STRATEGIES FOR IMPROVING VISUAL INSPECTION PERFORMANCE

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ABSTRACT

This paper summarizes recent results obtained in inspection studies including several studies performed by the authors. Both static and dynamic visual inspection tasks are included. Based on these results, a proposed new integrated design procedure for inspection tasks that will approach the optimal design has been formulated. The review of recent research results includes the following primary variables: the speed of the item passing the inspector, the spacing of items, the percentage of defective items, the illumination level, the contrast between the item being inspected and the background, and the effectiveness of individual versus group inspection. The authors have used their research results in combination with the results in the literature to formulate new integrated procedures for designing inspection stations and job procedures. The authors have also analyzed the effects of inspector performance on the overall quality control plans already in use in industry. The economic effects of changes in inspector performance which result from redesign of the inspection task are then demonstrated as a part of the overall design procedure.

INTRODUCTION

The topic of visual inspection has been of interest to human factors engineers for many years as evidenced by the number of papers published and presented in this area. A significant increase in the number of product liability cases where damages were assessed against the manufacturer has resulted in a review of the inspection procedures followed by these companies (Levy, 1973). An error made by an inspector results in a cost to the company, regardless of whether a defective product is shipped or a good item is classified as defective and scrapped. This paper is an attempt to present an approach for improving existing inspection systems and also the design of new systems. The approach is presented as a step-by-step procedure in the following sections, with the relevant literature cited in each section.

MEASURING INSPECTOR PERFORMANCE

In order to improve visual inspection performance, it is first necessary to be able to measure inspection performance under the existing conditions. Hoag (1973) has presented an approach for the measurement of both Type I and Type II inspector performance on the production floor. He argues that the evaluation of inspector performance on the production floor is superior to the use of laboratory tests for this purpose. He also presents a procedure for determining the sample size necessary to evaluate the α and β inspector errors for a given level of proficiency, regardless of whether a laboratory or production floor evaluation is performed. The procedure is based on a sequential test of hypothesis and is shown to result in the least cost of any procedure available for this purpose. A summary of this procedure is presented in Appendix A. Murrell (1965) cites a numer of studies relating to inspector efficiency, but the method used to evaluate proficiency is not presented in detail.

Other investigators have employed an informal, "downstream" type of secondary inspection to evaluate inspector performance without using a formal procedure to establish the precision of the measurement. In some instances inspection performance has been measured by using a group of "senior" inspectors to evaluate the other inspectors' performance.

The choice of a method to be used for evaluating inspector performance will depend on the following considerations:

1. The labor relations procedure specified by a union contract for dealing with poor inspectors.
2. The economic cost of an inspector commiting a Type I or Type II error.
3. The time available and the cost of measuring inspector performance.

It will sometimes be found that inspector performance is adequate and no further action is necessary after the measurement has been finished. However, there is often an indication of poor performance. Hoag, Cochran and Oates (1971) reported an inspector detection proficiency of 38% to 27%, while Murrell (1965) cites another study where the inspector proficiency ranged from 32% to 65%. In the following sections, it will be assumed that the objectives of improving inspector performance in existing systems or the design of a new system are to be satisfied.

IDENTIFYING CAUSE(S) OF UNSATISFACTORY INSPECTOR PERFORMANCE

If it is determined from an assessment of inspector performance that the proficiency is less than desired, it is then necessary to identify the cause(s) of the unsatisfactory performance. An initial attempt should be made to assign the principal cause of poor performance to one of the following three general areas:

1. Insufficient training or motivation of the

inspector.

2. An inherent inability of the inspector to sense the information necessary to classify a product as good or defective for certain items.

3. A vigilance decrement of the inspector as a function of the inspection task time interval.

The authors have observed that many inspector errors are the result of faulty training and retraining of inspectors. A common problem is the failure to provide the inspector with an established norm for a defective item which can be referred to as often as needed by the inspector. These norms may be in the form of samples of good and defective products, audio-visual presentations of defective and good items, or simply a tape recorded or written description of good and bad items.

The tendency for inspectors' concept of a defective item to vary over time requires that a re-training program be used regularly with inspectors.

The motivation of inspectors is a complex problem which cannot be dealt with adequately in a paper of this scope. But at a minimum, the inspectors need to know the importance of their work to the correct functioning of the product. Proper training and supervision can help to motivate inspectors as well as monetary or other types of incentives.

If the training and motivation of inspectors is successfully completed and performance still is inadequate, then attention must be given to the reasons for poor performance as stated in items (2) and (3) above. The two broad areas of potential problems are considered in the next two sections.

TASK AND INSPECTOR VARIABLES RELATED TO THE PERCEPTION OF DEFECTS

The inspection task may be considered a reward for good production-line performance in some industries and this selection procedure may result in persons with less than 20-20 static visual acuity being assigned as inspectors. While the testing of an inspector's visual acuity may appear to be obvious, the authors have observed that this is a relatively frequent cause of poor inspector performance. It has been shown by Burg and Hulbert (1959) that dynamic visual acuity may not be related to other visual skills such as static acuity, so it is important to distinguish between tasks that require static acuity versus those that require dynamic visual acuity and test the inspector accordingly.

After determining that the inspectors possess at least 20-20 static visual acuity, the next step in improving the process is an evaluation of the task variables and the re-design of the inspection task as required. The most comprehensive experimental model developed to date (Cochran, Purswell and Hoag, 1973) for dynamic visual inspection tasks offers some insight into the relationship of the primary task variables. The variables studied were:

1. Contrast between defect to be detected and background of the item

2. Illumination of item being inspected

3. Time to view the item being inspected

4. Angular velocity of item as it passed before an inspector

5. The rate of change of the visual angle as the item passed before the inspector

Through the use of response surface methodology the combined effects of these five variables were studied. The two variables found to be dominant in determining inspector performance were illumination and contrast. An illumination level of approximately 100 footlamberts was found to produce peak inspector performance, with levels of illumination at higher values producing a performance decrement. The decrement in performance was not appreciable (approximately two percent) for a range of 75-115 footlamberts of illumination. Thus, if the illumination level is in this range and the color spectrum of the source is satisfactory, illumination can be eliminated as a potential problem area.

A contrast level of at least 60 percent was found to be necessary for approaching the optimal level of inspector performance. Since this task variable is more difficult to control than illumination level for most inspection task designs, it is of interest to consider the interaction of illumination and contrast. Blackwell (1959) had found that the effects of decreases in one of these two variables on inspection performance could be overcome by an increase in the other variable. However, this result was most pronounced at low levels of contrast and illumination (one percent contrast and illumination levels of one footlambert or less), and did not exist at the higher levels which were tested by Blackwell (1959) or Cochran, Purswell and Hoag (1973). For illumination levels usually found for inspection tasks in industry (50-100 footlamberts), there is probably little which can be accomplished by increasing illumination levels to overcome problems of poor contrast.

The variable of time to view an item as it passes an inspector on a conveyor will probably not have a significant effect on performance if the time to view is at least 0.5 seconds for simple tasks. Graham and Cook (1941) and Niven and Brown (1949) found time to view in static visual acuity tests had an effect on performance in the range of 0.1 to 0.2 seconds, but not at higher levels. Cochran, Purswell and Hoag (1973) found that inspection performance was significantly affected for a viewing time of 0.25 seconds, but not at a level of 0.50 seconds. Thus, the time to view may possibly be reduced to less than 0.5 seconds without affecting performance, but levels of 0.25 seconds or less are likely to affect inspector performance significantly.

Angular velocity was found by Ludvigh and Miller (1949, 1954, 1955, 1958) in their numerous studies to have a significant effect on performance in the range of 10 to 170 degrees per second. However, for most inspection tasks, the range of angular velocity is probably going to be 10-30 degrees per second, and little change in performance was found for this range of values.

Rate of change of the visual angle was found to have a significant effect on inspector performance as it interacted with angular velocity (Cochran, Purswell and Hoag, 1973). This result suggests that more research is necessary to investigate this variable, and that it may help to explain some of the problems as presented by

Nelson and Barany (1969) in predicting whether a person will be a good inspector by using a dynamic visual acuity test. The overall problem may be viewed as one of the geometry of the inspection point in relation to the path traveled by items as they move past the inspector.

The environmental variables of noise and temperature have been shown to affect performance above certain levels, but no comprehensive studies of these variables as related to inspector performance have been found by the authors. The NIOSH Criteria Document for Occupational Exposure to Hot Environments (1972) presents data indicating that the environmental temperature should not exceed 87° F on the WBGT scale for unimpaired mental performance for an exposure time of 240 minutes. This value may be viewed as an approximate guideline for the upper temperature limit in designing inspection tasks, but more research needs to be done in this area for inspection. There is very likely to be an interaction of environmental temperature and vigilance which would suggest that a lower temperature level could be economically justified for an inspection station.

It should also be noted that the NIOSH Criteria Document recommends a set of work practices to be followed when the environmental temperature exceeds 76° F for women and 79° F for men as measured on the WBGT scale. These values are probably more acceptable as limits for environmental temperature in designing inspection tasks than the 87° F WBGT level.

Carpenter (1962) has shown that noise can have an affect on performance for inspection tasks when performance on other repetitive, well-practiced assembly tasks will not be affected at the same noise level. The noise level at the inspection station definitely should not exceed the OSHA standard of 90 dbA unless personal hearing protection is provided. In general, it is likely that the noise level for optimum inspection performance should not exceed 80-85 dbA, but more research needs to be done in this area.

After considering the task and environmental variables as presented for designing or re-designing an inspection task, the principal concern remaining to be addressed is that of vigilance. The next section presents this material.

VIGILANCE AND INSPECTION PERFORMANCE

It has been known for years that continuous performance on vigilance tasks leads to a degraded performance after as short a period as one-half an hour. Mackworth (1948, 1950) showed that for a two hour vigilance study the error rates for the four one-half hour periods were 15.7%, 25.8%, 26.8% and 28.0%, and in a second study consisting of one hour of observation the error rates were 24.2% and 30.4%. Hoag, Cochran and Oates (1971) reported actual production floor data on visual inspection of metal parts. The range of inspection errors as a function of time was 5.3% to 12.0% within a two hour period. Colquhoun (1959) reported the results shown in Figure 1. These are consistent with the results of Mackworth and Hoag, et al., and provide a direct comparison between one group of "inspectors" which had frequent rest breaks and the other group which received no breaks.

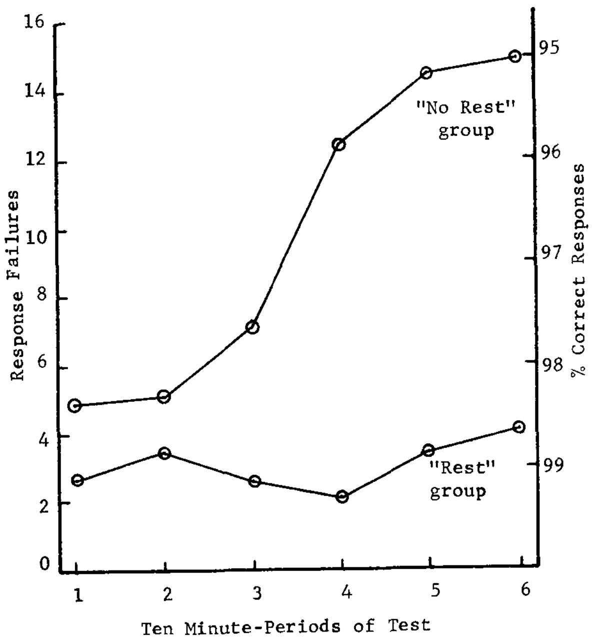

Figure 1. Mean response failures for "rest" and "no rest" groups in successive ten-minute periods of testing time (Colquhoun, 1959).

This decrement in performance can be eliminated by giving the inspectors breaks after thirty minutes of work. It has been shown by Mackworth (1948) that five minute breaks are sufficient and that they do not have to be rest breaks. Any activity which relieves the perceptual and cognitive demands of the inspection task appears to be effective in improving performance. In some situations a five minute rest break after one-half hour of work is more economical than the more traditional schedule of rest breaks in industry.

To illustrate the economics of frequent breaks, an example based on data gathered in an actual production facility will be used. Let's assume that under the traditional system the work schedule and performance is:

7:30- 9:30	work
9:30- 9:40	break
9:40-11:30	work
11:30-12:00	lunch
12:00- 2:00	work
2:00- 2:10	break
2:10- 3:50	work
3:50- 4:00	wash-up time

During the first half hour after the beginning of a shift, a break or lunch, the detection proficiency is 0.85. At other times the detection proficiency is 0.60. Under the new system there are no 10 minute breaks, but a 5 minute break is given after 30 minutes of work. The inspection rate is 12 parts per minute.

Table 1 summarizes the two schedules in terms of total working time, working time at each proficiency level and the required sample size for each lot inspected. A quick review of this table shows that under the "new" scheduling system 55 fewer minutes are spent inspecting per day and under the traditional scheduling system 122 items/lot are required to compensate for the reduced proficiency. Which of the situations is less desirable? One method of answering this question is to determine the number of lots inspected per day per inspector.

Table 1. Comparison of the Traditional and New Scheduling Systems

	Traditional System	New System
Total working time	450 minutes	395 minutes
Total break and wash-up time	30 minutes	85 minutes
Time working at .85 detection proficiency	120 minutes	395 minutes
Time working at .60 detection proficiency	330 minutes	0 minutes
Required sample size including an addition to sample size to account for detection proficiency	293 items/lot for first 30 minutes, then 415 items/lot	293 items/lot

The number of lots inspected per shift would be 16.2 for the "new" schedule and 14.5 for the traditional schedule. If inspector error was not included, 21.7 lots per day could be inspected. Therefore, the existence of inspection error reduces the work output by 33%. By changing the schedule of work and rest periods such that the detection proficiency is increased, the decrease in productivity is reduced to 25%. When the detection proficiency after the first half hour remains above 71%, then the traditional scheduling permits more lots to be inspected and below 71% the new scheduling system permits more lots to be inspected.

Another approach to eliminating the vigilance effect in inspection systems is the use of multiple inspectors, i.e., to use more than one inspector to make the same inspection. Schlegel, Boardman and Purswell (1973) have shown that inspection performance (in terms ot the number of defective items accepted) is significantly improved when a second inspector is added. For the three experimental levels used in their experiment, the probabilities of committing a Type II error for a single inspector were 0.087, 0.159 and 0.097 compared to 0.0, 0.0 and 0.028 for the two-inspector system. Both systems showed a decrement in performance with time, but the two inspector system showed a much smaller change compared with the single inspector system.

Waikar (1973) also investigated the effect of multiple inspectors on the outgoing quality. He concluded that increasing the number of inspectors from one to two, and from two to three inspectors improved inspection performance by decreasing the number of defective items accepted. Increasing the number of inspectors above three did not improve the performance of the inspection system. This result is shown in Figure 2. He further showed that when multiple inspectors are used in a system where all inspectors must recognize a defective item before it is rejected, the number of defective items rejected decreases as the number of inspectors increases.

The economic justification of a multiple inspector system can only be based on a comparison of the cost of incorrect inspection (the cost of scrapped or reworked good items plus the cost of accepting defective items) with the increase in inspection costs. Unfortunately, little work is available in the area of evaluation of the cost of inspection errors that is of a general nature which can be applied to design of inspection tasks.

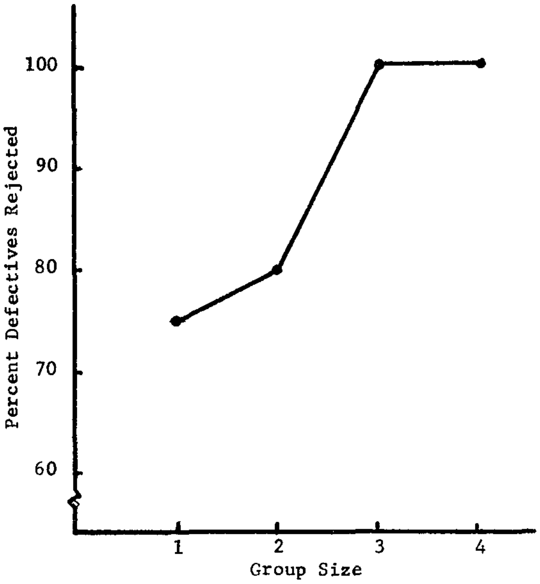

Figure 2. Plot of Percent Defectives Rejected vs. Group Size

SUMMARY

This paper has presented a systematic approach for measuring and improving inspection efficiency based on research completed by the authors and others over the past several years. The approach is also useful in the design of inspection tasks for new production systems.

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APPENDIX A

To evaluate the inspector's performance, two tests are run simultaneously. The first involves rejecting good parts while the second involves accepting bad parts. If only one of the two tests were run or they were conducted at different times, an inspector could defeat the purpose of the test by selecting the proper strategy. For example, if a test of accepting bad parts was being conducted, the strategy of rejecting any part with the slightest imperfection would maximize the inspector's chances of receiving a favorable evaluation.

In general the procedure requires collecting a sample of typical defective parts and good parts. These test parts are intermixed with production line parts before inspection. After inspection the test parts are examined to determine if the inspector correctly evaluated them. The procedure continues until the statistical test is completed.

A detailed discussion of the test procedure with an example follows:

1. Establish the desired probability of accepting good product and the probability of rejecting defective product, e.g., 0.80 and 0.90 respectively. The values selected will reflect the importance of detecting defective material, cost of rejecting good material and cost of conducting the evaluation.

2. Determine the minimum deviation from these probabilities that you wish to detect. For example, you might decide that for the probability of accepting a good product a change to 0.70 is important to determine and for the probability of rejecting a defective product a change to 0.80 is important. In the example we have established the following one-sided tests:

   Type I Error Test

   $H_o:p = 0.80 = P_o$

   $H_1:p = 0.70 = P_1$

   Type II Error Test

   $H_o:p = 0.90 = P_o$

   $H_1:p = 0.80 = P_1$

3. Select the α level (probability of rejecting H_o when H_o is true) and the β level (the probability of accepting H_o when H_1 is true). For our example we we might select $\alpha = 0.10$ and $\beta = 0.20$ for the Type I error test, and $\alpha = 0.10$ and $\beta = 0.05$ for the Type II error test. When selecting α and β levels (also P_o and P_1) two considerations must be balanced: The cost of the procedure increases as precision is increased; therefore, the cost of collecting data must be balanced against the required precision. For example, the β level for the Type II error test was decreased to 0.05 from 0.20 (increased precision) for the Type I error test. This reflects an increased importance of saying that inspectors are performing at the required

level when actually they are performing below this level. This additional precision increases the sample size by 14 observations (see Step 4). Thus, we have increased the accuracy of the procedure by collecting more information.

4. From Table 1[*] we estimate the expected number of parts required to conduct the study by obtaining the sample size for the appropriate α, β, P_o and P_1, then dividing by two. Table 1 gives the sample size required for the conventional test of hypothesis, and the sequential procedure requires approximately half the sample size of a conventional test. This number of parts will be adequate for approximately half the tests.

   The maximum number of data points taken should never exceed the values in Table 1. For our example the expected number of parts for the Type I test is 41 and for the Type II test is 55 for a total of 96 parts. If the maximum number (the number in Table 1) of test parts is arrived at without reaching a conclusion, then obtain the critical "r" values, the number of successes, from Table 2.[*] If the number of correctly identified parts (the number of successes) equals or exceeds these "r" values, accept the null hypothesis; otherwise, reject it. Notice that by increasing α, β, and/or the difference between P_o and P_1 the sample sample decreases. In setting up a test a compromise must be established between cost of the testing and accuracy of the test procedure. Increased precision requires more test parts.

5. From Table 3 determine the rejection limit (log A) and the acceptance limit (log B). In the example, for the Type I error test log A = 0.90 and log B = -0.65, and for the Type II error test log A = 0.98 and log B = -1.25.

6. From Table 4 determine the amounts to be added based on the data. In the example, a = -0.06 and b = 0.18 for the Type II error test a = -0.05 and b = 0.30.

7. Select from production line parts a set of verified defective parts representative of defects typically found at the station and a verified set of acceptable parts.

8. Using a random number table, for example, determine a random sequencing of test parts. Two sequences are required: the sequencing of acceptable and unacceptable parts, and the sequencing of test parts among regular production line parts. The ratio of approximately 1:3 or 1:2 should be maintained between test and the production line parts.

9. After the test parts have been marked so that members of the evaluation team can identify them without the inspectors being able to identify them, the parts are moved to the insertion point. Two men are required at this point: a material handler to place test parts on the line and a man to maintain the random sequencing. After inspection, another team of two men will remove the test parts and determine whether each was identified correctly. For each correctly identified part add "a" to the previous total (for the first part the previous total is zero) and for each incorrectly identified part add "b". The testing procedure ends when both tests have reached a conclusion, i.e., the totals are greater than their respective log A's or less than their respective log B's.

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[*] Because of the size of Tables 1 and 2, only a small portion of each is shown here. For the complete tables see Hoag (1973).

Table 1. Sample Size for a Conventional Test to Evaluate Inspector Performance

α	β	P₀	P₁ 0.60	P₁ 0.70	P₁ 0.80
0.05	0.05	0.70	244		
		0.80	54	200	
		0.90	19	39	133
	0.10	0.70	191		
		0.80	[illegible]	155	
		0.90	14	30	102
	0.15	0.70	160		
		0.80	34	129	
		0.90	12	24	83
	0.20	0.70	136		
		0.80	29	109	
		0.90	10	20	69
	0.25	0.70	118		
		0.80	25	94	
		0.90	8	17	59
	0.30	0.70	103		
		0.80	21	81	
		0.90	7	14	50

Table 2. Critical Number of "Successes," r, for the Test to Evaluate Inspector Performance

α	β	P₀	P₁ 0.60	P₁ 0.70	P₁ 0.80
0.05	0.05	0.70	133	129	
		0.80	26	[illegible]	
		0.90	8	23	98
	0.10	0.70	106		
		0.80	21	101	
		0.90	6	17	76
	0.15	0.70	89		
		0.80	17	84	
		0.90	5	14	62
	0.20	0.70	77		
		0.80	15	72	
		0.90	4	12	52
	0.25	0.70	67		
		0.80	13	63	
		0.90	3	9	38
	0.30	0.70	59		
		0.80	11	54	
		0.90	3	9	38

Table 3. Acceptance and Rejection Limits for Performance Tests

α	Limit	β 0.05	β 0.10	β 0.15	β 0.20	β 0.25	β 0.30
0.05	Rejection	1.28	1.26	1.23	1.20	1.18	1.15
	Acceptance	−1.28	−0.98	−0.80	−0.68	−0.58	−0.50
0.10	Rejection	0.98	0.95	0.93	0.90	0.88	0.85
	Acceptance	−1.26	−0.95	−0.78	−0.65	−0.56	−0.48
0.15	Rejection	0.80	0.78	0.75	0.73	0.70	0.67
	Acceptance	−1.23	−0.93	−0.75	−0.63	−0.53	−0.45
0.20	Rejection	0.68	0.65	0.63	0.60	0.57	0.54
	Acceptance	−1.20	−0.90	−0.73	−0.60	−0.51	−0.43
0.25	Rejection	0.58	0.56	0.53	0.51	0.48	0.45
	Acceptance	−1.18	−0.88	−0.70	0.57	−0.48	−0.48
0.30	Rejection	0.50	0.48	0.45	0.43	0.48	0.37
	Acceptance	−1.15	−0.85	−0.67	−0.54	−0.45	−0.37

Table 4. *Amounts Added (A) When Response is* Correct and Amount Added (B) When Response is Incorrect

P₀	P₁	log P₁/P₀ = a	$\log \frac{1 - P_1}{1 - P_0}$ = b
0.70	0.60	0.07	0.10
	0.70	0.00	0.00
	0.80	N.A.	N.A.
0.80	0.60	−0.12	0.30
	0.70	−0.06	0.18
	0.80	N.A.	N.A.
0.90	0.60	−0.18	0.60
	0.70	−0.11	0.48
	0.80	−0.05	0.30