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A DECISION TOOL FOR ASSEMBLY LINE BREAKDOWN ACTION

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ABSTRACT

Assembly lines with closed loop parallel lanes have the potential to continue to be productive when individual stations breakdown. A requirement in such parallel lane systems is that the products must exit the parallel lanes in the same sequence as they entered. Such lines offer the opportunity to run the line partially either by shutting down an affected lane or by bypassing the failed station to continue to run on all lanes. Bypassing a station, however, requires a backup station that can pick up the incomplete work at a later stage in the process. However, when a station breakdown occurs, it is not readily obvious as to whether to bypass the affected lane or just the affected station. This decision will vary depending on which station failed and the length of the repair. This paper presents a discrete-event modeling approach to provide a decision-making tool during breakdowns.

1 INTRODUCTION

Automated closed loop assembly lines are widely used in manufacturing and consist of a main line connected to a series of parallel lanes, which are tied back to the main line. The material handling systems in general are asynchronous where carriers can circulate if not blocked or starved. The main line consists of stations that are configured in series, with the first station being the load station followed by a number of geometric set stations. Once the geometry is defined, a large amount of work is required in a series of workstations to finish the assembly prior to the unload station. In order to reduce capital investment, non-value added time is minimized by processing the high work content at stations that are organized in a multiple parallel lane layout. Since these parallel lanes process duplicate work, the system has the ability to also provide a reduced capacity instead of zero capacity during a breakdown. Finally, parts are unloaded at the unload station in the main line.

This paper will address the development of a decision tool for such assembly lines during breakdowns. In the following we describe the relevant features of the assembly line and the decision faced by the operational manager when breakdowns occur.

Figure 1 shows the typical assembly line layout. Carriers arrive at the start of the line and go through the load and geometric set stations that have relatively low process time operations. After the initial operations, the carriers enter two or more parallel lanes; Figure 1 shows two parallel lanes. The two parallel lanes are mirror images of each other and the same operations are performed at corresponding stations in the lanes, though there may be slight differences in the cycle times at corresponding stations in the two lanes. After a carrier emerges from either parallel lane, it proceeds to the finishing part of the line, where the remaining operations are performed and the full assembly is unloaded.

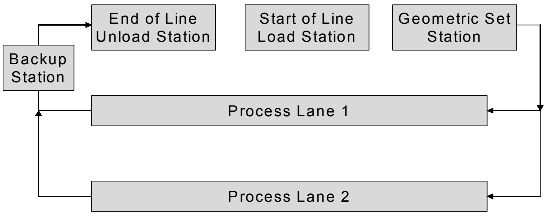


Figure 1: A Generic Assembly Line Layout

A requirement in automated assembly lines would be a “backup” station in the “end of the line” segment, which has the ability to perform the work of any station in process lanes 1 and 2. The backup station is typically a manual station that is used to repair the assembly from a failed station. Unfortunately, however, the process time at the backup station is likely to be much larger than at the automatic station at which the operation is performed regularly.

This backup station feature permits two possible scenarios: (1) the breakdown station is to be bypassed, while the lane itself can remain operational indefinitely and in this case all jobs going through that lane will have to be repaired at the backup station, and (2) the entire lane with the breakdown station to be closed while the other lane(s) could be operational and in this case the job at the failed station as well as a finite number of jobs that preceded the failed job are to be fixed at the backup station.

A possible requirement in assembly lines would be a need to ensure that assemblies leave the entire line in the same sequence in which they were entered in the line. This requirement, in turn means that the finished assemblies leave the parallel lanes in sequence and in the same order as they came to the lane.

Generally, it is thought that assembly lines with parallel lines can handle breakdowns with less throughput degradation, than lines without parallel lanes. This is true, but operational managers are faced with selecting the action with the minimum throughput degradation when faced with a breakdown; with no parallel lanes, there are two options left that require either shutting the line down or bypassing the station and repairing at a later stage in the process.

In the above discussion, we see that three decision options are possible, and these have to be compared for degradation in order to make a good decision. It appears as if it is always preferable to bypass a broken down station instead of the entire lane, but due to the transition behavior in the line after a breakdown, this is not necessarily true.

One example of a typical assembly line is shown in Figure 2. Figure 3 shows a typical plot of throughput as a function of time when a breakdown occurs for the case when bypassing an entire lane. After a breakdown there is a short period of decision-making time, when the line is shut down resulting in zero throughput. There is an initial transition time, Tb, which has two parts. During the first part, the carriers in front of the breakdown station are flushed out without use of the manual backup station, and the throughput is at 100% at this time. During the second part, all units go through manual processing at the backup station, resulting in throughput drop to below 50%, since the breakdown lane is shut down under this action. During the repair phase with a duration of Tr, the throughput is at 50% with one lane operating. After the repair is complete and the second lane is made operational, there is a transition time of Tu, during which loaded carriers fill up the second lane. It is only after this transition time that the throughput goes back to 100%. This example illustrates the complexities of the transitions in throughput in such closed loop assembly lines during a breakdown.

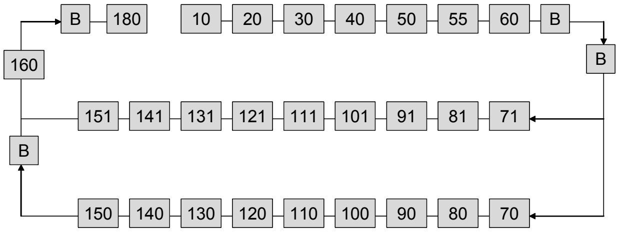


Figure 2: A Typical Assembly Line Layout

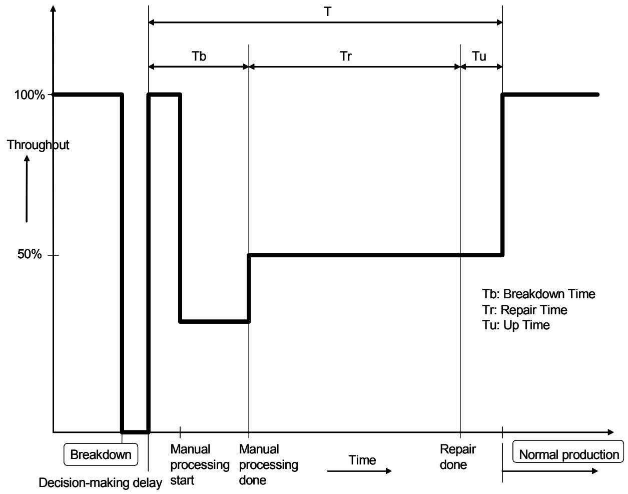


Figure 3: Throughput Variation during Transition

There are several factors that affect the throughput degradation: which station broke down, how long it will take to fix, what is the time required for the alternate operation, when is the next opportunity during the work day to get into the line and perform the maintenance work, how much inventory is available for the next area of the plant to consume while this assembly line puts out a lower throughput than normal, etc.

Several researchers have studied the effect of breakdowns on assembly line performance. Yang, et al. (2000) model and analyze multi-stage transfer lines with unreliable machines and finite buffers. The machines have exponential operation, failure, and repair processes. First, a mixed vector-scalar Markov process model is presented based on some notations of mixed vector-scalar operations. Then, several steady-state system properties are deduced from this model.

Li and Shaw (1998) study dynamic job shop rescheduling where machine workstations are not always available due to breakdown or preventative maintenance. A visual interactive simulation model using the AWESIM discrete event modeling tools was constructed to show how the state dependent rescheduling technology is used.

In order to better understand assembly line system dynamic behavior and provide a basis for developing effective production control, Lin and Cochran (1990) studied three unexpected real time events, including sudden machine breakdown at a work station, parts supply shortage, and high priority job order processing. Short-term system performance is evaluated by dynamic response variables associated with assembly time and work in process (WIP) inventory. Simulation is used as the modeling tool, and the results are further described by mathematical metamodels for overall system behavior.

Liao and Chen (2003) consider a practical problem encountered in a textile company where the machine breakdown occurs frequently. A heuristic is developed as the solution approach for the problem. The basic idea of the heuristic is to provide a longer setup time (or equivalently, a longer idle time) to reduce the breakdown rate.

Lee and Lin (2001) deal with scheduling problems involving repair and maintenance rate-modifying activities. When a machine is running at less than an efficient speed, a production planner can decide to stop the machine and maintain it or wait and maintain it later. If the choice is made to continue running the machine without fixing it, it is possible that the machine will break down and repair will be required immediately.

The above cited research, however, does not address the operational problem faced by assembly line personnel when a breakdown occurs. In section 2, we present the problem description, assumptions, and the objective of this paper. In section 3, after analyzing the problem, possible actions and corresponding consequences are defined, and the decision criteria and possible outcomes are presented. In section 4, an implementation of the simulation model is presented. Actions 1 and 2 are modeled using ProModel, and typical results are shown.

2 PROBLEM DESCRIPTION

Figure 2 shows a typical closed loop assembly line where carriers enter the area in sequence at Station 10 and have to exit in sequence from station 180. After station 60 the carriers are sequenced in the two parallel lanes alternately. After going through the operations on one or the other lane, the carriers reach station 180, and exit from the assembly area of interest here. Following station 180, an inventory of assembled units is built up, referred to here as a buffer, which is then processed by the next area in the manufacturing plant of which the subject assembly line is a part. If a breakdown occurs at one of the stations, different actions that line personnel can take must be defined.

The following assumptions are used to further define the problem:

- The assembly line is never starved.
- The next area operates normally even after a breakdown occurs in the assembly line; this means that the next area will continue to consume from the output buffer of this line at a constant rate.
- Process times at each station and travel times along the paths are given and are fixed; the times are fixed as all these steps are fully automated.
- Station 160 is a backup station to perform the operation of the breakdown station manually; the process time at this station would be several times more than the automated process at any station.

The objective of the paper is to define the possible actions that can be taken in case of a breakdown in such an assembly line, to analyze the throughput degradation, and to enable the line manager to pick the best action for a given breakdown situation.

3 DECISION ALTERNATIVES

We first identify the actions that are possible when a breakdown occurs. The actions and the corresponding consequences are as follows:

Action 1
Bypass the station that has failed and finish that operation at the manual backup station (station 160 in our example).
Action 1 Consequences
The manual operation at station 160, for approximately half the units produced during the downtime for the station, will take several times more than the station time (relative to time of the station that has broken down). This will reduce throughput. Also, there is possibly a manpower cost associated with station 160.
Action 2
Bypass the lane in which the breakdown occurred. In this case, station 20 will begin to load every other carrier, and the entire lane where breakdown has occurred is bypassed; this must commence only after empty carriers are parked in each of the stations on this lane.
Action 2 Consequences
A few units must go to the manual backup station 160, which takes several times more than the station time (relative to time of the station that has broken down). This will reduce throughput, and also have a manpower cost associated with station 160. After the lane bypass commences, the throughput for the assembly line will go down due to only one lane operating.
Action 3
Shut down the entire assembly line.
Action 3 Consequences
Production from the line will stop during the entire duration of the repair causing a loss in throughput.

Decision on a course of action is dependent upon the following variables:

- Problem diagnosis time.
- Station repair time including availability of the spare parts and equipment for repair.
- Availability of the workforce at station 160.

The decision tool must provide an estimate of the loss in throughput for each course of action. Since repair times are often difficult to estimate, it will be useful to know how long it will take after the breakdown for the output buffer after this line to be fully depleted by the consumption of the next area.

4 SIMULATION MODELING AND ANALYSIS

Of the three actions, the consequence of Action 3 is to reduce throughput to zero for the duration of the breakdown, and therefore would not require a model. For the scenarios corresponding to Actions 1 and 2 simulation models have been built using ProModel version 6.0. The models have the following features:

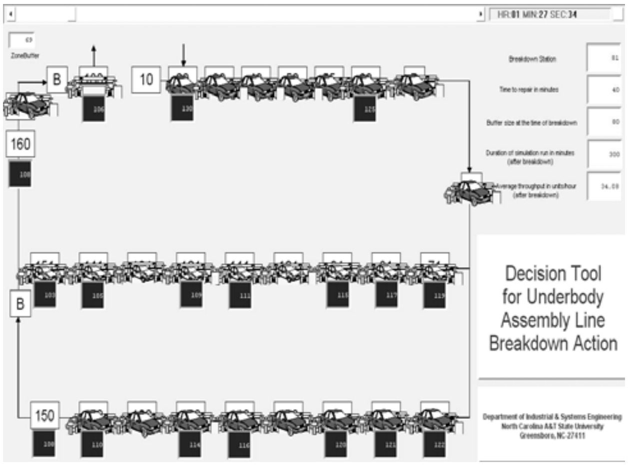
- A spreadsheet file is used to input all process times for the model; this enables process times of each station to be modified if necessary without changing the model (see Table 1).
- At the beginning of the simulation, the user is asked to input four values: breakdown station number, estimated repair time, number of units in buffer at the instance of a breakdown, and the simulation run length.
- The job number being processed at each station is shown in a dynamic fashion (see dark boxes at each station in Figure 4).
- The four user input values are shown on the simulation screen (see four boxes at top right in Figure 4).
- The outputs of interest, from the simulation, are shown dynamically: number of units in the buffer, and the average throughput from the assembly line after the breakdown occurs (see bottom box on right edge of Figure 4).
- In each of the models instantaneous throughput is determined from the times of successive departures of units from the last station S180.
- In each model, the production loss in units, beginning from the time when the breakdown occurs to the time when normal production is restored some time after the repair is completed, is accumulated; this loss is relative to the normal production level.
- Each model uses a warm-up period; note the initial duration in Figure 5 when no throughput is reported.
- After the simulation, the data generated, such as instantaneous throughput, production loss in units and output buffer depletion time can be collected.

The graph of instantaneous throughput shown in Figure 5 for Action 2 closely resembles the expected variation shown in Figure 3.

Tables 2 and 3 show the production loss in units for Actions 1 and 2 respectively for different repair times. As would be expected, for each of the actions, the production loss increases with repair times, though not linearly. The production loss numbers show that Action 1 is preferred for some combinations of breakdown stations and repair times and vice versa. The preferred actions are shown in Table 4.

Table 1: Input Data

Station Number	Transfer Time	Processing Time
S10	10.00	0.00
S20	14.40	23.00
S30	14.40	24.00
S40	14.40	23.80
S50	10.00	0.00
S55	10.00	0.00
S60	13.93	25.72
S70	100.00	0.00
S71	63.00	0.00
S80	14.40	56.34
S81	14.40	56.34
S90	14.40	66.34
S91	14.40	66.34
S100	10.00	0.00
S101	10.00	0.00
S110	14.40	56.30
S111	14.40	58.24
S120	14.40	41.20
S121	14.40	41.20
S130	10.00	0.00
S131	10.00	0.00
S140	14.40	63.00
S141	14.40	63.00
S150	14.40	42.00
S151	14.40	42.00
S160	60.00	0.00
S180	14.40	16.46



Breakdown Station: 81
Time to repair in minutes: 40
Buffer size at the time of breakdown: 80
Duration of simulation run in minutes (after breakdown): 300
Average throughput in units/hour (after breakdown): 34.08

Figure 4: Snapshot of Simulation

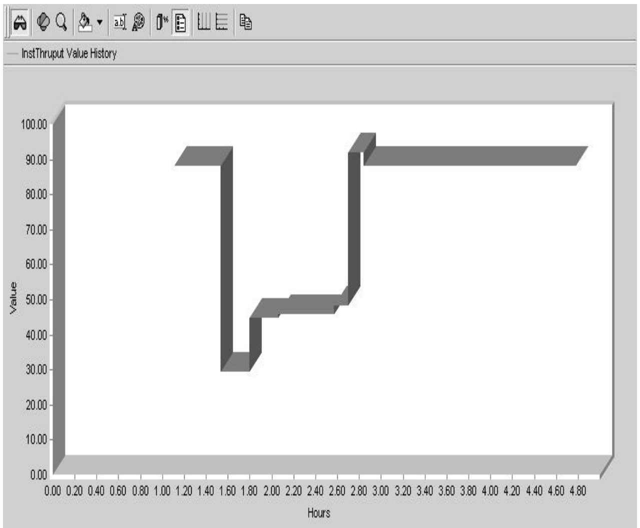


Figure 5: Instantaneous Throughput for Action 2

Table 2: Production Loss for Action 1

Breakdown Station #	Repair Time Duration 30 min	60 min	90 min
S81	49	78	103
S91	56	83	115
S111	44	71	98
S121	35	58	81
S141	41	70	96
S151	41	66	88
S80	49	75	103
S90	56	83	111
S110	43	68	97
S120	33	56	79
S140	41	70	96
S150	35	59	80

Table 3: Production Loss for Action 2

Breakdown Station #	Repair Time Duration 30 min	60 min	90 min
S81	43	64	86
S91	49	71	92
S111	50	71	93
S121	47	70	92
S141	62	83	105
S151	54	76	98
S80	42	62	84
S90	47	68	90
S110	48	69	91
S120	47	68	92
S140	62	83	105
S150	54	74	96

Table 4: Preferred Action

Breakdown Station #	Repair Time Duration 30 min	60 min	90 min
S81	2	2	2
S91	2	2	2
S111	1	1 or 2	2
S121	1	1	1
S141	1	1	1
S151	1	1	1
S80	2	2	2
S90	2	2	2
S110	1	1	2
S120	1	1	1
S140	1	1	1
S150	1	1	1

As mentioned earlier, when a breakdown occurs repair times are often difficult to estimate. For a specified initial output buffer quantity, Table 5 shows the time it takes after a breakdown for the output buffer to be fully depleted. These times in Figure 5 provide information on the longest repair time the assembly line can have, without shutting down the next area in the manufacturing plant which is feed by this assembly line.

Table 5: Buffer Depletion Time

Breakdown Station #	Buffer Depletion Time (min) Action 1	Action 2
S81	104	111
S91	93	105
S111	98	104
S121	118	108
S141	92	98
S151	106	104
S80	103	111
S90	94	106
S110	100	104
S120	120	107
S140	91	96
S150	106	101

5 CONCLUSION

This paper discusses a decision problem faced by assembly line personnel when a breakdown occurs in a multiple lane line. A discrete-event simulation based approach is presented to help line personnel make a decision that minimizes throughput degradation of the line. The simulation models help visualize the effect parameters such as breakdown station number, repair time, and buffer size have on the throughput degradation of the line.

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REFERENCES

Lee C., and C. Lin. 2001. Single-machine scheduling with maintenance and repair rate-modifying activities. *European Journal of Operational Research*. 135

Li Y., and W. Shaw. 1998. Simulation Modeling of a Dynamic Job Shop Rescheduling with Machine Availability Constraints. *Computers & Industrial Engineering*. 35: 117-120

Liao C., and W. Chen. 2003. Scheduling under machine breakdown in a continuous process industry. *Computers & Operations Research*. 31

Lin L., and J. Cochran. 1990. Estimating simulation metamodel parameters for unexpected shop floor real time events. *Computers & Industrial Engineering* 19: 62-66

Yang S., *et al*. 2000. Modeling and analysis of multi-stage transfer lines with unreliable machines and finite buffers. *Annals of Operational Research*. 93

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