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T.I. Ören, C.M. Delfosse, C.M. Shub (Eds.)

A GENERALIZED MODEL AND SIMULATION ANALYSIS OF A MULTIPLE PARALLEL CONVEYOR SYSTEM FOR FLEXIBLE MANUFACTURING

Dr. William Biles
Professor and Chairman
Industrial Engineering Department
Louisiana State University
Baton Rouge, LA 70803

Mr. Eugene Y. Yang
Systems Analyst
The Procter and Gamble Company
Cincinnati, OH

This paper describes a simulation modeling tool for experimenting with alternative configurations for parallel conveyor systems. Incorporated into this simulation model are "degrees-of-free" routing strategies that enables system flexibility in the case of stochastic machine jamming and equipment failures.

1. INTRODUCTION

The costs in designing, building, and maintaining a large-scale manufacturing system are rising prohibitively. There is, therefore, a strong need to explore and develop system "flexibility" in maintaining desired levels of system utilization. An area for examination is in the vital material handling component of the system. With manufacturing systems becoming more complex, the increasing system utilization burden will fall on the material handling component to provide, maintain, or divert, the flow of materials to the necessary sectors of production.

This paper deals with this problem from two perspectives. Not only is a computer simulation modeling tool developed for experimenting with alternative multiple parallel conveyor line configurations, but also incorporated in the model are "degrees-of-freedom" routing strategies to provide system flexibility in the event of stochastic machine jam and equipment failures.

1.1 Flexibility Manufacturing

The term "flexible manufacturing" used in the title is somewhat of a misnomer. It implies a machine, or system of machines, of a high-technology nature, incorporating computer-numerical controls, to manufacture large volumes of a variety of precision-machined parts at minimum setup times and cost. Thus, the machine, or system of machines, has the ability to readily and quickly adapt to manufacture a variety of parts, regardless of volume -- hence being "flexible".

"Flexibility manufacturing", on the other hand, deals with a manufacturing system's ability to adapt to failures in system components. The system itself produces high volume, low variety parts. Suppose a machine of the system fails. Usually, the machine is considered "down", and then is not used until a "repair" period has elapsed and startup occurs. However, suppose the system "sensed" the failure. Through gates and routing strategies, parts to and from the failed machine could be diverted to a like machine that is operable. Though idle time still occurs, a significant increase in the system utilization results, due to the "flexibleness" of diverting parts away from the failed machine. This is the "degrees-of-freedom" concept; through routing strategies, with backup components, a system can be flexible to accommodate failures in individual system components in order to maintain a desired throughput.

1.2 Literature Survey

This paper presents a simulation model of a material handling conveyor system with routing strategies for flexibility manufacturing. The literature cited in the References encompasses the areas of previous conveyor modeling techniques, research in degrees-of-freedom techniques, review of manufacturing computer simulations, and an update on manufacturing simulators and languages.

Conveyor Modeling

Conveyor modeling has taken two distinct paths. Muth and White (1979) have indicated that analytical models and largescale, general purpose simulation models are the two areas of work.

Kwo (1958) provided the underlying principles and theory in analytical conveyor modeling. He stressed that the conveyor is part of the system, and should not be considered as an isolated object independent of the areas it is linking together. Analytical models inherently examine simple systems. But this simplicity goes far in explaining the fundamental relationships of the conveyor parameters, such as speed, length, spacing of carriers, and material flow rates.

General-purpose simulation models, on the other hand, do much for explaining actual systems, their complexity, and the tradeoffs needed for design and/or present operating characteristics.

A basic model, as seen by Muth and White (1979) and Kwo (1958), deals with the explanation of a single source (loading point) connected to a single sink (unloading point) by a conveyor. Typically, there is just one loading station at the source and one unloading station at the sink. A variation of the basic model is the loop (recirculating) conveyor.

Multiple conveyor lines have been tried. However, this "multiplicity" is merely a duplication of a prime conveyor line, meaning each line is independent from any other.

Degrees-of-freedom Flexibility Manufacturing

Degrees-of-freedom flexibility manufacturing is essentially the ability of a manufacturing system to utilize as many system components as possible in case of failure in one or more components. Gershwin et al (1978) have identified the need for flexibility within a system when machine failures occur. Their present solution to increase flexibility is to include finite-sized buffers prior to work stations. The buffers then increase production rates and machine utilizations. However, the "buffered" system is still inflexible and, though a need is identified, no solutions are offered for attempting routing strategies.

Review of Manufacturing Simulations

Computer simulations have been performed to explain the material handling aspects of manufacturing/production situations. This section reviews different types of manufacturing simulations. All simulations were programmed in some type of simulation language, as in GASP-IV, GPSS-V, or SIMSCRIPT II.5.

Material handling equipment is, for the most part, an important component of a total manufacturing/production system. Therefore, simulators have been developed to explain the complex interface between material handling systems and production equipment. Biles, Guild and Enscore (1980) discussed the modeling and analysis of automatic transfer lines. Their simulation studied the effects on throughput of the operational characteristics of machines or work stations; operational characteristics of material handling and offline storage components; failure and repair of equipment; and automatic inspection of workpieces. Biles, Enscore and Pegden (1980) simulated a production line system. They indicate that further studies on the impact of equipment breakdown in the material handling component are needed. They propose the use of parallel equipment to serve as backup to the most unreliable equipment on line; however, no commitment was made as to how this may be modeled. Zimmers and Brinker (1978), Reasor, Davis, and Miller (1977), Siebauer (1979), Schruben and Moser (1978), all simulated production line systems involving discrete simulation techniques. The linking factors of these latter simulations were that the material handling component was implied (items were assumed to move from one station to the next); no stochastic failures were introduced; and the various system components' production rates, buffers, unit numbers, could be altered to examine a new configuration.

Another aspect of material handling is with storage/retrieval systems. Heimburger (1973) discussed a generalized simulation model for transporting highvolume, lowcost consumer cased goods from packaging to warehouse. Multiple dependent conveyors were illustrated by having a single merging conveyor fed by two or more packing lines. Also included was the activity of control gates that allow alternating entry of cases from two different packing lines onto a merging conveyor. Warehousing simulations by Waugh and Ankener (1974) and Douglas, Mazzaro, and Myers (1978) discussed not only the development of the model logic to explain equipment operation, but also the routing strategies for storage and retrieval of an item.

Finally, there are generalized simulation models that examine the actual material handling sytem. Biles (1978) developed a generalized model to select material handling alternatives. His model has the capability to select any number of conveyors, monorails, tranfer machines, and accumulators; place them in a desired system configuration, and determine a result. The result was obtained by simulating machining operations, failures and repairs of machines, tool changes on production machines, etc. Karg et al (1979) examined various batching schemes for a particular batching conveyor configuration.

Review of Manufacturing Simulators

Manufacturing simulation languages have been developed to model and simulate a variety of material handling configurations. The configurations may or may not interface with a production set-up. All the simulators are discrete simulators. The philosophy is to provide a would-be modeler with the tools to design one or more material handling configurations easily. Typically, a network-graphics depiction is the visual aid to assist in assigning the various components their proper locations. The main difference these simulators have from a manufacturing model is that the simulators have been developed with their own distinct modeling framework; the simulations discussed earlier, on the other hand, relied on an outside simulation language to provide the modeling framework.

DYNAFLO, a manufacturing simulator developed by Wilson et al (1978), uses network flow modeling techniques. The simulator is essentially analytic in nature, and thus no provisions are made to insert probabilistic machine cycle times or equipment failure rates.

GEMS (Generalized Manufacturing Simulator) developed by Phillips et al (1978), is the most complete simulator to date. While providing the user with a network-graphics depiction for easy layout, the activity-in-box capabilities allows the user to model flow of materials through complex manufacturing systems. It provides stochastic machine cycle times, conveyor travel times, and in-process buffer storage. This language, however, requires the user to learn a certain modeling technique for programming.

GALS (Generalized Assembly Line Simulator), is a simulation tool for laying out a production or assembly line. The depiction, again, is by using network-graphics. Developed by the IIT Research Institute, the main advantage is that the user needs no previous modeling or computer experience. However, the material handling equipment is implicitly used.

INDECS (Integrated Description and Evaluation of Conveyorized Systems), is also a development of Wilson (1977). This program is an aid in the design and flow of conveyorized facilities for discrete items. The unique aspect of this simulator is that it provides a data base structure (library) of modelled material handling components. INDECS was developed prior to DYNAFLO and is rather archaic in comparison. INDECS places much of the modelling and programming burden on the user.

PROSIM W, developed by Kroll (1974), is a production system simulator geared to simulating a multi-line shop environment. It was developed primarily as a tool to aid students in understanding the interface between production and inventory.

The thrust of this paper is in simulation modeling, and for several reasons. Muth and White (1979) admit that analytical techniques only express the relationships of a conveyor line in simple systems. Also, analytical techniques do not provide for stochastic failures and repairs of equipment. Simulation, on the other hand, provides a powerful tool for coming close to duplicating the operations of an actual system.

Finally, the literature cited has examined the exploration and development of work in flexibility manufacturing. Though Gershwin et al (1978) touched on the subject, storage buffers were used to increase "flexibility", but in essence were only "buying time" for the failed machine. Biles et al (1980) mentioned using backup components of high-failure machines as a solution, but offered no specific design to accomplish this feat.

The objectives of this paper are then:

(1) To develop a model of a multiple parallel conveyor system.
(2) To include stochastic failure and repair times of system components.
(3) To give the model "degrees-of-freedom" routing strategies to increase flexibility and overall system efficiency.
(4) Develop a generalized simulation model.
(5) Make the model user-oriented and portable for computer systems with like compilers.

2. THE MODEL

Conveyor modeling, in the past, involved three components: a single source, connected to a single sink, by a conveyor. A source is an entity that provides input to the system. A sink is an entity that enables items to exit from the system. Typically, both the source and sink have only one opening to the conveyor. An example of this configuration is a packaging line. At the source, items are wrapped and placed on a conveyor. The conveyor transfers the wrapped items to the sink. The sink then places the items into packing cases.

This modeling configuration works well for analytical means. Developing a more generalized model to include a conveyor lines produces only a system of <u>independent</u> conveyor lines. This model is not flexible enough. It cannot have multiple sources or sinks servicing one conveyor, nor allow any particular source (or sink) to have multiple openings. Also, little has been done in considering the effect of component failure. The modeling so far only indicates that, when a component fails, the particular line of the failed component is "down", and will not be useful again until the component is reactivated.

This paper addresses those problems by developing and analyzing a generalized model for a flexible multiple parallel conveyor system. The system will consist of parallel conveyor lines, with each source and sink (per line) having multiple openings to their respective line. The sources and sinks will have access to all the conveyors of the system; that is, items should have the flexibility of moving from one conveyor to the next, in case of line overload or failure. To insure continued production, in a case of source failure, a "surge" (redundant) source is to be present, substituting at the failed source's conveyor. Figure 1 shows the overall system configuration.

2.1 Description of System Components

The overall system essentially consists of these major components: parallel conveyors, sources, and sinks. In addition, three components contribute to system flexibility: transfer accumulators, redundant (surge) sources, and control gates.

<u>Parallel Conveyors</u>

The basic foundation of the system is that it consists of parallel conveyors. At no time are the conveyors allowed to cross (i.e., form an intersection). Each conveyor may vary in length

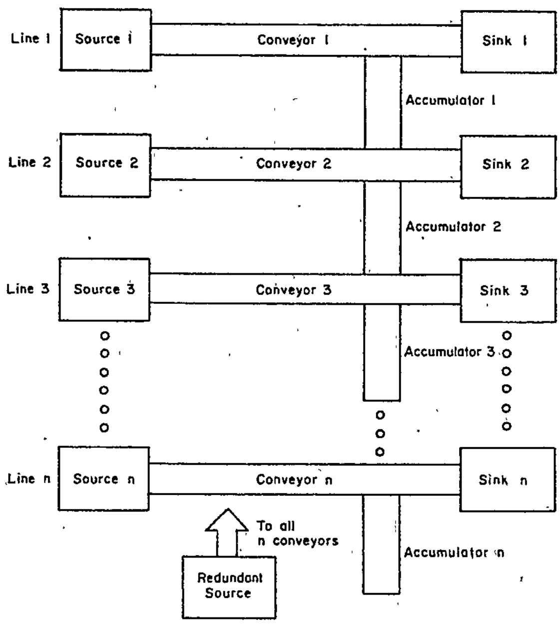

Figure 1. Conveyor System Configuration

and speed from its neighbors. Each conveyor is assigned an exponential probability of reliable service.

Sources

There is designated one source per each conveyor line. Each source may have k_i openings to the conveyor, where i(i=1,2,...,n) is the identity of the particular conveyor. This produces a more uniform placement of discrete items on the conveyor. The input rate can vary from one source to the next. Sources can fail two ways: jam failure caused by poor product quality, and machine failure caused by a faulty internal mechanism. Failures are determined by exponential and normal distributions. If a source's conveyor fails, the source will have the capacity of providing product to another conveyor until its own conveyor is repaired.

Sinks

There is designated one sink per each conveyor line. Each sink may have m_i openings to remove items, where i(i=1,2,...n) is the number of the particular conveyor. This is for the situation where a unit package of items is desired. The sink also fails by two ways: jam failure caused by poor product quality and machine failure caused by a faulty internal mechanism. Failures are determined using exponential and normal distributions.

Transfer Accumulators

For every conveyor line, there is an associated transfer accumulator. Though a transfer accumulator is a conveyor, it does not have a source or sink. This type of conveyor transfers materials from one conveyor section to another. In doing so, the materials tend to "accumulate". In this model, the accumulators are used as bridges, or spans, between conveyor lines. The accumulators are assumed to have the capability to match speeds with the conveyor they are receiving items from and with the conveyor they are putting items onto. The accumulators are also assumed never to fail and of infinite size (they accommodate as many items as would the conveyor).

Redundant Source

There is one redundant source designated for the system. This source also has, as variables, input rates and number of openings to the system. The redundant source operates either on an "infinite-serve" basis or a "first-come, first-serve" basis. By "infinite-serve", no matter how many main sources fail at a given time, the redundant source can provide product to their respective conveyors. A "first-come, first-serve" basis means that the redundant source can only provide product at one conveyor at a time, regardless of the number of main sources down. The redundant source also is assumed never to fail and also has an infinite capacity to provide material to the system. The redundant source can be placed anywhere along the conveyor so long as it is upstream from the sink.

Gates

Gates are employed in this model to control the flexibility flow of product, say, from one conveyor to an accumulator to another conveyor. Figure 2 shows the gate activity for the redundant source. The redundant source has two positions, as shown. The closed position is when the conveyor is operating normally. The gate then "opens" when there is a source failure. Figure 3 shows the gate activity for the accumulator. The accumulator has two gates per each conveyor, acting in conjunction with each other. Gate A has two positions, where the "open" position is for transferring items from conveyor to accumulator. Gate B has three positions. "The "(+)" indicates the gate's position when passing items from accumulator to conveyor. The "(-)" indicates the gate's position when moving items from conveyor to accumulator.

2.2 Process Scenarios

The following are descriptions of process situations where the system adapts to circumvent component failure to insure continuous production. Also included are descriptions for multiple opening-batch input schemes.

Source Failure

A source fails in either two ways: by being jammed by poor product or by an equipment failure. When the source is jammed, it is made inactive. The time for start-up is determined by a stochastic

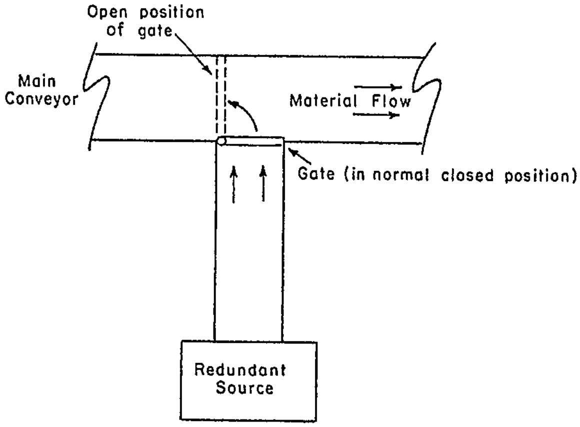

Figure 2. Redundant Source Gate Activity

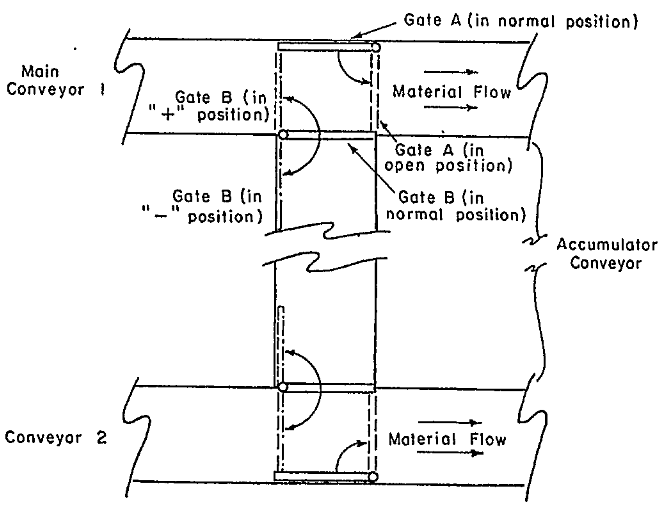

Figure 3. Accumulator Gate Activity

distribution. If this "repair" period is longer than a desired mean time, then the redundant source is activated. For a machine failure, the source is made inactive, and the redundant source is immediately activated.

Sink Failure

There are two scenarios for sink failure. As mentioned earlier, there are two ways for the sink to fail: by a product jam or by an equipment failure. In the case of a jam failure, the conveyor line stops until the jam is cleared. Both the source and conveyor are stopped until the sink is cleared to start again. However, for equipment failure, a complex procedure occurs, as follows:

1. The sink fails due to machine failure.
2. The downed sink's source is set inactive.
3. The materials on the downed sink's conveyor are transferred into that conveyor's accumulator, forming a "slug" of materials.
4. An alternative sink is chosen. Its source is made inactive. Thus, a "slug" of materials is formed on the alternative sink's conveyor.
5. The slug on the alternative sink's conveyor is processed first.
6. When the last item is processed, the slug from the accumulator is processed by the alternative sink.
7. When the last of these items are processed, both the downed sink's source and the alternative sink's source are reactivated.
8. The subsequent first item on the downed sink's conveyor reaches the accumulator entrance. A "signal" is sent to shut off the downed sink's source. On the alternative conveyor, the first item reaches the accumulator entrance, thus shutting off the alternative sink's source. Therefore, slugs again are formed on the two conveyors.
9. The alternative sink processes its slug first. When the last item is processed, the slug from the accumulator is processed.
10. This "switching back-and-forth" continues until the downed downed sink is repaired and made active.

Conveyor Failure

The conveyor is the heart of each conveyor line. When it fails, the source and sink are paralyzed. In conveyor failures, then, the source is rendered inactive, and then the conveyor is set inactive. The sink may be allowed to remain active; however no product is arriving.

Multiple Openings Schemes

An added feature of the model is that every source and sink, including the redundant source, may be modeled to include multiple openings. This is to provide the batch input/output situations desired in some packaging/ manufacturing situations. In multiple openings, the item enter or leave the system one of two ways: batch mode ("tandem" fashion) or in a sequential mode (deposited one after the other, single file). With the batch mode, items can be deposited initially in an "minislug" or collected sequentially into blocks and then deposited.

3. THE SIMULATION

Simulation was the chosen tool of describing the aforementioned model because it deals with explaining the interactions of the components of a system. A system philosophy usually evolves into a model of high complexity, and simulation provides a procedure for defining and analyzing the model for experimental problem-solving. This paper has described a model that uses conveyors to link two areas of manufacturing together. This model focuses on discrete items being transported; thus, a discrete-event simulation technique is the underlying philosophy.

The simulation is to be performed using the digital computer. A user, if he is so capable, can develop a simulation scheme that controls his simulation model, but that is usually too complex a task and tends to distract him from his more important task of simulating a system. There are several simulation languages available, such as GPSS-V, GASP-IV, and SIMSCRIPT II.5.

GASP-IV was selected for this simulation because it:

1. Reduces the programming task by using the simulation language program for event filing, data storing, etc.
2. Provides conceptual guidance by forcing the programmer to identify system entities to be simulated, the attributes of the entities, and the event that takes place.
3. Allows flexibility for changing user input without requirint total program examination.
4. Is easy to learn, well-documented, highly flexible, requires little user maintenance, and written in well-documented language of FORTRAN-IV.

3.1 Simulaton Modeling Concepts

A strong advantage GASP-IV has is that it forces the user to identify and define specific, fundamental simulation concepts when modeling a system. These concepts are as follows:

1. Entities
2. Attributes
3. Activities
4. System State
5. Files
6. Events

Entities

The entities of the system are sources (input machines), conveyors, sinks (output machines), redundant source, transfer accumulators, control gates, product items, inspectors and repairmen (implicit).

Attributes

Attributes were chosen from the perspective of each individual product item. Hence, the attributes of an item are the conveyor the item is on, its relative conveyor position, its quality, time-of-arrival, source/sink opening number, and positional flags (for "last item" assessment).

Activities

These are the processes the entities engage in. Generally, in simulation, these are represented by the time it takes to "perform" an activity. For instance, the process of moving an item from one discrete conveyor position to the next involves a certain time period, indicated by the speed of the conveyor. Other activities include repair and failure, item removal from system, and placing items on the conveyor.

System State

The condition of the system, at an instant in time, can be represented by system state variables. These variables usually operate in a "go-no go" fashion. The following is a list of the state variables:

Variable	Description
IBAD	Incoming product quality
JBAD	Outgoing product quality
JSORC	Source machine status
JSINK	Sink machine status
JRED	Redundant Source Status
MON	Accumulator operating status
JCONV	Conveyor status

Files

Files are needed in simulation for storing data, entities, attributes, etc. Files were used in this model to describe accumulators, storage arrays for downed conveyors, and storage arrays for batch input/ output. (For GASP-IV, the event file is always File 1. Files 2, 3, ..., n are user defined.)

Events

Model behavior and process, in discrete simulation, is described by events -- instances in time where activities involving any number of entities occur. The following is a description of the events (subroutines in GASP-IV) that define the model.

3.2 Further Description of Events

ARCON

This is the arrival to the conveyor event. Items arrive to the conveyor either from a main source or the redundant source. Before an item is allowed to enter, this event asks the following questions:

1. Has the conveyor failed? (If so, stop the input.)
2. Will the incoming item jam the source? (If so, schedule source failure event.)

3. Is the item input from a main source a redundant source?
4. Has the source failed?
5. Is the accumulator operating?
6. Has the conveyor's sink failed?
7. Are there multiple openings in the source? If so, is the item input batch or sequential?

This event contains the logic for "boot-strap" entity creation, multiple opening operation, and "last item flagging".

ARPOS

This is the arrival to the next discrete position event. The main operation of this event is to move an item, in discrete steps, down a conveyor. Since this event is concerned with conveyor movement, it also must monitor the locations, or relative positions, of the redundant source entrance to the conveyor and the accumulator entrance to the conveyor. This monitoring of the locations is called making "position checks". This event is also important because it contains the logic to control the switching-flexibility in the event of sink machine failures. Finally, a check is made on the multiple openings of the sink, where it must be decided to load sequentially or by batch.

DPCON

This is departure from the conveyor event. The purpose of this event is to remove items from the system. Checks are made on the sink status, the item quality, and if the sink has multiple openings. Also in this event, the time in the system by an item is recorded. For multiple openings, the items either leave via batch or sequential modes. For sink failures (due to jams), the failure of sink event is scheduled to occur. Finally, a check is made for when an item is coming from either a main source or redundant source.

FAILR

The failure of source event records and shuts off the conveyor line source. A determination is then made on the cause of failure: jam or machine breakdown. If the failure was caused by a jam, then the source is scheduled to start-up after an exponential repair period. If this repair period is longer than a desired mean repair period, the redundant source is then scheduled to operate until repairs are "complete". For a machine failure, the event ARCON is scheduled to occur so that the last item out of the failed source may be "flagged". This "flagging" technique indicates to the redundant source that there are no items behind the flagged item, thus allowing product from the redundant source to enter the conveyor.

START

The source start-up event activates the source after a repair period. If the redundant was being used, it is deactivated at this time. ARCON is scheduled to allow items to arrive from the main source. If the failure was due to a machine breakdown, then the next machine failure is scheduled by using an exponential distribution.

REDSO

The redundant source event is concerned with placing items on the conveyor from a redundant source in case of source failure. This event distinguishes between a "infinite-serve" capability or a "first-come, first-serve" capability. Batch or sequential input logic exists for multiple openings situations. The redundant source, in the case of machine failure, schedules the machine start-up (START), based on an exponential distribution.

SINKF

This is the sink failure event. Remember that the sink can fail one of two ways: jam or machine breakdown. A check is made to see if the sink is already down. This is in case of the situation where the sink is jammed, and during cleaning, the machine breaks down. The type of failure is determined. If the failure is jamcaused, the conveyor is stopped and a sink startup is scheduled. For machine-caused failures, a search is performed to locate an alternative operating sink. If there is no alternative sink, the items are placed in an accumulator until a sink is available or the failed sink is repaired. A sink start-up is also scheduled.

SSINK

The sink start-up event reactivates a failed sink. If the failure was jam-caused, the conveyor was stopped. In this event, the conveyor is reactivated. The accumulator of the now-repaired sink is checked for items. If the accumulator is full, the items are processed by the now-repaired sink. A check is made to see if other accumulators are full. If so, the repaired sink now becomes an alternative sink to the next full accumulator. If the failure was due to a machine breakdown, then the next machine failure is scheduled.

ACCUM

The accumulator event models the operational characteristics of the transfer accumulator. Items have already been placed in the accumulator during the ARPOS event. The accumulator is activated, and the items are removed from the accumulator to be processed by an alternative sink. The source of the downed sink and the source of the available sink are both scheduled to be activated when the last item from the accumulator is processed.

CONF

This is the conveyor failure event. The conveyor is set inactive, as well as its source. Since the conveyor is "stopped", the items on the conveyor need to be placed in a holding file until the conveyor is reactivated. The conveyor start-up is then scheduled at some exponential time in the future.

CONUP

In the conveyor start-up event, the conveyor is reactivated. The source of the conveyor is also reactivated. Since the conveyor is started, the items are removed from the holding file and rescheduled on the repaired voneyor. The next conveyor failure is then scheduled at some exponential time in the future.

4. SUMMARY

This paper has dealt with presenting a particular material handling model that has built-in alternative strategies to increase system utilization. This multiple conveyor model, because it is generalized, can examine any multiple conveyor scheme involving the routing strategies for any number of conveyors, of varying lengths, speeds, with different input and output rates. Further, the model gives a semblance of reality by using probability distributions to represent failure and repair times of the various system components. This conveyor model, then, is a tool in providing an analyst with a "feel" of a complex, multiple component system. And, in the long run, it is an inexpensive tool for exploring alternative configurations of the material handling system.

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