package group then moves into the next buffer to access the next conveyor.

Control of the first cell of the conveyor defines the input rate for each conveyor segment. The cell must only be controlled for the time necessary to represent the capacity. An example of how the capacity was defined follows:

Conveyor capacity = 150 packages / minute
Package groups represent 10 packages

A group must therefore occupy the first cell for:

$$\frac{\text{Package group size (packages / object)}}{\text{Conveyor capacity (packages / minute)}}$$

For the above example, the calculation would be as follows:

$$\frac{\text{10 packages / object}}{\text{150 packages / minute}} = .067 \text{ minutes /object}$$

The control of the first cell is shown in Figure 2. A method for controlling the constrained resource while moving the package group along the length of the conveyor was devised. The resource needed to be controlled for a specific amount of time (see above calculation) before it was available to the next package group waiting for the conveyor. There are two options for modeling the first conveyor cell resource.

The first option involves splitting the package group into two separate objects when it accesses a conveyor. The first object, referred to as the "physical object", is delayed for the amount of time required for the group to traverse the length of the conveyor. The second object, referred to as the "control object", is delayed for the amount of time required for the group to traverse only the first conveyor cell. After its delay, the "control object" releases the resource so the next package group can access the conveyor. After releasing the resource, the control object is destroyed. Hence, the "control object" controls the conveyor entry point.

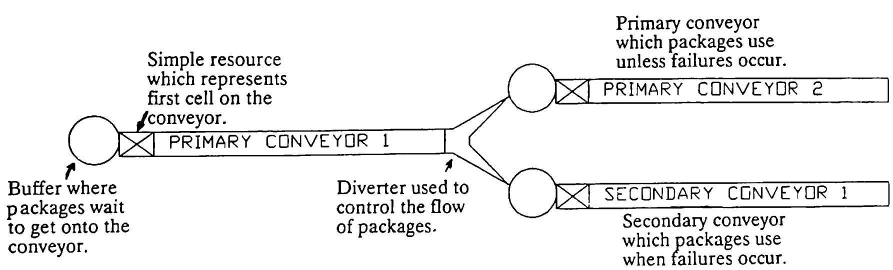

Figure 1. Conveyor Representation

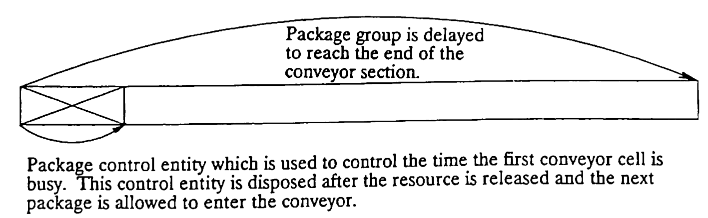

Figure 2. Conveyor Cell Control

Another option for modeling this area would have been to use the package group to control both the physical and control areas of the model. When a package group accesses a conveyor (and has control of the constrained resource), it is delayed for the amount of time to traverse the first conveyor cell. After its delay, the package group releases the resource so the next group can access the conveyor. The package group is then delayed for the remaining amount of time to reach the end of the conveyor (total time on the conveyor minus the time to traverse the first conveyor cell). This method was not used because of the additional calculations involved in the delay times for the package group and for graphical animation reasons.

The constructs developed had a number of advantages and disadvantages listed below.

Advantages:

1) Execution time of the model is relatively fast. By avoiding the use the conveyor constructs to model the thousands of individual conveyor cells, computations were reduced greatly.

2) Simulation model code is reduced because of the ability to use a "macro" concept for all conveyor segments. The "macro" concept simply refers to multipurpose generic code modules. See [Pegden et al. 1990] for details.

3) Conveyors are accurately represented, along with capacities and failures.

Disadvantages:

1) Conveyor failures require several assumptions. Methods for handling conveyor failures had to be developed.

2) Grouping of objects may have caused the simulated system to perform slightly differently than the actual system. For example, the 1st package was delayed on the conveyor until the total package group of 10 arrived at the destination point.

3) Methods for capturing conveyor utilization had to be developed. Conveyor utilization in the case study simply recorded the average number of packages on each conveyor. By virtue of the conveyor length, the average packages per foot were determined.

The method of defining the entities and conveyors was one key to successfully modeling such a large distribution system. The second important factor was properly representing the control of the diverters in the system to direct the packages onto the proper conveyors.

6. DECISION LOGIC OF THE SYSTEM

In constructing the model, a great deal of logic was needed to control the flow of material on the conveyor segments. Control logic was necessary for changing the package routing from one conveyor to a different conveyor in the case of conveyor failures, conveyor overflows and buffer balancing.

At the end of each conveyor segment, there is a diverter which is used to change the routing of packages from one conveyor to another conveyor (Figure 1). Each diverter has an original "primary" setting to send packages down a "primary route" towards a specific buffer area. Based on the status of the system (for example, full buffer areas), conveyor failures or over capacity flows, the diverter position is changed to send packages down a "secondary route". The diverter remains in the "secondary" position until the status of the system changes to allow flow of material down the original "primary route" conveyor.

7. CONVEYOR FAILURES

Breakdowns should be considered when modeling conveyor systems. The flow of material during a conveyor breakdown can be handled in several different ways.

Material which is currently on the conveyor when a breakdown occurs may remain on the conveyor until the breakdown is repaired. This would occur if conveyor constructs were used.

When standard conveyor constructs are not used, a different method of handling conveyor failures must be devised. As described previously, a resource is used to regulate the flow of material onto each conveyor entry point. During a conveyor failure, the constrained resource controlling the entry point must become unavailable. When the conveyor entry point resource is not available (i.e. during a failure), packages must be routed onto a "secondary" conveyor. This alternative routing requires special diverters and must be modeled appropriately, as described below.

When a conveyor segment fails, packages intended for that conveyor are routed elsewhere to minimize the backup at the beginning of the failed conveyor. Diverters located at the end of each conveyor were used to reroute the packages onto a "secondary" conveyor. If packages are not rerouted onto a different conveyor, the buffer at the beginning of the conveyor will increase, causing a back up on the preceding conveyor. When the failed conveyor is repaired, the diverter is switched back to its original "primary" position and packages begin to flow down the repaired conveyor.

Once a package group has entered an operational conveyor, it is delayed until the time to exit that particular conveyor segment (i.e. "physical object"). Therefore, a package may not actually control a conveyor cell resource at the time of the conveyor failure. Because the conveyor segment lengths are relatively small, the material on the conveyor (currently travelling to the conveyor exit points) at the time of a breakdown is considered negligible. The package groups on the conveyor continue to be delayed until they reach their destination point.

8. FINAL BUFFER AREAS FILLED

Materials flow on high volume conveyors from various input areas to one of several final buffer areas. Flow of material into each of the buffer areas is regulated to balance the number of packages in each area. This balancing allows the maximum throughput out of each buffer area.

To balance the flow of material evenly between the buffer areas, the level of material in each buffer area is monitored carefully. Flow of packages to specific areas can be minimized or eliminated by the changing of diverter positions at many of the conveyor segments from a "primary route" position to a "secondary route" position. This causes material to be routed on different conveyor paths in order to balance the buffer areas.

Each diverter point at the end of a conveyor was associated with a particular buffer area. In balancing these areas, the diverters associated with the most full buffer areas were switched to reroute packages to "secondary" package routes. The diverters were modeled with a simple "flag" that designated the conveyor ("primary" or "secondary") onto which the packages would flow. When a buffer area became full, the diverter "flag" was changed from the "primary route" position to the "secondary route" position until the area became less full, at which time the "flag" was returned to its original position.

9. OVER CAPACITY FAILURES

Each conveyor segment in the simulation model has a given capacity (packages per hour). If the flow of packages onto a conveyor segment is such that the capacity is exceeded, a failure will occur. There are many instances in the conveyor system in which two or three conveyor segments merge into one conveyor segment. If the rate of packages exiting the conveyors which merge into one conveyor is more than the receiving conveyor capacity, a failure will occur at the receiving conveyor. This failure will then cause the diverter at the receiving conveyor to switch into a "secondary" position, rerouting the packages to a different conveyor segment, preferably one with greater capacity.

For example, conveyor "A" and conveyor "B" merge into conveyor "C". If the flow of packages from conveyors "A" and "B" is 10,000 packages per hour for each conveyor, the capacity for conveyor "C" must be at least 20,000 packages per hour in order to handle the load.

10. COMPLETED MODEL

The model code and many details of the Federal Express application described in this paper are confidential. The simulation model has been used at one of the Federal Express facilities to evaluate how the conveyor system reacts to unexpected conveyor failures and overflows.

The model was developed in such a way that analysts are able to easily modify decision logic for package routings in the conveyor system. Thousands of packages each night are sorted through the actual system in a matter of hours. Decisions related to where packages are routed should failures or overflows occur normally happen instantaneously with no realization of what the decision might impact further along the conveyor system. Because timing is crucial in the actual sorting system, the wrong decisions for sending packages onto "secondary" conveyors could have serious financial implications.

A graphical representation of the simulation model was also developed to allow analysts to easily evaluate how changes in package routings impact the total flow of packages in the system.

11. SUMMARY

This paper examined five options for modeling high volume conveyors. Each of the five options were explained and the advantages and disadvantages of each option were noted. A high volume conveyor sorting system at a Federal Express facility was used to illustrate how one modeling option has been successfully implemented. The option selected required unique conveyor constructs be developed. These constructs provide all of the control of the physical system and make the model efficient from a computer memory and execution speed standpoint.

The application examined at Federal Express is currently being used by their project engineers to evaluate responses to conveyor failures and over capacity issues. The results of these studies will help Federal Express react quickly to problems and maintain their superior door-to-door commitments to their millions of customers.

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