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IMPROVEMENT OF INSPECTION PERFORMANCE

BY

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Major Professor

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INTRODUCTION

Westinghouse Electric Corporation, located in Salina, Kansas manufactures two different types of lamps. One is a four-foot 40-watt bulb while the other is an eight-foot slimline or 75-watt model. Both lamps are made in a variety of colors.

One area of concern to the Quality Evaluation Systems Department has been the manufacture and particularly the inspection of the lamp bulb ends (called mounts henceforth). Faulty mounts, once past the present inspection station, cannot be 100% accurately detected until the bulb is fully assembled as a finished product. Thus this particular inspection process has considerable importance.

Four assembly lines, two lines for the slimline and two for the 40-watt bulbs, presently are in operation. Each assembly line is supplied by two different mount manufacturing lines, one a tubular and one a nontubular line, making a total of eight mount manufacturing lines with one manual inspection station each.

The mounts from the two types of lamps are similar except in the type of coating and the mounting of the filament. In addition each type of lamp has two different types of mounts, one that is sealed shut (nontubular) and one with an evacuation tube to remove the air in the lamp and allow for the addition of inert gas and mercury before being sealed off (tubular). In general, the mount ends are inspected for the same things (see Appendix A).

The shift system is rather complicated in that the inspectors work four days, are off three days, then work three, and are off four. There are two shifts, the day shift that works from 6:00 a.m. to 6:00 p.m. and the night shift that works from 6:00 p.m. to 6:00 a.m.

These shifts are divided up into eight teams one team for each mount manufacturing line. The teams are made up of four individuals each; they rotate from tubular inspection, to nontubular inspection, to assisting, and to break, on a pre-arranged schedule, approximately every 20 minutes.

Two mount manufacturing lines/assembly line, two assembly lines/shift, two shifts/day, two crews/week and four individuals/mount manufacturing lines means that a total of 32 different individuals are involved in the inspection process of just the 40-watt bulbs during the course of one week. In addition there are 18 different individuals involved in the manufacture of the slimline model.

The slimline inspectors receive the mounts and must transfer approximately 75% of these to the demand conveyor. Of those 25% excess pieces/h, the ones that are not defective are put into storage trays for use when the mount manufacturing machine is not in operation. This presently requires a mean transfer and inspection time of approximately 2.45 s/part.

The 40-watt inspectors receive the mounts at an erratic rate and must transfer approximately 85% to the demand conveyor which runs at a constant rate. The extra 15% also are stored in trays. Thus the 40-watt operator acts as both a "shock absorber" and an inspector who presently must transfer and inspect the lamp bulb ends at a rate of 1.4 seconds/part. These inspectors remove the mounts from one conveyor which is moving left to right and transfer it to another conveyor which also is moving left to right at a different (slower) speed (see Figure 1). The extra mounts are placed into trays for storage to be used during the time when the machine which

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manufactures the mounts is not operational. These trays hold 25 pieces each. The trays when full are accumulated in bins until a total of 6,000 mounts has been reached. The storage of mounts in the trays may help the inspection process in that the mounts potentially might be inspected twice. It may, however, hinder in that the temperature of the mount would be reduced, thereby making the glass less workable.

In addition to the mount inspection station, the bulbs undergo additional automated inspections after they are assembled. However, these inspections are not 100% effective as they do not detect Class II and Class III (see Appendix A) defects which cause shortened life of the lamps (reduced percent of normal life) rather that immediate failure.

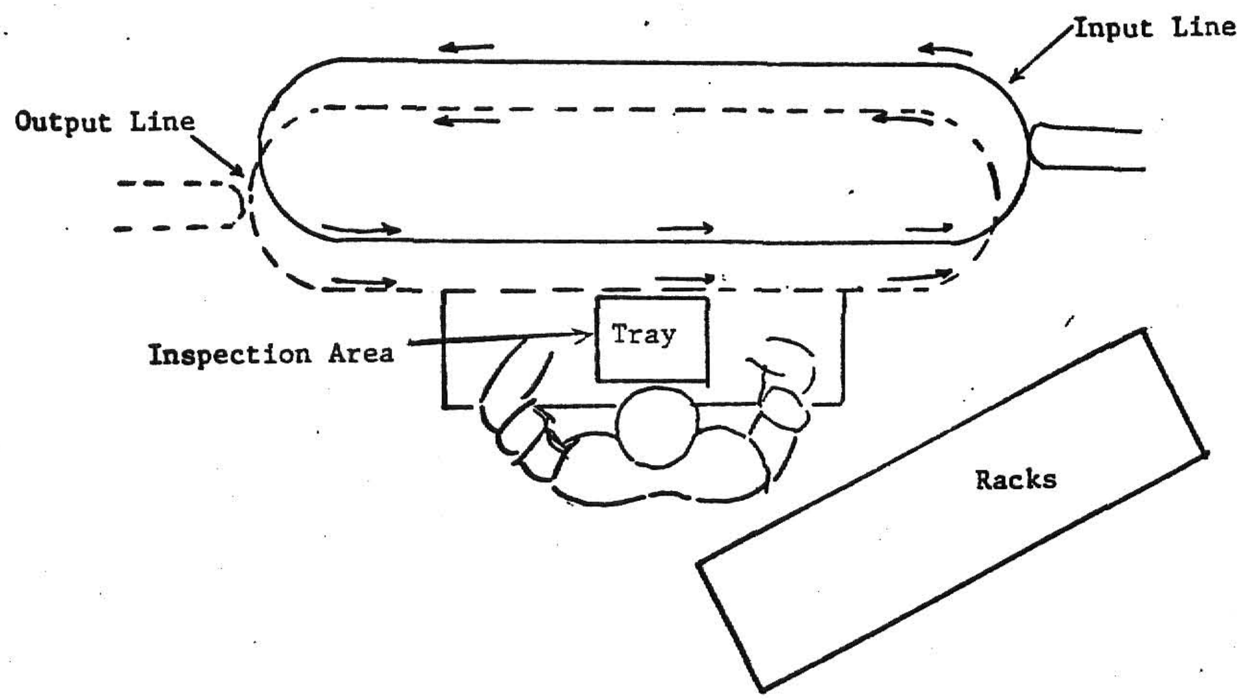

FIG. 1: THE PRESENT MOUNT INSPECTION STATION ARRANGEMENT.

The cost of a short life bulb shipped from the manufacturer is significant. If caught at the lamp bulb inspection or the final inspection station a savings of approximately 88% can be realized on the manufacture's cost.

Presently there are six automated inspection stations and two manual inspection stations per line, totaling eight inspection stations a lamp must pass before being packed (see Fig. 2). These are described as follows:

A. Mount Making Machine or Automount

There are two automounts per manufacturing line. One produces tubular mounts and the other produces nontubular mounts. The two lead wires and a tungsten wire are assembled with the glass flare. The assembled mount is checked automatically for the presence of both kinds of wires. If either one of them is missing the mount is kicked off the line. A counter at this station is capable of measuring the number of rejections; however, it is not being used presently.

B. Manual Inspection Station

At the manual mount inspection station an inspector visually checks for 32 other major or minor defects (see Appendix A). In addition, the inspector has to transfer the mounts to one of three places, the outgoing conveyor, storage trays or, if they are bad, a disposal bucket. This station is considered to be the most crucial from an efficiency improvement point of view, because here is the only place where human error can occur.

C. Automated Leaky Tube Station

This station is located downstream from the mount sealing machines (see Figure 2). There are 62 positions for holding the rejected tubes at this station. Here the tube is inspected automatically for the following defects:

Defect	Control Panel Indicator
Leakage	Orange
No lead wires at the nontubular end	Blue
No lead wires at the tubular end	Green

Here the operator attempts to repair the automatically rejected tubes; about 20% to 30% of the tubes are salvaged and reused.

D. Automated No Light Station

Located here are three ozone arc guns which are used to check the pressure and mercury content level. If the bulb shows any one of the following three defects, it is automatically removed.

Indicator	Defect
Purple Ring	Leakage
Yellow Ring	Absence of Inert Gas
Dead	Broken, Damaged, etc.

E. Automated No Base Inspection Station

Here the inspection is handled by two photocells which detect the presence of a base (a base is the black plastic cap on either end). If a base is missing, the tube is kicked out to an operator who puts on a new base and returns the lamp, saving about 90% of the rejected lamps.

F. Automated Bottom Pan Station

At this station a weak current is passed to check the resistance

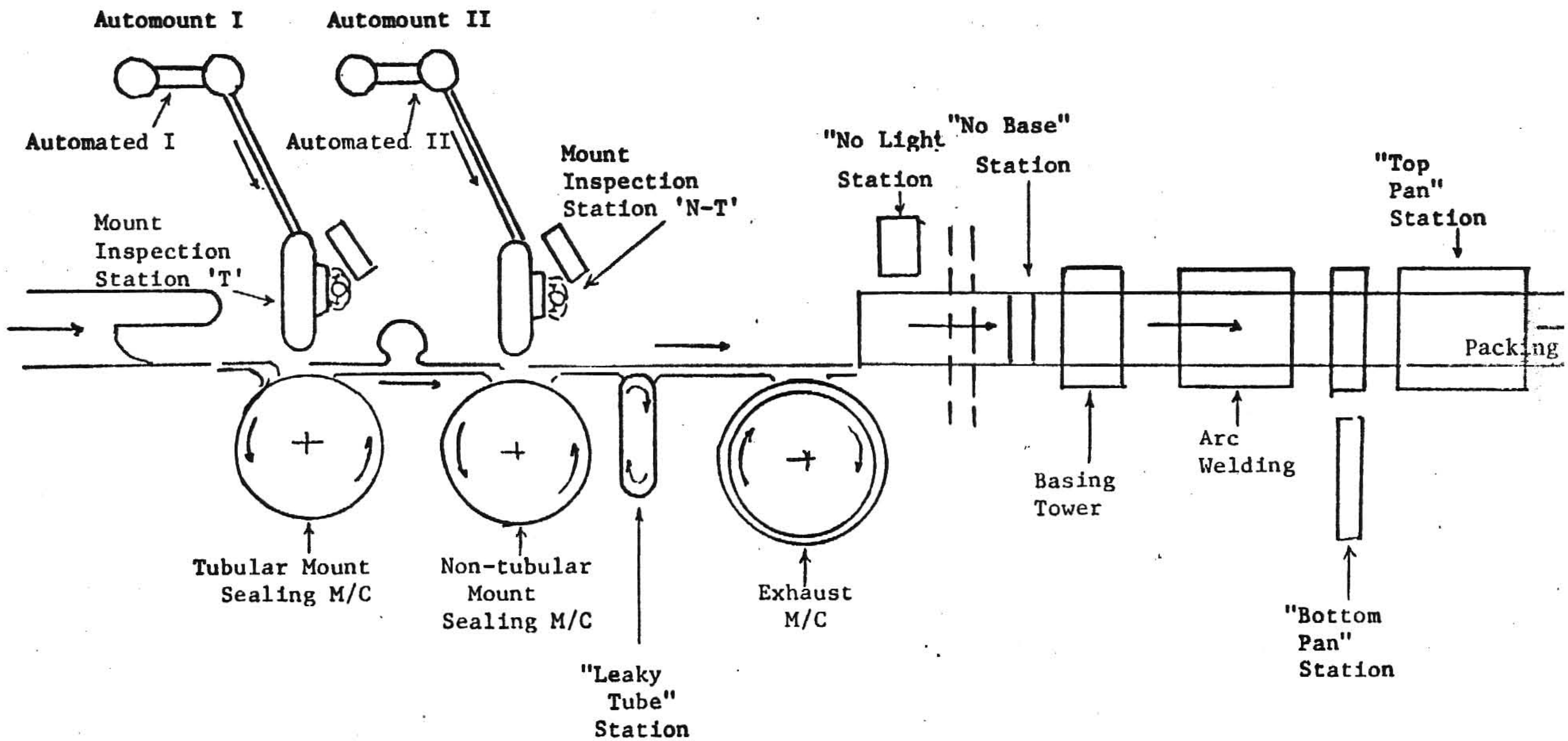

FIG. 2: 40-WATT BULB MANUFACTURING LINE (HAP I).

of the mount wires. If the observed resistance is matched with the known resistance, the tube is accepted; otherwise it is rejected. This is an important continuity test which rechecks for some of the same defects as the mount inspector such as clamp defects or missing coils.

G. Automated Top Pan Station

This is last automatic inspection station. Here the tube is lit up by 101-105 V AC supply (lower limit of the household supply). The intensity of the light is compared with the known amount using photocells.

The hypothesis to be tested in this study was that the use of a magnification lens of 2x to 4x power, increased lighting, and a constant background could increase operator efficiency, provide more visual comfort and thus increase performance.

OBJECTIVE

The objective of the study was to increase the quality of the inspection process and, in turn, increase the quality and decrease the cost of the product.

METHOD

This study dealt with two major areas, magnification and lighting. Although there are numerous other factors which could affect or increase the quality of the inspection process they were not dealt with at this time. In addition all tests were run on the 40-watt line called HAP I (Highly Automated Production), to minimize the effect of belt speeds and machine variance.

Basically there was a series of three test runs. The first test was run in order to establish the present operating efficiency of the system as it now exists. Second, a test was run which examined the effects of magnification (both 2x and 4x). Third, a test was run which examined the effects of increased lighting, the orientation of the present lighting scheme, and the effect of various background conditions.

This resulted in tests at the two inspection stations structured as follows:

Test No.	40-Watt Nontubular	40-Watt Tubular
1	Control and Initial Quality Measurement	Control and Initial Quality Measurement
2	2x Magnification	4x Magnification
3	Increased Lighting and Improved Direction	Background Conditions

Since the tubular and nontubular mounts on one line are inspected by the same people at the same rate, for the same assembly line, and the inspection stations are identical, there should be no significant variance in the total percentage of defects missed.

TEST 1

The first challenge which had to be overcome was that of assessing the quality of the bulbs as they came off the line. This was a particularly difficult task because not all of the defects for which the ends were inspected result in immediate failure. Some may just cause shortened life and leave the plant undetected (see Appendix A).

The first test was run in order to establish the present quality being achieved, as a base from which to work. The results of this test then were used as a control to determine if any significant change in quality had occurred.

The mounts of the defective bulbs from the bottom pan were cut off and examined for defects. These defects were classified into various groups (see Appendix B) and compared with the defective mounts found by the mount inspector station. A percentage of defects found at the mount inspection station was calculated.

$$\frac{\text{(\# found by mount inspectors)}}{\text{Total found by inspectors and in bottom pan}} = \text{Percent defective}$$

From this data an approximation of the total number of defects and the number of each type that reach this point was made without isolating one operator or one particular time of day. A record of the time, number and type of defects, and inspectors working was kept. The same system was used after each of the subsequent tests and the defects recorded and compared in a similar manner.

TEST 2

There are several factors affecting the seeing task. These factors include the size of the work contrast and brightness. As size increases, visual acuity increases, and up to a certain point, makes the tasks easier. Guidelines for the design of microminiature work are few in number. For example, level of magnification for a given task rarely is specified. However, Nayyar and Simon (1963) and Smith and Adams (1969) showed that magnification increases performance on microminiature tasks. In those cases in which a level of magnification is specified, there appears to be no factual or rational basis by which the levels are chosen. In addition, there is a dearth of published experimental information available (see Simon, 1964).

Here, the question arises can magnification be used to improve inspector performance, without interferring with the actual task at hand? Some studies seem to indicate that depth of field may be a problem but otherwise magnification has benefits. In order to answer this, two tests were run:

(1) On the nontubular HAP I Line, a 2x magnification lens was installed.

(2) On the tubular HAP I Line, a 4x magnification lens was installed.

These magnification lenses were installed with the advice of inspectors who are presently working. They were mounted out of the way of work yet in such a location so as to be helpful in the inspection process. Three choices existed for placement. First, locate the magnification on the area where the mount was picked up. Second, locate the lens at the point where the mount was placed on the removal conveyor. Third, locate the lens downstream after the transfer so that the inspector could inspect the mounts after the transfer occurred.

Again the mounts of the defective bulbs from the bottom pan were to be cut off and examined for defects. These defects were to be classified and compared with the defective mounts found by the mount inspector station. A percentage of defects found at the mount inspection station also was to be calculated $\frac{\text{(\# found by mount inspectors)}}{\text{Total found}}$.

TEST 3

It has been accepted widely that good lighting is essential in reducing visual fatigue (Ferguson et al, 1974) and in increasing fault conspicuity.

The most obvious way in which the illumination can be varied is by changing its intensity. A large body of research exists which has been directed at defining the relationship between task brightness and task performance levels (Konz and Wei, 1978). However, this field of research has been characterized by controversy. Some report that visual performance continues to improve as the quantity of light is increased to levels of 10,000 lux or more, whereas in the American IES Code (1972) levels of 500, 1,000 and 2,000 lux are given for ordinary, difficult and highly difficult inspection work. These values are based on Blackwell's findings that low contrast targets can be made equally as visible as high contrast targets by increasing the levels of illumination (Blackwell, 1959). Others have indicated that there are no additional improvements at levels higher than 500 lux. A review of the research conducted from 1950 to 1970 has been provided by Hopkins and Collins (1970). The more recent research has become increasingly sophisticated and complex but questions continue to be raised about the validity of proposed methods of specifying the optimal levels of illumination needed for various tasks (Faulkner and Murphy, 1973) (Bellchambers and Philipson, 1962).

There are a few studies which have used performance measures to evaluate different qualities of lighting. Lion et al (1968) compared performance on a simulated inspection task under tungsten and fluorescent lighting. Feinstein (1970) reported improvement in the inspection of worsted cloth after the introduction of oblique lighting and Boyce and Simons (1977) measured color matching performance under different types of fluorescent tubes.

In their study on the inspection of cold-rolled sheet steel, Dekoker and Frier (1969) described how the optimal lighting conditions can be reached. Two types of fault were involved, those with different specularity and those resulting from a distortion of the surface.

The conclusion that more than one type of lighting is necessary when there are faults with different characteristics is reinforced by a study by Gillies (1975) involving the redesign of a work-place for the inspection of large heavy glass items.

Before testing started the level of illumination on the task at the 40-watt inspection station was 550 lux and at the slimline station it was 1,000 lux.

The light at the 40-watt mount inspection station was provided by two cool white 40-watt bulbs, approximately 36 inches above the work station. The orientation of the light was actually behind the place of where the inspection took place, putting the light further away from the operator.

The question arises, how do we improve the inspection station by varying the lighting? Based on the previous studies cited and literature reviewed, two changes were investigated.

(1) On the nontubular HAP I Line, the level of illumination was increased to a level of 1,000 lux. This is the level recommended by the 1972 American IES Code for difficult tasks.

This level of illumination was obtained with a combination of general lighting plus specialized supplementary lighting. The code also specifies that the design and installation of the combination system must not only provide for sufficient amount of light, but also the proper direction of light, thus requiring that the work station supplementary light be reoriented so that it would shine on the area where the inspection is taking place as opposed to the area from which the parts are picked up.

(2) The second test involved the use of an opaque background. Various colors including red, blue, white, yellow and a cream color were sampled by the inspectors for short periods of time and one color was selected. This was then to be placed as a background to the inspection task and used for a 12-hour period, with data collected in a manner similar to previous tests.

As far as is known, inadequate lighting is not physically harmful and good lighting does not preserve eyesight. Good lighting would, however, lessen eyestrain, fatigue, and frustration; and thus, improve efficiency and comfort while the inspection tasks were being performed. Therefore, by improving lighting conditions the task became less fatiguing and more effective.

CRITERIA

With this series of tests the increase in percentage of defects and the quality of the bulbs as determined by the mount inspection stations was determined.

Upon completion of each series of tests the operator was asked a series of questions and the responses tabulated (see Appendix C). These questions were designed to assess the operator's opinion of the particular changes implemented.

RESULTS

TEST 1 - CONTROL

On January 15, 1980, starting at 6:00 a.m. and continuing for 12 hours all of the defective bulbs from the bottom pan inspection station on HAP 1 were collected and saved. In addition, all of the defective mounts from both the tubular and nontubular mount inspection stations on HAP 1 were retained. In all 200 lamps and 599 mounts, 212 tubular and 387 nontubular, were gathered.

The defective lamps were cut open, the ends inspected and the mount defects classified and recorded (see Appendix B for a complete listing of defects). In addition, all of the rejected mounts were reinspected and the defects classified and recorded. A summary of those defects is shown in Table 1.

Table 1. Summary of Defects From Test 1.

Defect	(1) No. From Mount Inspection Station	(2) No. From Lamps at "Bottom Pan"	(3) % Detected (1)/(1 + 2)
Tubular			
Dumet	13	24	35%
Coil	65	11	85%
Clamp	63	27	70%
Emission	35	1	97%
Misc.	144	10	93%
Total	320	80	80%
Nontubular			
Dumet	13	18	42%
Coil	53	10	84%
Clamp	42	9	82%
Emission	7	1	87%
Misc.	91	10	90%
Total	206	53	79%

The results of this first test indicate that the inspectors at the tubular and nontubular mount station are not detecting an equal percentage of each type of defect, but they are failing to detect an approximately equal proportion (20%) at each station. This 20% figure does not include the rejection figures at any of the other inspection stations, but rather gives a base line for judging the effect of any changes which might be made in the future. Rejection made at the other lamp inspection station have relatively little to do with the quality of the mount. This accuracy should remain relatively constant even during times of machine difficulty.

One item of particular interest is that the total number of defective mounts, including both those found at the mount inspection station and those found in the defective bulbs, constitute only approximately 2% of the total mounts produced during this 12-hour period. This figure was calculated by dividing the total number of defective mounts by the total mounts produced during the same time period.

A second item of interest is that the percentage of dumet defects found in both the tubular and nontubular mounts is considerably lower, 35% and 42% of the total defects respectively, than for any other type of defect. That is, the inspectors miss 60%.

TEST 2 - MAGNIFICATION

On Thursday, March 6, 1980, some preliminary tests were run to determine, in the inspectors opinion, the optimum placement for the magnification lens. This consisted of placing the magnification lens and performing the inspection task on HAP II during repair time. None of the three positions tried proved significantly better than the others.

On Friday, March 7, 1980, at 5:30 a.m. an attempt was made to mount the lenses, 2x on the tubular and 4x on the nontubular, on the lines. The first position tried was one which attempted to encompass the entire procedure. This resulted in two major difficulties.

(1) The lens prohibited performing the inspection task, i.e., it prevented the operator from carrying on the transfer task efficiently.

(2) The inspectors judgment of distance and depth-perception was altered, resulting in the breaking of mounts and what appeared to be an immediate danger to the operator's safety due to the breaking glass.

Minor adjustments or moving the lens by hand were not satisfactory.

In a last attempt to place the lens in a position of usefulness, yet not impair the inspection process, the lens was located downstream from the operator so that the mounts could be viewed under magnification after they had been loaded. This proved unsatisfactory in two ways. First, if the operator fell a little behind, she had difficulty loading the mounts because of the lens and second, the inspectors are required to work at a speed which is so demanding they have little or no time in which to inspect mounts after they have been loaded.

Within one hour after the start of the test the lenses were removed because they proved to be too much of a hinderance to job performance and safety. It would appear that the use of magnification in a task requiring the transfer of parts from one place to another, such as this one, is unfeasible. In addition, the reduction of visual depth perception could prove to be dangerous considering all of the moving machinery and potential hazards to an operator.

TEST 3 - LIGHTING AND BACKGROUND

On Thursday, March 6, 1980, starting at 6:00 a.m. and continuing for 12 hours, Test 3 was run on HAP I.

On the nontubular machine the lighting fixture was cleaned, the bulbs replaced, and the fixture both lowered (approx. 8") and focused more directly on the work space. This was done with the consultation of an operator while working, in order that the light would not glare in her eyes, increasing eye fatigue. By 6:00 a.m. an agreeable position had been reached, and the lighting level on the work station has been improved to 1,000 lux.

On the tubular mount machine, colored backgrounds (red, white, yellow and a cream or off-white color)(see Fig. 3) were experimented with for a short periods of time. Figure 4 shows a sketch of the background location. Various comments were made on each by the inspectors. They felt that the white would be best except that it caused too much glare. Therefore, the off-white was selected and installed. Both the yellow and red seemed to be too "bold" or "different" as described by the inspectors (see Fig. 3).

Both the lighting and background test started at 6:00 a.m. and continued for 12 hours (see Appendix B). At the end of the test period, while removing the background and returning the light to its previous position, both the line supervisor and the inspectors requested that the stations be left as they were during the test. They found this "more comfortable" and "better". Table 2 shows a summary of the defects as collected in Test 3.

From Table 2 it appears that a significant improvement has been made in detection of defects by the addition of an opaque off-white background in the areas of the coils (85% to 93%) the clamping of coils (70% to 91%), and minor improvements were made in dumet defect detection. However, a reduction in the detection of emission defects (97% to 87%) occurred. This improvement and reduction both can be attributed to the contrast of the inspected part with the background. While the coils and clamps contrast quite well, the emission (which is white) apparently is more difficult to discern when placed in front of an off-white background. The addition of the off-white background would result in a reduction in the number of dumet defects overlooked by each operator of approximately 52/hr.

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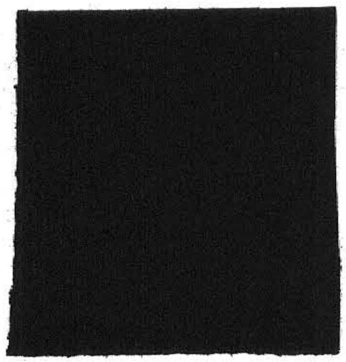
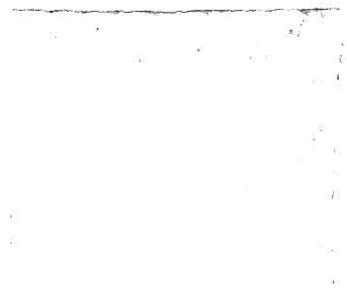
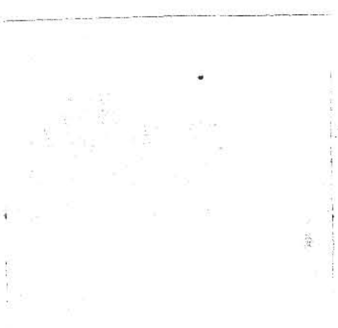


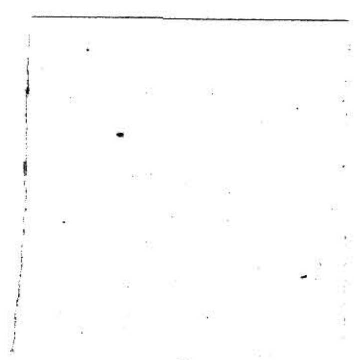
RED



WHITE



YELLOW



OFF-WHITE

FIG. 3: COLOR SAMPLES FOR TEST 3 (BACKGROUND)

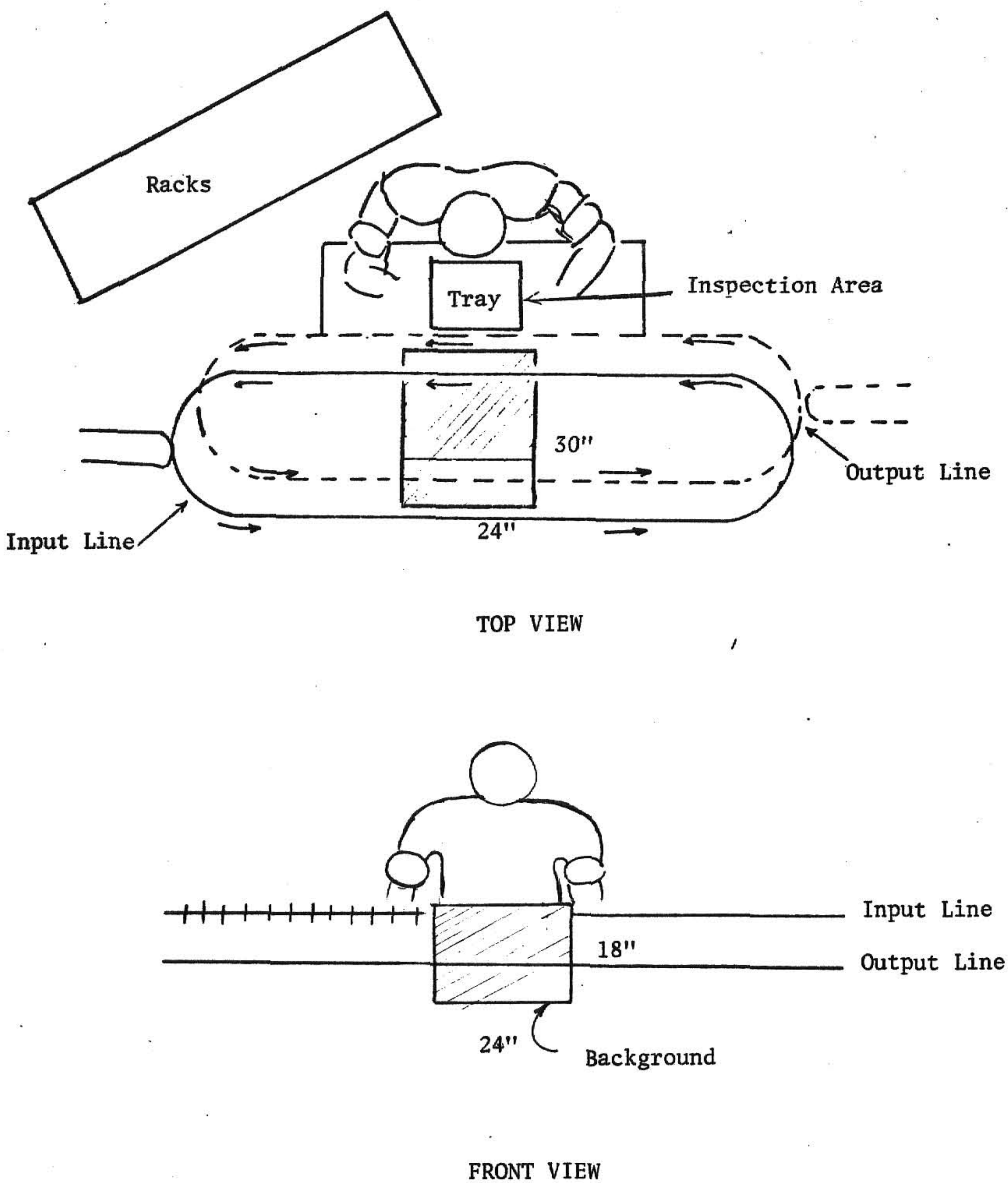


FIG. 4: BACKGROUND LOCATION

Table 2. Summary of Defects From Test 3.

Defect	(1) No. From Mount Inspection Station	(2) No. From Lamps at "Bottom Pan"	(4) % Detected (1)/(1 + 2)	Change (3)-(4)
Tubular (Improved Background)				
Dumet	13	22	37%	2%
Coil	53	4	93%	8%
Clamp	59	16	91%	21%
Emission	34	5	87%	-10%
Misc.	116	6	95%	2%
Total	275	53	84%	4%
Nontubular (Improved Lighting				
Dumet	17	10	63%	21%
Coil	63	10	86%	2%
Clamp	37	7	82%	0%
Emission	11	2	85%	-2%
Misc.	110	8	93%	3%
Total	238	37	86%	7%

The results from the test involving improved lighting at the work station had a large effect on detection of the dumet defects, which improved by 21% (42% to 63%). Coil and miscellaneous improved 2% and 3%. Emission was 2% worse. However, the overall effect was what was anticipated. The success of increased lighting in increasing the inspection quality is probably due to the fact that the lighting was increased from 550 lux to 1,000 lux. This amount (1,000 lux) was selected because it could be done without a complete restructure of the existing lighting set up.

The financial benefit which could be gained by these changes can be evaluated by placing a hypothetical finished product cost of $1.00 on the completed lamp after it is packed. In this same manner we then can establish that detection of a faulty mount, which results in zero lamp life, at the mount inspection station will result in a hypothetical savings of $.88/lamp. This figure is based on the actual cost figures.

Failure to light can be detected with 100% accuracy at the "no light" station. The savings realized by the detection of those defects which result in shortened life is more difficult to assess in that not only is there a loss in that single lamp but future sales also are affected along with the customers opinion of product reliability. I will assume an estimated cost of $.05/lamp.

The results of the questions asked of the four operators are shown in Table 3.

Table 3. Responses to Operator Questions

Question No.	Magnification 2x Yes	Magnification 2x No	Magnification 4x Yes	Magnification 4x No	Increased Lighting Yes	Increased Lighting No	Improved Background Yes	Improved Background No
(1) Was this change helpful?		4		4	4	0	3	1
(2) Did this modification allow more time to inspect the mounts?		4		4	0	4	0	4
(3) Should this change be implemented?		4		4	4	0	3	1

RECOMMENDATIONS

Based on the previously described tests the following is a summary of recommendations accompanied by the justification for each.

(1) Transfer the mounts from the automount to the lamp assembly machine mechanically. The present process utilizes an inspection person as a transfer mechanism. This requires that the primary function be to physically move the mounts and relegates the inspection process to one which occurs only when time permits. By transferring the mounts mechanically the primary function becomes inspection. This allocates more time for this task. In addition, with the mechanical transfer a reduction in hand movement can be achieved and magnification then may be feasible.

(2) Increase the lighting level to 5,000 lux or more. This is the amount specified by the 1972 IES Code for very difficult tasks. An increase in overall inspection performance (number of defects found at mount inspection station divided by the total number found during the testing time) from 79% to 86% was experienced by increasing the lighting level to 1,000 lux. Although this improvement is not linear, a continuing increased inspection performance rate could not reasonably be expected, but some additional increase could.

(3) Install an off-white opaque background at each work station, as shown in Figure 4. The test involving the opaque background indicates an overall improvement in performance due to the addition of the background (80% to 84%). Although there is a significant

reduction in the detection of emission defects, these are responsible for only 44 of the 599 defects, approximately 6%. The tremendous improvement in the detection of both coil and clamp defects more than compensates for this by improving the overall inspection quality by a total of .08% of all mounts produced (47% reduction in mount defects) x (2% of all mounts produced are defective).

(4) Continue research into the identification of a background material which would contrast with both the coil and clamps and also the emission. This would reduce the negative effect of the off-white background and still show a significant increase in the detection of coil and clamp defects. Various other colors were experimented with by the author (pale blue, light green and dark blue). Of these, the pale blue appeared most acceptable.

Hopefully the combination of these four changes would increase the inspection quality thereby improving the overall plant efficiency.

We have not considered the effects of any duplication of improvement in defect detection caused by these changes (i.e., although the lighting increased inspection performance by 7% and the background changes improved it by 4% a total improvement may not be 11% due to duplication). We could estimate the effective savings as follows:

x = number of lamps produced during a 12-hour period.

1.00 = the hypothetical unit cost of one lamp.

(1.00)(x) = the unit cost of x lamps.

(2)(x) = 2x = the number of mounts produced during a 12-hour period.

(2%)(2x) = (.04x) = the number of defective mounts produced during a 12-hour period. Two percent is the overall percent of defective mounts.

(.04x)(11%) = (.0044x) = the reduction in the number of defective mounts produced during a 12-hour period due to recommendations 2 and 3 (lighting improvement and background installation).

(.0044x)(.88) = .00387 x = effective dollar cost savings of x lamps over a 12-hour period.

From this figure a hypothetical savings in dollars/week for one line can be calculated as follows.

(.00387)(x) for one line over a 12-hour shift. In one week there are approximately 12.5 operating shifts.

[(.00387)(x)] (12.5) = (.048375)(x)

If there are 25,000 lamps produced per shift (or x = 25,000) the result is (.48375)(2,500) = $1209/week on each line.

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APPENDIX A

DEFINITION OF A DEFECT

The types of defects are divided into four classifications. Class I are those which are critical and will result in detection at the bottom pan station by failure to light. Class II are those which may or may not result in immediate but will result in shortened lamp life or color distortion. Class III are those which may not result in shortened life or color distortion, but should be avoided. Class IV are those which are a progressive type of machine errors which occur slowly and should be eliminated immediately upon detection by the linesman.

CLASSIFICATION OF DEFECTS (MOUNTING)

CLASS I (Critical; failure to light at bottom pan)

101 - High air line
102 - Exposed inner knot
103 - Broken or cracked glass
104 - Wrong coil
105 - No blow hole
106 - Coil out of clamp
107 - Bubbled dumet
108 - Red dumet
109 - Multiple coils or wires
110 - Misplaced wire
111 - Oil or grease
112 - Damaged coils
113 - No coil
114 - Burned dumet
115 - Wire or glass adhered to mount
116 - Coil broken

CLASS II (Shortened lamp life, poor color)

201 - Emission on wires
202 - Emission length
203 - Scissor clamp
204 - Off center flare
205 - Crooked or off-center tube
206 - Poor dumet seal
207 - Coil out of clamp pocket
208 - Coil loose in clamp

<u>CLASS III</u> (Avoid if possible as it results in possible failure)

301 - Emission coverage poor
302 - Blow hole small
303 - Blow hole shape poor
304 - Coil off center
305 - Ridged flare
306 - Out of round flare
307 - Burned dumet
308 - Foreign material on mount

<u>CLASS IV</u> (Progressive machine errors; special tests off line)

401 - Clamp thickness wrong
402 - Clamp spacing before stretch wrong
403 - Clamp spacing after stretch wrong
404 - Hook depth wrong
405 - Emission weight wrong
406 - Strain excessive
407 - Flat thickness wrong
408 - Re-entrant angle poor

APPENDIX B

Test 1 Results

Defective Bulbs   Number *186 x 2 = 372 Mounts

DEFECT	# TUBULAR	%	# NONTUBULAR	%
Dumet				
Red	16		13	
Burnt	8	33	5	37
Coil				
Double	3		1	
Skeleton	1		0	
Broken	5		6	
No Coil	2	15	3	21
Clamp				
Out of Clamp	19	37	2	
Loose	3		5	
Scissor	5		2	19
Emission				
Length	1		1	
Weight	0		0	
Coverage	0	1	0	.5
Misc.				
Glass Chipped or Cracked	1		3	
Air Bubbles	2		2	
Bad Lead Wire	2		3	
Triple Wire	0		0	
Knot	5	14	2	22.5
	73	100	48	100

*NOTE: Dead bulbs were not included. (14)

Test 1 Results (Cont'd)

Defective Mounts

DEFECT	# TUBULAR	%	# NONTUBULAR	%
Dumet				
Red	11		9	
Burnt	2	4	4	6
Coil				
Double	21		43	
Skeleton	3		1	
Broken	5		1	
No Coil	36	19	8	25
Clamp				
Out of Clamp	5		8	
Loose	5		3	
Scissor	53	19	31	20
Emission				
Length	29		2	
Weight	3		1	
Coverage	3	10	4	3
Misc.				
Glass Chipped or Cracked	63		49	
Air Bubbles	11		4	
Bad Lead Wire	19		9	
Triple Wire	17		16	
Knot	31		3	
Misc.	3		10	
O.K.	17	48	6	46
	337	100	212	100

Test 3 Results

Defective Bulbs

DEFECT	# TUBULAR	%	# NONTUBULAR	%
Dumet				
Red	13		6	
Burnt	9	41	4	27
Coil				
Double	1		1	
Skeleton	0		1	
Broken	3		3	
No Coil	0	7	5	27
Clamp				
Out of Clamp	12		2	
Loose	2		4	
Scissor	2	30	1	19
Emission				
Length	3		2	
Weight	0		0	
Coverage	2	9	0	5
Misc.				
Glass Chipped or Cracked	0		2	
Air Bubbles	3		2	
Bad Lead Wire	1		1	
Triple Wire	0		0	
Knot	2	11	3	22
	53	100	37	100

Test 3 Results (Cont'd)

Defective Mounts

DEFECT	# TUBULAR	%	# NONTUBULAR	%
Dumet				
Red	12		12	
Burnt	1	4	5	7
Coil				
Double	26		49	
Skeleton	1		2	
Broken	4		1	
No Coil	22	18	11	25
Clamp				
Out of Clamp	6		5	
Loose	4		3	
Scissor	49	20	29	15
Emission				
Length	31		4	
Weight	2		4	
Coverage	1	11	3	4
Misc.				
Glass Chipped or Cracked	56		57	
Air Bubbles	14		7	
Bad Lead Wire	12		8	
Triple Wire	18		21	
Knot	21		3	
Misc.	5		14	
O.K.	14	47	12	49
	299	100	250	100

APPENDIX C

Please answer the following questions:

(1) Was this change helpful?

(2) Did this modification allow more time to inspect the mounts?

(3) Should this change be implemented?

IMPROVEMENT OF INSPECTION PERFORMANCE

BY

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B.S., Kansas State University, 1975

AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

Kansas State University

Manhattan, Kansas

1980

ABSTRACT

Four operators tried to locate manufacturing defects in parts inspected during production. The study deals with the measured effect of various inspection considerations such as magnification, lighting, and background on the inspection process and the quality.

Each area was studied on an individual basis. A comparative analysis then was run to determine the effect of each specific area. These areas then were ranked for importance. An attempt was made to determine the significance of each one and how it related to an increase in quality (a decrease in defects).

Both the lighting and the background proved beneficial while the magnification proved infeasible since the transfer of parts were involved.