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Simulation of discrete conveyor systems

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Abstract

Most of the conveyors that appear in simulation models tend to be fairly simplistic. The conveyor only provides a means of moving an object from one place to another. It is driven by a single speed motor and very little, if any, control logic is applied during operation. A number of objects or products can be conveyed in this manner with no difficulty. For example, boxes, kitting tubs and pallets of bricks are all relatively sturdy and relatively insensitive to damage. In fact, the conveyor system may be designed such that the objects touch or accumulate at a given station. The flow of objects through the system is also important. If there is a momentary stoppage in the system, the input of objects to the system may be interrupted so that saturation is avoided.

However, what if the product is very sensitive to damage and input to the system cannot be temporarily interrupted? Such a system requires a high degree of control over the operation of the individual conveyor sections. In order to develop a control philosophy and thereby shape the simulation logic, we must first understand the constraints of the product and how it is produced.

We all know that glass is naturally fragile. Excluding breakage, the product may be rendered useless due to edge damage or surface damage. Edge damage occurs when adjacent pieces collide. Usually both are damaged beyond usefulness. Prevention of these collisions means that only one piece can occupy our smallest, definable control unit. In this case, the smallest, definable control unit is one conveyor section. Surface damage is due to abrasion. This is caused by relative motion between the piece and the conveyor. In practice, the constraint must be that adjacent conveyors must be running at the same surface speed.

Using the previous two concepts as a foundation, we can develop control logic, and therefore simulation rules and constructs to deal with specific problems. Some of these problems are: right-angle transferring, equipment that necessarily runs at something other than line speed and increasing the separation between adjacent pieces. Sample simulation code will be presented in GPSS/H. The reader is invited to implement the constructs in other simulation languages.

Operational Philosophy

At the beginning of any manufacturing project, objectives must be established to guide the overall direction. In our business, these objectives are usually:

a) do not induce bottlenecks by design

b) do not damage the product during transport through the system

C) preserve the ability to function well with widely varying product dimensions

d) consistency in logic design

One of the most important aspects of simulation is to be able predict system behavior. Analyzing these process systems before construction has made considerable difference in the duration of the start up phase and continued smooth operation.

Multiple Line Speeds

Some systems necessarily contain machines that are restricted in speed range. The restrictions may be due to high energy consumption and/or residence time requirements. For example, a number of automotive glass processing lines use drying ovens as an intermediate step in a two-part printing procedure. After the first print procedure, the paint must be thoroughly dry before the second print procedure can occur. Since the paint may be damaged by a rapid increase in temperature, a gradual temperature rise is desired. To achieve a satisfactory residence time that will insure that the paint is dry requires slow movement through the dryer. This speed, (about 400 in/min), is much slower than the usual line speed of the rest of the conveyor system, (about 1,500 in/min).

We have stated that surface damage due to abrasion may result if there is relative motion between the glass and the conveyor. Figure 1 shows the arrangement of conveyors at the entrance and exit of the dryer. All of the conveyors have single speed drives. As the piece enters the dryer, it will partially reside on the entrance conveyor and partially on the dryer conveyor. Since the two conveyors are running at different speeds, the resultant speed of the piece will be continually changing until the piece is entirely on the dryer conveyor. Relative motion occurs and damage is possible.

The solution to the problem is to remove the relative motion problem by matching the speeds of the conveyors. This requires that the drive system of the entrance conveyor be capable of two speed operation. Figure 2 shows the revised system.

Now that we have the physical arrangement of the system, the control logic must be determined. As the piece moves along the entrance conveyor, at some point the speed must be changed to match the dryer speed. If the piece is allowed to tail onto the entrance conveyor at the high speed, the speed may be shifted to the slow setting. The piece then crosses the entrance conveyor at dryer speed and then enters the dryer. Although we have accomplished our objective of no relative motion, this is not the complete solution. Since we desire to eliminate relative motion, we cannot allow the next piece to move onto the entrance conveyor until the section returns to high speed. When the tail of the piece clears the entrance conveyor, then the conveyor may be shifted into high speed. If the time that the entrance conveyor spends running at the slow speed is greater than the spacing between pieces, then we may choose to run the piece at high speed until the leading edge reaches the end of the entrance conveyor. This will minimize the time that the section is occupied. The entrance conveyor speed is then shifted to match the dryer speed. The sample GPSS/H code is given in Figure 3. Note that the DRYENTR conveyor is not released as soon as the piece starts to move onto the DRYER conveyor. If the next piece were allowed to enter the DRYENTR conveyor at this point, the conveyor would be running at the wrong speed.

Right-Angle Transferring

Since some of the manufacturing lines may allow multiple product types or multiple sizes in the system at one time, it follows that all of the pieces do not have to have the same destination. We may choose to transfer pieces off the main system to a spur for some specific processing. Figure 4 shows a typical main conveyor system and spur leg. The "A" pieces are to be transferred out to the spur leg and the "B" pieces continue straight through the system.

In this case, the transfer conveyor is constructed with rolls in the straight through direction and pop-up belts between the rolls that lift and convey for the transverse direction. While the belts are raised for a transfer, the transfer conveyor is unavailable for use by another piece. The trailing edge of the transferred piece must be off the belts before the belts may be lowered. Time to raise and lower the belts is also included in the delay.

On the surface, this situation seems to be relatively simple. However, the complication is that there are two events that must occur in parallel. The movement of the piece on the transfer exit conveyor is coincident with the lowering of the transfer belts. The sample GPSS/H code in Figure 5 shows the appropriate logic. According to the mechanics of the language, a facility may only be released by the transaction that originally seized it. Therefore, as the code illustrates, the parent releases the TRANSFER conveyor and is terminated; the offspring assumes the identity of the parent and continues through the system.

Inducing a Separation Between Pieces

When raw flat glass is manufactured, it is made into a continuous ribbon. As it moves, it solidifies and hardens during cooling. After cooling, pieces are cut away from the contiguous ribbon. Since edge damage results when two pieces touch, we must induce a separation. Once again, two speed conveyor sections may be used to create the desired effect. However, conveyor section size has a considerable impact on system operation.

Figure 6 shows roll positions around the breaker bar area. A score line has been previously placed on the glass. As the score line moves over the breaker bar, the breaker bar rises and glass breaks at the score line. The contiguous ribbon moves at 500 in/min. When the desired piece is broken away from the ribbon, it is accelerated to 1000 in/min. At this point, the size of the conveyor downstream comes into play. Suppose the length of this section is 24" and the roll spacing is 12". The time required to tail off the section at 1000 in/min is 1.44 seconds. At this time, the section may return to the slow speed. However, the leading edge of the contiguous ribbon travels 6" in .72 seconds to reach the next conveyor roll. In order to avoid surface damage, the section should return to the low speed. However, the section cannot accept another piece since it won't be able to change speeds for an additional .72 seconds. The conclusion is that the 24" section after the breaker is too long.

Suppose we resize the conveyor section to 6". This means that the section contains only one roll. Repeating the calculations as above, at 1000 in/min, .36 seconds is required for the piece to tail off the section. As before, the leading edge of the ribbon travels the 6" in .72 seconds at 500 in/min. Therefore, .72 seconds - .36 seconds leaves an excess of .36 seconds to allow for acceleration and deceleration of the roll. By this method we may induce a spacing between the pieces as they enter the remainder of the conveyor system.

For completeness and to add one more data point, the time to tail of a 12" section is .72 seconds. Assuming instantaneous acceleration and deceleration, the section would return to slow speed just as the leading edge of the ribbon arrived.

Intuitively, we can see a pattern emerging. If the ratio of high speed to low speed is 2:1, then the length of the conveyor section can be no longer than two times the distance the leading edge of the ribbon travels to reach the beginning of the next conveyor section. Since the time required to accelerate and decelerate the conveyor should be included, in reality the length should be slightly less than the 2x ratio. The complete layout appears in Figure 7 with individually driven one roll, two roll and four roll sections. An eight roll section would be the last conveyor needed, but is not show due to clarity.

<u>Summary</u>

We view simulation to be a two part process: the modeling of the physical arrangement of the machinery and the emulation of the control logic that runs the system. Both portions are considered to be equally important as we strive to build efficient and globally competitive manufacturing facilities.

The techniques discussed have been shown to work for materials handling applications in the flat glass industry. We hope that this paper will serve as a catalyst for further development by others. You are encouraged to adapt these methods for other situations involving the conveyoring of fragile products.

Eliminating Surface Damage

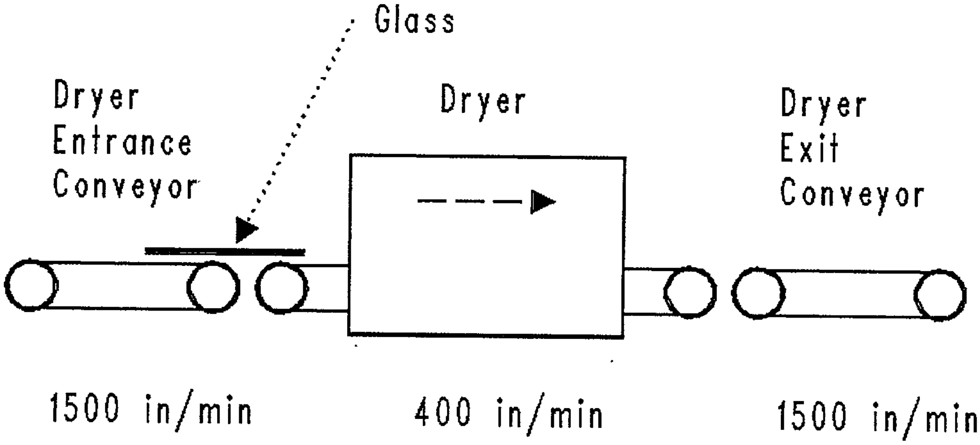

Fig. 1

Eliminating Surface Damage

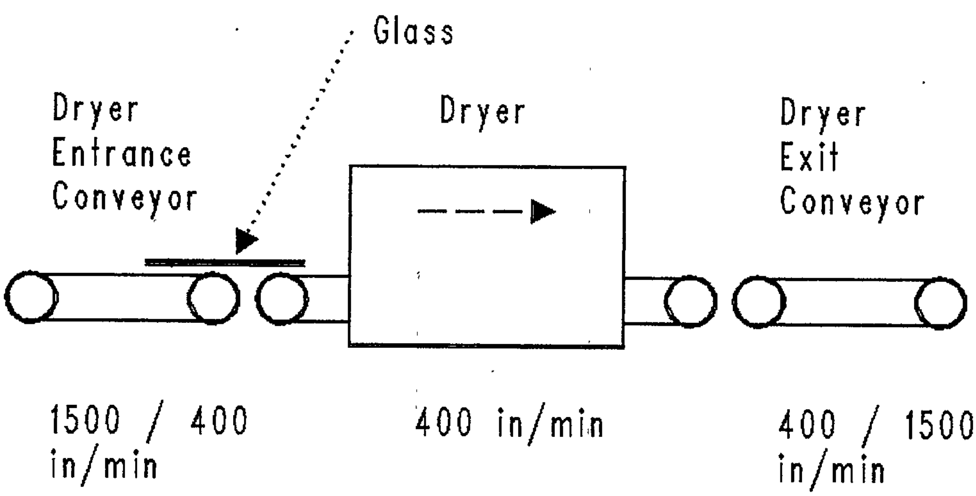

Fig. 2

Sample GPSS/H Code

Eliminating Surface Damage

```
*
*
*
*
           QUEUE          DRYENTR          Queue Up, Dryer Entrance
           SEIZE          DRYENTR          Occupy Dryer Entrance
           DEPART         DRYENTR          Exit Dryer Entrance Queue
           RELEASE        PREVCONV         Release Previous Conveyor
           ADVANCE        V$ONDRYEN        Tail On Dryer Entrance
*                                          Conveyor @ 1500 in/min
           ADVANCE        V$ENDDRYEN       Move to End of Dryer
*                                          Entrance Conveyor
*                                          @ 400 in/min
*
           QUEUE          DRYER            Queue Up for Dryer
           ENTER          DRYER            Enter to Dryer
*                                          Note: Dryer May Contain
*                                          More Than One Piece,
*                                          Defined as Storage
           DEPART         DRYER
           ADVANCE        V$ONDRYER        Tail On Dryer Conveyor
*                                          @ 400 in/min
           RELEASE        DRYENTR          Release Dryer Entrance
*                                          Conveyor
           ADVANCE        V$ENDDRYER       Move to End of Dryer
*                                          Conveyor
*
*
*
```

Fig. 3

Right-Angle Transfers

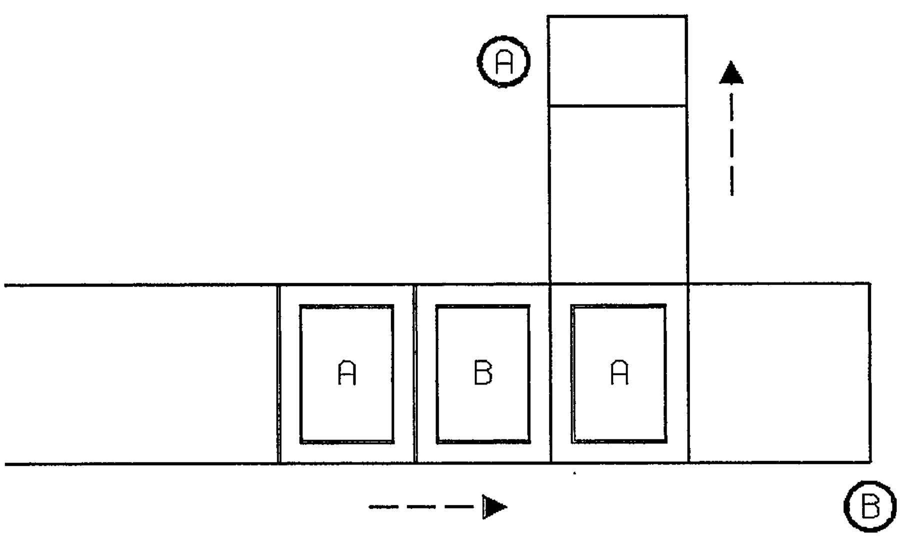

Fig. 4

Sample GPSS/H Code

Right-Angle Transfer

```
*
*
*
*
           QUEUE        TRANSFER        Queue Up for the Transfer
           SEIZE        TRANSFER        Occupy the Transfer
           DEPART       TRANSFER        Exit Transfer Queue
           RELEASE      PREVCONV        Rel. Conv. Before Transfer
           ADVANCE      V$TRANCNTR      Center Piece on the Trans.
           ADVANCE      XL$TRANUPDN     Raise Transfer Belts
           SPLIT        1,CONTINU       Replicate the Transaction
*                                       (Piece), Offspring Goes to
*                                       CONTINU
           GATE LS      LOGICSW1        Retain Control of Transfer
*                                       Until Piece Tails Off
           LOGIC R      LOGICSW1        Reset Logic Switch Until
*                                       Next Time
           ADVANCE      XL$TRANUPDN     Lower Transfer Belts
           RELEASE      TRANSFER        Release the Transfer
           TERMINATE                    Destroy the Transaction
*
*
 CONTINU   QUEUE        TRANEXIT        Queue Up for the Transfer
*                                       Exit Conveyor
           SEIZE        TRANEXIT        Occupy the Transfer Exit
*                                       Conveyor
           DEPART       TRANEXIT        Exit Transfer Exit Queue
           ADVANCE      V$OFFTRANS      Time to Tail Off Transfer
           LOGIC S      LOGICSW1        Set Logic Switch to Lower
*                                       Transfer Belts
           ADVANCE      V$ENDTRNEX      Time to End of Transfer
*                                       Exit
*
*
*
*
```

Fig. 5

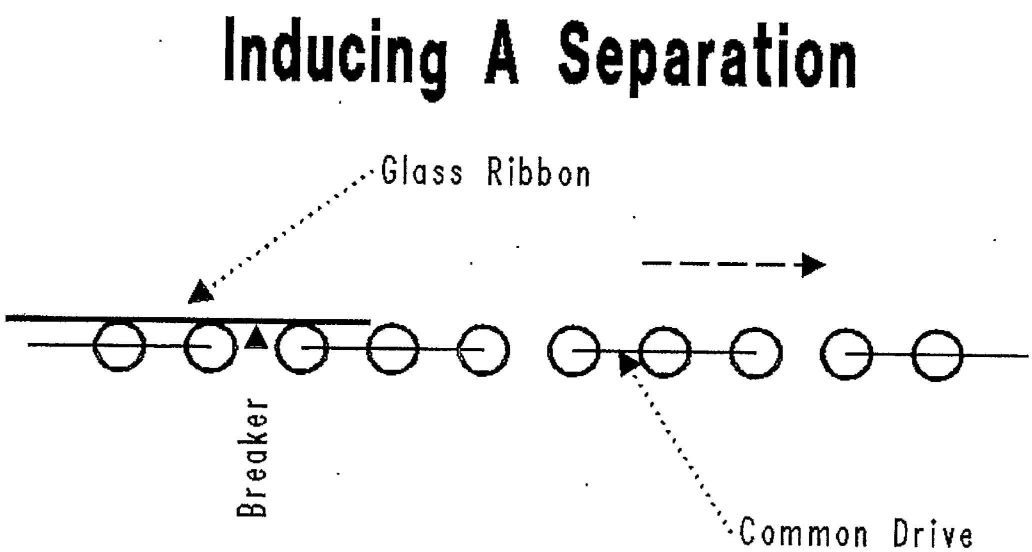

Fig. 6

Inducing A Separation

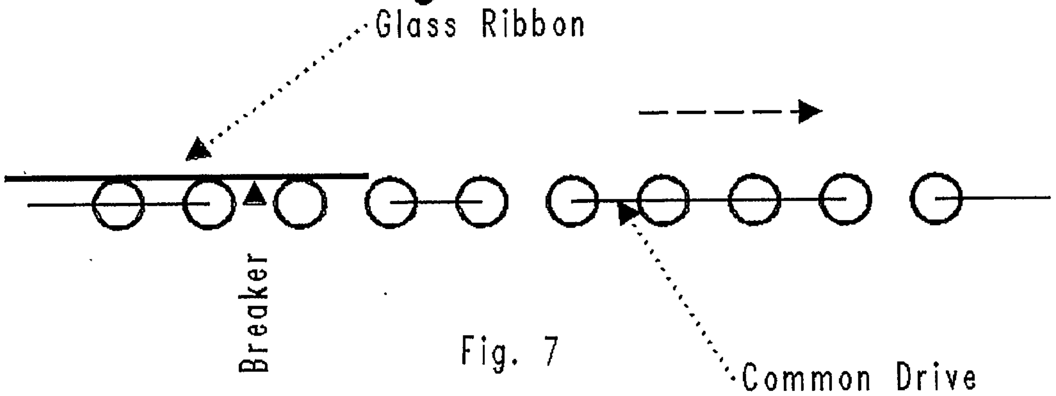

Fig. 7

Sample GPSS/H Code

Inducing a Separation Between Pieces

```
*
*
          QUEUE        SPEEDUP1         Queue Up for Speed Up
*                                       Section 1
          SEIZE        SPEEDUP1         Occupy Spd. Up Section 1
          DEPART       SPEEDUP1         Exit Spd. Up Sec. 1 Queue
          ADVANCE      V$LDENDSU1       Lead Edge to End of Spd.
*                                       Up Section 1 @ 500 in/min
*
*
          QUEUE        SPEEDUP2         Queue Up for Speed Up
*                                       Section 2
          SEIZE        SPEEDUP2         Occupy Spd. Up Section 1
          DEPART       SPEEDUP2         Exit Spd. Up Sec. 2 Queue
          TEST LE      XL$PIECEHGT,24.0,CONTINU1
*                                       Is Piece Hgt. LE to 24" ?
          ADVANCE      V$TOSCORE1       Time to Move Score Over
*                                       Breaker @ 500 in/min
          RELEASE      SPEEDUP1         Release Speed Up Section 1
          ASSIGN       10,2,,PF         Cut Piece Is Separated
*                                       From Ribbon, Running at
*                                       High Speed
          ADVANCE      V$LDENDSUZ       Lead Edge to End of Spd.
*                                       Up Section 2 @ 1000 in/min
          TRANSFER     ,CONTINU2        Go to CONTINU2 Label
*
CONTINU1  ADVANCE      V$LDENDSUY       Piece GT 24", Lead Edge to
*                                       End of Spd. Up Section 2
*                                       @ 500 in/min
*
*
CONTINU2  QUEUE        SPEEDUP3         Queue Up for Speed Up
*                                       Section 3
          SEIZE        SPEEDUP3         Occupy Spd. Up Section 3
          DEPART       SPEEDUP3         Exit Spd. Up Sec. 3 Queue
          TEST LE      XL$PIECEHGT,78,CONTINU3
          TEST LE      XL$PIECEHGT,72,CONTINU4
          TEST LE      XL$PIECEHGT,48,CONTINU5
          TEST LE      XL$PIECEHGT,30,CONTINU6
          TEST LE      XL$PIECEHGT,24,CONTINU7
*                                       Action Taken Depends on
*                                       Piece Height
          ADVANCE      V$MOVEPCE1       Time to Tail Off Spd. Up
*                                       Sec. 2
          RELEASE      SPEEDUP2         Release Speed Up Section 2
          ADVANCE      V$LDENDSUX       Time to End of Spd. Up
*                                       Section 3 @ 1000 in/min
          TRANSFER     ,CONTINU8        Goto CONTINU8 Label
*
*
```

```
CONTINU7 ADVANCE       V$MOVEPCE2        Time to Tail Off Spd. Up
*                                        Section 1 @ 1000 in/min
         RELEASE       SPEEDUP1          Release Speed Up Section 1
         ADVANCE       V$MOVEPCE3        Time to Tail Off Spd. Up
*                                        Section 2 @ 1000 in/min
         RELEASE       SPEEDUP2          Release Speed Up Section 2
         ADVANCE       V$LDENDSUW        Time to End of Spd. Up
                                         Section 3 @ 1000 in/min
         TRANSFER      ,CONTINU8         Goto CONTINU8 Label
*
*
CONTINU6 ADVANCE       V$MOVEPCE4        Time to Move Score Over
*                                        Breaker @ 500 in/min
         ADVANCE       V$MOVEPCE5        Time to Tail Off Spd. Up
*                                        Section 1 @ 1000 in/min
         RELEASE       SPEEDUP1          Release Speed Up Section 1
         ADVANCE       V$MOVEPCE6        Time to Tail Off Spd. Up
*                                        Section 2 @ 1000 in/min
         RELEASE       SPEEDUP2          Release Speed Up Section 2
         ADVANCE       V$LDENDSUV        Time to End of Spd. Up
*                                        Section 3 @ 1000 in/min
         TRANSFER      ,CONTINU8         Goto CONTINU8 Label
*
*
CONTINU5 ADVANCE       V$MOVEPCE7        Time to Move Score Over
*                                        Breaker @ 500 in/min
         ADVANCE       V$MOVEPCE8        Time to Tail Off Spd. Up
*                                        Section 1 @ 1000 in/min
         RELEASE       SPEEDUP1          Release Speed Up Section 1
         ADVANCE       V$LDENDSUU        Time to End of Spd. Up
*                                        Section 3 @ 1000 in/min
         TRANSFER      ,CONTINU8         Goto CONTINU8 Label
*
*
CONTINU4 ADVANCE       V$MOVEPCE9        Time to Move Score Over
*                                        Breaker @ 500 in/min
         ADVANCE       V$LDENDSUT        Time to End of Spd. Up
*                                        Section 3 @ 1000 in/min
         TRANSFER      ,CONTINU8         Goto CONTINU8 Label
*
*
CONTINU3 ADVANCE       V$MOVEPCEX        Piece Longer Than 78",
*                                        Time to End of Speed Up
*                                        Section 3 @ 500 in/min
*
*
CONTINU8 .........
*
*
```

Fig. 8

References

Henriksen, J.O. and Crain, R.C., Wolverine Software Corp., GPSS/H User's Manual, 1983

Schriber, T.J., Simulation Using GPSS, J. Wiley & Sons, 1974

Biography

DONALD B. HOPINGS, PE

D.B. Hopings, originally a mechanical engineer and machine designer, is currently the senior member of the Simulation and Operations Analysis Department at Libbey Owens Ford Co. He is a registered Professional Engineer, a patented inventor and a holder of a BSME degree from the University of Toledo.