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EVALUATION OF HEURISTICS FOR INSPECTION STATION ALLOCATION IN SERIAL PRODUCTION SYSTEMS

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ABSTRACT

The performance of four inspection station allocation heuristics is evaluated on the basis of job completion time in serial production systems under different operating conditions. Inspection time emerges as the most influencing factor in the selection of the proper heuristic. Moreover, the performance obtained in the time domain can be related to the performance in the cost domain within which a cost analysis can be performed.

1. INTRODUCTION

A major decision in establishing an effective quality assurance program is the planning and management of resources dedicated to the inspection and testing of critical product attributes. Adding quality control into any production process constitutes an incremental cost burden. But at some level of inspection effort, cost incurred can be set off by screening out unacceptable or defective items. An operational problem generally encountered is where and when in the production process should the actual inspection be performed.

A number of mathematical models have been developed to determine the optimal location of inspection stations in serial production systems. These models are usually based on a dynamic programming solution technique.

Beightler and Mitten [1964] propose a dynamic programming model that provides a sequence of interrelated sampling inspection plans which minimize total cost of accepting non-conforming units. Inspection is considered to be error free. Lindsay and Bishop [1964] propose another dynamic programming model that assumes 100% inspection of production run rather than sampling. The model minimizes the sum of unit inspection costs and the cost of lost production due to improper production in serial systems.

White [1966] developes a dynamic programming model for serial systems with error free inspections. Pruzan and Jackson [1967] provide two variations to the model developed by Lindsay and Bishop, accounting for fixed cost of inspection per station, cost of improper processing and cost of accepting defective units. Hurst [1973] proposes a model that accounts for inspection errors of both types: acceptance of defective components and rejection of good components, for a serial system. A solution to this model is provided by Eppen and Hurst [1974] using dynamic programming. In addition, Brown [1968], White [1969], Dietrich [1971], Ercan [1972] and Woo and Metcalfe [1981] all have applied dynamic programming to find the optimal location of inspection stations in serial systems. On the other hand, Garey [1972] applies non-linear programming to find the optimal location of inspection stations.

Although mathematical models can provide an optimum solution, the solution processes are usually time consuming and are sometimes subject to rather restricting assumptions. Consequently, heuristics are widely used by practitioners.

Ballou and Pazer [1982] develop a computer program to simulate performance of serial systems with inspection errors. The input to the program consists of the number of stages, the value added at each stage, unit inspection costs, and the penalty cost of accepting a non-conforming unit. The program then calculates the total cost per conforming unit produced. They examine the sensitivity of the production cost to the various cost and error parameters of the model. Peters and Williams [1984] investigate the performance of five heuristic rules applied to the location of error free inspection stations in serial systems. Under a variety of cost and processing conditions, the numerical value of the criterion variable is systematically incremented. Subsequently, the optimum solution is found with a dynamic programming algorithm, and the two values are compared.

In this paper, four heuristics are evaluated under different operating conditions. The complete problem is described in the next section followed by an explanation of the simulation model used. Data analysis and cost analysis are presented in Sections 4 and 5, respectively, followed by the summary.

2. PROBLEM STATEMENT

The objective of this research is to examine the performance of four inspection station allocation heuristics on the basis of job completion time in serial production systems under different operating conditions. Specifically three issues are addressed:

1. Among a number of system parameters that can impact the heuristic performance, which parameter has the most significant influence?
2. Once the significant parameter is identified, is it possible to identify a favorable operating range of the significant parameter for each heuristic?
3. How should the information obtained from the first two steps in the time domain be related to cost factors?

The four heuristics considered in this paper are:

1. Locate one inspection station before the station with the longest processing time and locate another at the end of the total process.
2. Locate one inspection station after the operation which is likely to generate a high proportion of defective items and locate another at the end of the whole process.
3. Locate one inspection stations after each machine. The intent is to recognize a defect as early as possible.
4. Locate one inspection station at the end of the whole process.

3. THE SIMULATION MODEL

The simulation package SLAM - II is used to simulate operations of a serial production system of 5 workstations. The inspection policy is 100% inspection. After the inspection, the product is classified into two categories: good or defective. The good product proceeds to the next station while the defective product is routed to a rework station. The material transportation time between workstations is negligible. In addition, infinite buffer space is assumed for all workstations and inspection stations. The simulation network is illustrated in Figure 1.

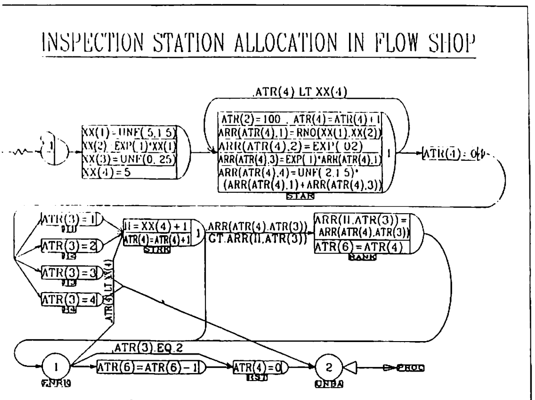

Figure 1. The Simulation Model

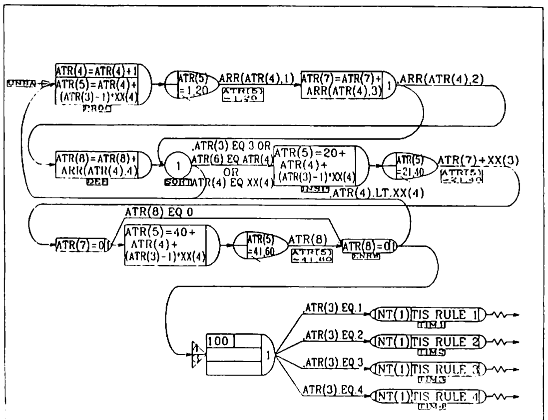

Figure 1. The Simulation Model (continued)

The simulation model considers the following process variables: (1) the mean of the operation time, (2) the standard deviation of the operation time, (3) the defective percentage, (4) the inspection time, (5) the rework time, and (6) the set up time for inspection stations.

The operation time is assumed to follow a normal distribution. The mean and standard deviation for the normal distribution follow uniform and exponential distributions respectively. The defective percentage is assumed to follow an exponential distribution. The inspection time is expressed as a percentage of machining time. The inspection time percentage is generated using an exponential distribution. Rework time is expressed as a fraction of the sum of the machining and inspection times. The fraction for each operation is generated using a uniform function.

A concept of accumulation of the inspection time and the rework time is used. This means if inspection is not done after a particular station, then the inspection time and rework time after the next station will increase by the values corresponding to the former station. A part accumulates the inspection time as well as the rework time until it encounters an inspection station. At the inspection station accumulated values are used to estimate the actual inspection and rework time required for a part. After inspection, the defective part is sent to the rework station. Time in system for a batch of 100 components is simulated under different heuristics. The heuristic that gives the least processing time for a batch is considered to be the best under the given system parameters.

4. DATA ANALYSIS

The experiment is conducted in two stages. In the first stage, the values of these six process variables are varied to determine the effect they have on the ranking of heuristics. The objective was to identify the most influencing process variable. In the second stage, the value of the most influencing variable is changed with the objective being to identify the best operating range for each heuristic.

In the first stage, mean values of system parameters are altered (first decreased and then increased), one parameter at a time. Heuristics are ranked according to time in system for a batch. The changes in ranking of heuristics are noted for further studies and the results are summarized in Table 1.

Table 1. Completion Time with Different Process Variables

			Heuristic			
VARIABLE	DATUM	CHANGED TO	#1	#2	#3	#4
Mean Process	UNF(.5,1.5)	UNF(.2,.5)	31.4	31.4	31.7	31.3
		UNF(2,5)	312.0	312.0	313.0	312.0
Std Dev Process	EXP(.1)	EXP(0)	84.1	85.1	87.8	84.1
		EXP(.2)	94.7	94.7	95.0	94.5
Defective %	EXP(.02)	EXP(.005)	86.3	86.3	86.6	86.2
		EXP(.2)	84.4	84.9	85.6	84.8
Inspect Time	EXP(.1)	EXP(.02)	85.9	85.9	86.3	85.8
		EXP(.5)	232.0	150.0	106.0	264.0
Rework Time	UNF(.2,1.5)	UNF(.2,.5)	86.3	86.3	86.7	86.2
		UNF(2,5)	86.3	87.1	87.2	86.2
Fixed Insp Time	UNF(0,.25)	UNF(0,.02)	86.1	86.1	86.2	86.1
		UNF(5,10)	78.0	76.3	77.6	77.9

The result suggest that the mean operation time, the standard deviation of the operation time, the defective percentage, the fixed inspection time, and the rework time have little effect on the ranking of heuristics. However, the inspection time factor changes the ranking completely. Formal statistical analysis is unnecessary to conclude that the inspection time magnifies the differences between the time-in-system for different heuristics and is the most influencing parameter.

In the second stage, the percentage of the inspection time factor is varied from 1% to 95%. The simulation results are shown in Table 2. As the inspection time increases, the total processing time also increases. To facilitate comparison of different values obtained from different runs, we define the total processing time for Heuristic 4 to be the datum, 100%. Total processing time for other heuristics can be calculated as percentages of the datum. The resulting values are shown in Table 3 and Figure 2. It can be seen from the figures that Heuristic 1 is the most effective heuristic at low values of the inspection time factor. But as the percentage is increased to about 5%, Heuristic 2 becomes more effective. When

Table 2. Time in System Under Different Levels of the Inspection Time

Percentage*	Rule #1	Rule #2	Rule #3	Rule #4
1	120.64	120.71	121.70	120.71
5	120.90	120.86	121.91	120.90
10	124.36	124.32	122.06	124.40
15	133.32	133.24	122.46	133.46
20	146.51	146.68	122.70	147.85
25	166.93	167.29	125.15	169.39
30	190.76	191.46	129.26	194.10
35	215.58	217.42	134.87	220.38
40	240.99	243.53	140.90	247.32
45	267.24	270.29	147.38	274.17
50	320.39	324.00	163.69	329.47
55	346.80	351.02	172.93	356.49
60	346.80	351.02	172.93	356.49
65	373.47	377.95	182.76	384.00
70	400.55	405.63	192.86	411.73
75	427.74	432.58	203.07	439.47
80	454.44	459.90	213.64	467.09
85	481.39	487.12	224.47	494.82
90	508.35	514.54	235.83	522.67
95	535.35	541.74	247.30	550.51

* The percentage of mean inspection time over the mean processing time

Table 3. Modified Time in System Under Different Levels of the Inspection Time

Percentage*	Rule #1	Rule #2	Rule #3	Rule #4
1	99.95	100.00	100.82	100.00
5	100.00	99.97	100.84	100.00
10	99.97	99.94	98.12	100.00
15	99.89	99.84	91.76	100.00
20	99.09	99.20	82.99	100.00
25	98.55	98.76	73.88	100.00
30	98.28	98.64	66.59	100.00
35	97.82	98.66	61.20	100.00
40	97.44	98.47	56.97	100.00
45	97.47	98.58	53.75	100.00
50	97.24	98.34	49.68	100.00
55	97.28	98.47	48.51	100.00
60	97.28	98.47	48.51	100.00
65	97.26	98.42	47.59	100.00
70	97.28	98.52	46.84	100.00
75	97.33	98.43	46.21	100.00
80	97.29	98.46	45.74	100.00
85	97.29	98.45	45.36	100.00
90	97.26	98.44	45.12	100.00
95	97.25	98.41	44.92	100.00

* The percentage of mean inspection time over the mean processing time

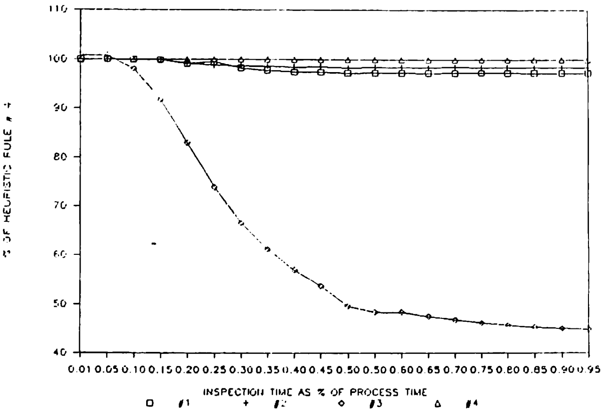

Figure 2. Performance Comparison

5. COST ANALYSIS

This section addresses the issue of performance of the four heuristics in the time domain in relation to a proposed cost measure. Costs considered in this paper include repair cost, processing cost, fixed inspection cost and variable inspection cost. Table 4 illustrates a calculation example. Cost Savings corresponding to the reduction in time in system can be calculated as follows. These sample calculations have been done for inspection as 55% of the operation time. Machine rate and labor charges have been taken to be $30/hr. Inspector rate is $9/hr. Fixed setup cost for inspection is $9/hr. Fixed cost has been taken as $500.

Table 4. Cost Calculations

COST FACTOR	RULE NUMBER			
	1	2	3	4
TOTAL PROCESS TIME (MINS)	346.80	351.02	172.93	356.49
LABOR+MACHINE RATE($/MIN)	$2.50	$2.50	$2.50	$2.50
PROCESSING COST ($)	$867.00	$877.56	$432.32	$891.22
TOTAL INSPECTOR TIME(MINS)	346.80	351.02	172.93	356.49
INSPEC LABOR RATE ($/MIN)	$0.30	$0.30	$0.75	$0.15
VARIABLE INSP COST ($)	$104.04	$105.31	$129.69	$53.47
FIXED INSP TIME (MINS)	12.00	12.00	36.00	6.00
LABOR+INSTRU RATE ($/MIN)	$0.15	$0.15	$0.15	$0.15
FIXED INSP COST ($)	$1.80	$1.80	$5.40	$0.90
TOTAL INSPECTION COST ($)	$105.84	$107.11	$135.09	$54.37
FIXED COST ($)	$500.00	$500.00	$500.00	$500.00
TOTAL COST ($)	$1,472.84	$1,484.66	$1,067.41	$1,445.59
TOTAL COST AS % OF #4	101.88	102.70	73.84	100.00

Inspection rate varies for different heuristics, depending on number of inspection stations. In Heuristic 1 and Heuristic 2 there are two inspection stations, therefore, the total inspector rate is $0.30/min. ($9*2/60). Similarly the inspector rate can be calculated for other heuristics.

Although there is a reduction in savings (percentage wise) when figures are converted from time domain to cost domain because of additional fixed cost, but the total savings can still turn out to be significant. The actual saving is 26.16% and not 51.49%. In practice this figure should be used instead direct time saving as an indicator of actual savings to be realized.

If due to cost constraint, it is not possible to have an inspection station after each operation, then a cost-benefit analysis will have to be conducted to find out after which operations should inspection stations be located. Trade off will be between the decrease in the batch processing cost versus the increase in the inspection cost. Past work in the field has shown several dynamic programming models for this problem.

6. SUMMARY

The experiments conducted in this research for the four popular inspection station allocation heuristics in serial production systems, the following conclusions are derived.

1. Inspection time is the most influencing factor at the selection of a particular heuristic.
2. When the inspection time is a high percentage of the machining time (above 10%), location of an inspection station after each

operation is preferable so that faster manufacturing lead time can be achieved. This conclusion is quite reasonable since inspection immediately following an operation eliminates the increase increase in time required for inspections at later inspection stations. This results in longer queues at later inspection stations, thereby slowing down the flow shop.

3. As the inspection time becomes a less significant percentage (on the order of 5%) of machining time, it is better to locate an inspection station after the operation likely to produce maximum percentage defective and locate another inspection station at the end of the whole process. An inspection station at the end of each operation is unnecessary to achieve faster manufacturing lead time.
4. When the time required for inspection is a negligible percentage of machining time, then inspection stations should be located before the station with the highest processing time and the end of process. Again, an inspection station at the end of each operation is unnecessary to achieve faster manufacturing lead time.

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