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THE APPLICATION OF COMPUTER SIMULATION TECHNIQUES TO INDUSTRIAL PACKAGING LINES

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ABSTRACT

A General Purpose Simulation System (GPSS) computer program was used to help analyze potential changes to four industrial packaging lines. When recommended changes were implemented, productivity was improved by 6.7% per line. This was accomplished by changing accumulation levels and achieving a better operating balance among machines.

The paper includes a description of the problem, model development and discussion of procedures used starting with data collection and concluding with an audit of implemented changes. Initially, one line was modified and monitored for a trial period. Following the trial period, all lines were modified.

Emphasis is directed toward experiences with the specific packaging line simulation as opposed to simulation methodology.

INTRODUCTION AND PROBLEM DESCRIPTION

Each packaging line studied consisted of seven machines operating in series. Packages were first serviced sequentially through (1) package maker, (2) product filler, (3) checkweigher, and (4) top closer machines. Following these steps, cases were formed at a (5) case packer and serviced sequentially through a (6) case sealer and (7) transfer conveyor. The means of transfer through the system was by conveyor belts.

Preliminary analysis of the packaging line indicated that it was subject to frequent and short intervals of downtime. In addition, some bottlenecking occurred between the package maker and product filler machines. The package maker is the limiting factor in the line in that it is the slowest machine. Downtimes directly associated with machines 2 (product filler) through 7 (transfer conveyor) would cause backing up of packages and eventually shut down machine 1 (package maker) because the queue following it was at 100% utilization.

The objective of the simulation application was to identify changes to economically improve the packaging line's productivity measured in units of cases produced per hour. In addition, it was given that the slowest machine was already at its maximum speed and no major mechanical improvements were to be made. Potential changes were to be identified in the areas of accumulation points, accumulation levels, and operating balance among machine feeds and speeds.

SYSTEM DEFINITION

The first step in the simulation application consisted of system definition. The packaging line was described as a series of seven servers and queues. Machine speeds were converted into service times and conveyor lengths and speeds to queue capacities and package travel times. Refer to Table 1.

DATA COLLECTION

A continuous monitoring of each piece of equipment's status (operating or broken down) was conducted. Two data distributions were required for each of the seven machines: (1) duration between successive downtime and (2) duration of downtime. The summarized machine data were verified by comparing them with actual year-to-date line efficiency and reviewing with the operating department personnel. After verification and approval, the data were used in the model to schedule each machine to run and to breakdown according to its actual performance.

Line data were collected for 120 hours of operation and summarized into histograms. The data collection was performed by outside temporary help people. Initially, a two hour training program was set up for each data collector to become familiar with the packaging line and to learn the procedure and format for data collection. Machine downtimes were recorded independently. Interdependency would occur only when full accumulation was reached and "backing up" was experienced.

Fourteen distributions were required to represent the operating behavior the line and equipment, two per machine for each line. The individual machine runtime and downtime periods were scheduled based on their respective distributions.

TABLE 1.

Packaging Line Operating Characteristics

Machine (Identification)	Service Time (Secs./ Pkg.)	Preceding Queue (Packages)	Travel Time To Next Machine (Secs.)
Machine 1 (Package Maker)	.88	200	.7
Machine 2 (Product Filler)	.85	64	17.4
Machine 3 (Check-weigher)	.83	10	3.7
Machine 4 (Top Closer)	.81	20	5.5
Machine 5 (Case Packer)	.76	70	25.3
Machine 6 (Case Sealer)	.72	100	7.4
Machine 7 (Transfer Conveyor)	.72	100	6.2

MODEL DEVELOPMENT

Based on the interrelationships among the equipment on the line, design of the system's flow was performed. The nature and behavior of the line was represented in the design. The packaging line was then programmed in the GPSS format. The line's flow, operating characteristics and data distributions were incorporated into a simulation model.

The computer simulation of the system employed the General Purpose Simulation System (GPSS/6000). Transactions generated at the beginning of the system were considered to be packages. Each transaction was subject to the various server (machine) and queue (conveyor) conditions as it moved through the packaging line. Figure 1 presents the logic and testing involved for a transaction to move from machine "n" to machine "n + 1." Approximately 3400 transactions were generated for each 8-hour simulated period. The system reached "steady-state" after 8 hours. The 8-hour period represented 288,000 time units, where 1 time unit was equal to 0.10 second. Figure 2 is an example of the GPSS programming to move a package through a machine-queue-machine sequence.

MODEL TESTING AND VALIDATION

After completion, the model was executed and tested. The machine utilization statistics, storage statistics of conveyors, downtime histograms were all verified to ensure the model was an accurate representation of the packaging line.

Next, "What if?" situations were executed with the model. Machine speeds, conveyor lengths (levels of accumulation), conveyor speeds and downtime/runtime profiles of machines were varied within predefined allowable limits. Different combinations of these parameter values produced different results in overall line efficiencies.

SIMULATION RESULTS

Many potential changes were identified and tested using the simulation model. The effect of these changes was accurately quantified. As a result, a 6% increase in productivity was projected with the following changes to the line:

1) increase accumulation level of conveyor 1 which is between machine 1 and machine 2 from 64 packages to 137 packages,

2) decrease service time of machine 2 by .03 secs./package,

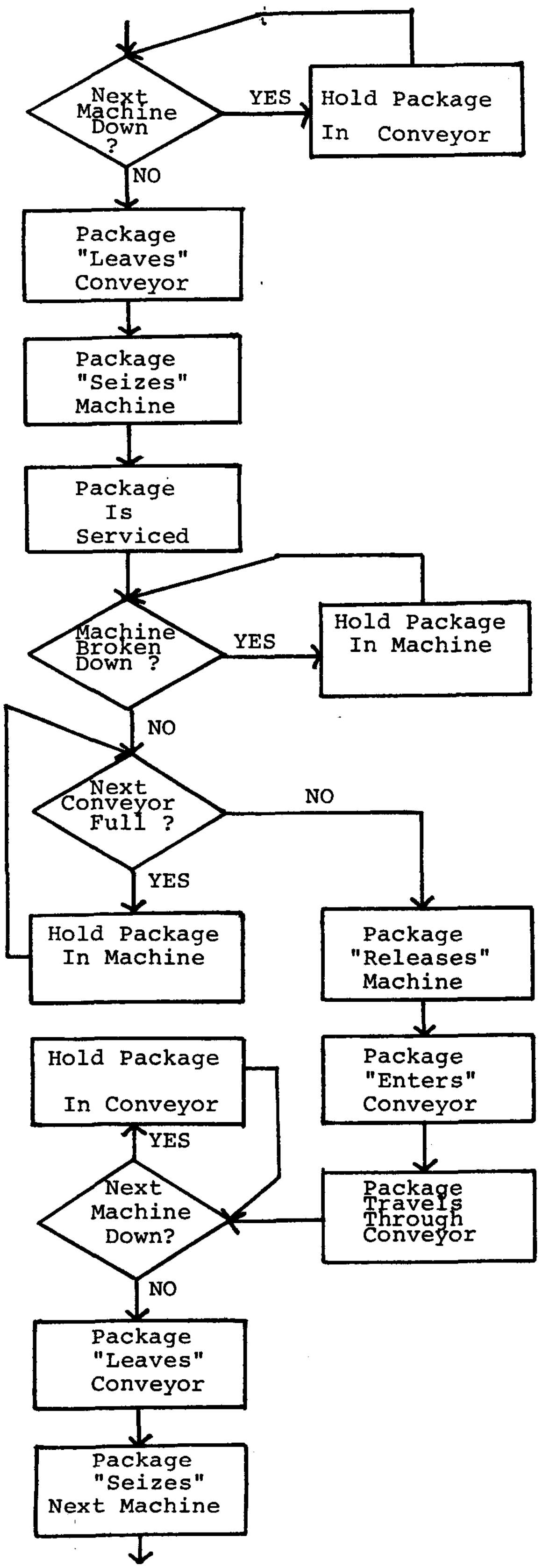
3) decrease service time of machine 3 by .03 secs./package,

4) decrease service time of machine 4 by .03 secs./package,

5) increase speed of conveyor 1 (which follows machine 1) from 130 feet per minute to 155 feet per minute,

FIGURE 1.

SIMULATION LOGIC FLOW FOR
MACHINE-QUEUE-MACHINE SEQUENCE



6) increase speed of conveyor 2 (which follows machine 2) from 120 feet per minute to 145 feet per minute, and

7) increase speed of conveyor 3 (which follows machine 3) from 135 feet per minute to 160 feet per minute.

The key modification was the increased accumulation capacity between machine 1 and machine 2. This allows machine 1 to continue operation for over two minutes after machine 2-7 stops. In addition, the increased buffer enables the rest of the line to be productive while machine 1 experiences its frequent, short interruptions. Refer to Table 2.

FIGURE 2.

Example of GPSS Programming
For the Machine-Queue-Machine Sequence

Function Name	Variable Name	Comment Statement
GENERATE	85	CREATE PKGS TO MOVE THROUGH SYSTEM
. . .		
SEIZE	P1	CAPTURE MACH P1
ADVANCE	V$ADJ3	MACH SERVICE TIME
GATE LR	P1	IF MACH P1 IS DOWN, HOLD PKG
GATE SNF	P1	IF CONV P1 IS FULL, HOLD PKG
RELEASE	P1	RELEASE PKGS FROM MACH P1
ENTER	P1	HOLD PKG IN CONV P1 PER SERVICE TIME
ADVANCE	FN$RATE2	HOLD PKG IN CONV P1 PER SERVICE TIME
GATE NU	V$1NCR	TEST IF NEXT MACH IS NOT IN USE
LEAVE	P1	PKG LEAVES CONVEYOR P1
ASSIGN	1 +, 1	INCREMENTS PARAMETER P1 BY 1
SEIZE	P1	CAPTURE MACH P1
. . .		
TERMINATE		STOP

IMPLEMENTATION OF SIMULATION RESULTS ONE INITIAL PACKAGING LINE

The recommended operating conditions for the line, after engineering approval and cost justification, were implemented. Approximate cost and savings data are presented in Table 3.

TABLE 2.

Summary of Predicted Improvements to Overall Packaging Line Operation

Area of Change	Cumulative Effect of Proposed Improvements
A. Better balanced machine speeds	+ 1,8%
B. Better balanced machine speeds plus Better balanced conveyor speeds	+ 2.0%
C. Better balanced machine speeds plus Better balanced conveyor speeds plus Increased accumulation	+ 6.0%

TABLE 3.

Cost and Savings Estimates

A. ESTIMATED COSTS:

Machine Speed Changes....	$125
Conveyor Speed Changes...	75
Build & Install 40' Conveyor...............	5500
TOTAL......	$5700

B. ANNUAL SAVINGS

Line Efficiency. Improvement of 6%.....$9000

C. CALCULATED RATE OF RETURN

Rate of Return>50% for 5 Year Life of Project

AUDIT OF CHANGES IMPLEMENTED

Four months after the modifications were implemented on the line, an audit was conducted. Production reports showed an actual 6.7% improvement.

In addition, a demonstration was conducted to show the effect and benefit of the additional accumulation on the packaging line recommended using the simulation analysis. A 30 minute test demonstration for upper management was conducted on two identical packaging lines under identical downtime/runtime conditions. One line had been modified as described; the other was not modified. The basis for comparison was the number of packages outputted from each line during the 30 minute period. Additional details on the test conditions are shown in Table 4.

TABLE 4.

Test Conditions* For Management Demonstration

	Modified Line	Unmodified Line
Speed Machine 1	68 Pkgs/Min	68 Pkgs/Min
Speed Machine 2	72 Pkgs/Min	72 Pkgs/Min
Accumulation Capacity Between Machines 1 and 2 (Conveyor 1)	137 Pkg	64 Pkgs
Conveyor 1 Speed	155 Ft/Min	130 Ft/Min
Conveyor 1 Length	80 Ft	39 Ft

*The modified and unmodified lines were identical in all other respects.

Results from the 30 minute tests showed the modified line outputted 1720 packages while the unmodified line outputted 1590. Hence, this 130 package difference is shown to be attributable to changes made to the packaging line. The 30 minute downtime pattern used for the test was similar to what actually occurs during normal operations. As compared to the 100% standard of 68 pkg/min, line efficiency was 6.4% greater for the modified packaging line.

IMPLEMENTATION TO ADDITIONAL LINES

After four months of successful operations (confirmed by an audit) and a special management demonstration, three additional lines were simultaneously analyzed. Basically, the same procedures used on the first packaging line were used. However, a few changes were made. Since the additional three packaging lines were similar to the first line studied, the data collection phase was shortened. Data were collected following a random sample of the three lines over an eighty hour period. Each sample was one hour in length. Also, the physical constraint of two minutes accumulation on the machine 1 to machine 2 conveyor was relaxed and allowed to be as high as eight minutes.

As in the case of the initial line, potential changes were identified and tested using the simulation model. The effects of these changes were then quantified. Potential efficiency increases amounted to greater than 5%, 8% and 9% for each of the three additional lines analyzed.

Again, as in the case of the initial line, the key modification was the increased accumulation capacity between machine 1 and machine 2. This allowed machine 1 to continue operation beyond the one minute accumulation capacity after machine 2 stopped. In addition, the increased buffer enables the rest of the line to be productive while machine 1 experiences its frequent, short interruptions.

Other benefits accrued by reducing forced shutdowns of machine 1. The package maker uses glue and wax to seal the packages, thus with less stopping, the adhesives don't set up on the machine and cause a shutdown for required cleaning of the machine.

SUMMARY

The simulation approach used permitted an evaluation of various potential modifications to machine speeds, conveyor speeds and conveyor accumulation levels for a series industrial packaging line. The simulation results were used as input to an economic analysis which lead to modification of one of four similar pack ging lines. An audit of 4 months actual performance indicated a 6.7% overall thruput improvement on the initial line modified. As a consequence, the operation of three additional lines was simulated, changes were made and similar improvements occurred. In dollar terms. projected savings are a minimum of $9,000 per packaging line per year. The project's cost for data collection, model development and computer time were approximately $8,000. Equipment modifications cost approximately $6,000 per line. For all four lines this would indicate a payback period of 10 to 11 months.

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KEY WORDS

1. GPSS Simulation

2. Packaging line simulation

3. Accumulation level simulation