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INSPECTION STRATEGY - CONSIDERING CONVEYOR SPEED, WINDOW SIZE AND TARGET ARRANGEMENT

by

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INTRODUCTION

Inspection is necessary for the maintenance of quality assurance in many manufacturing situations. Probably the most common type of inspection task is that of visual scanning to detect items that do not meet a specified standard. Inspection, for example, may be required to scan microelectronic components for improper wiring, medicines for improperly filled capsules, or woven cloth for dropped threads. Often these inspection tasks require the human operator to scan a large number of items at a very rapid rate; for example, inspection for blemishes of fruits and vegetables on a moving conveyor belt.

Decision Processes in Inspection

There are three sub-processes in an inspection task as analyzed by Colquhoun (1964): (1) Detection of a discrepancy in the material being examined; (2) Judgment of whether the discrepancy as perceived exceeds the specified standards and, therefore, constitutes a fault; and (3) Decision as to whether an item judged as being faulty is rejected. The flow chart of decision processes in inspection is in Figure 1. From this flow chart, the good items and the bad items require different time to inspect. This raises the problem of flexibility (Let the inspector have more freedom in allocating the inspection time among good and bad items.) in inspection.

Theory of Signal Detection

During the process of inspection, the inspector may make

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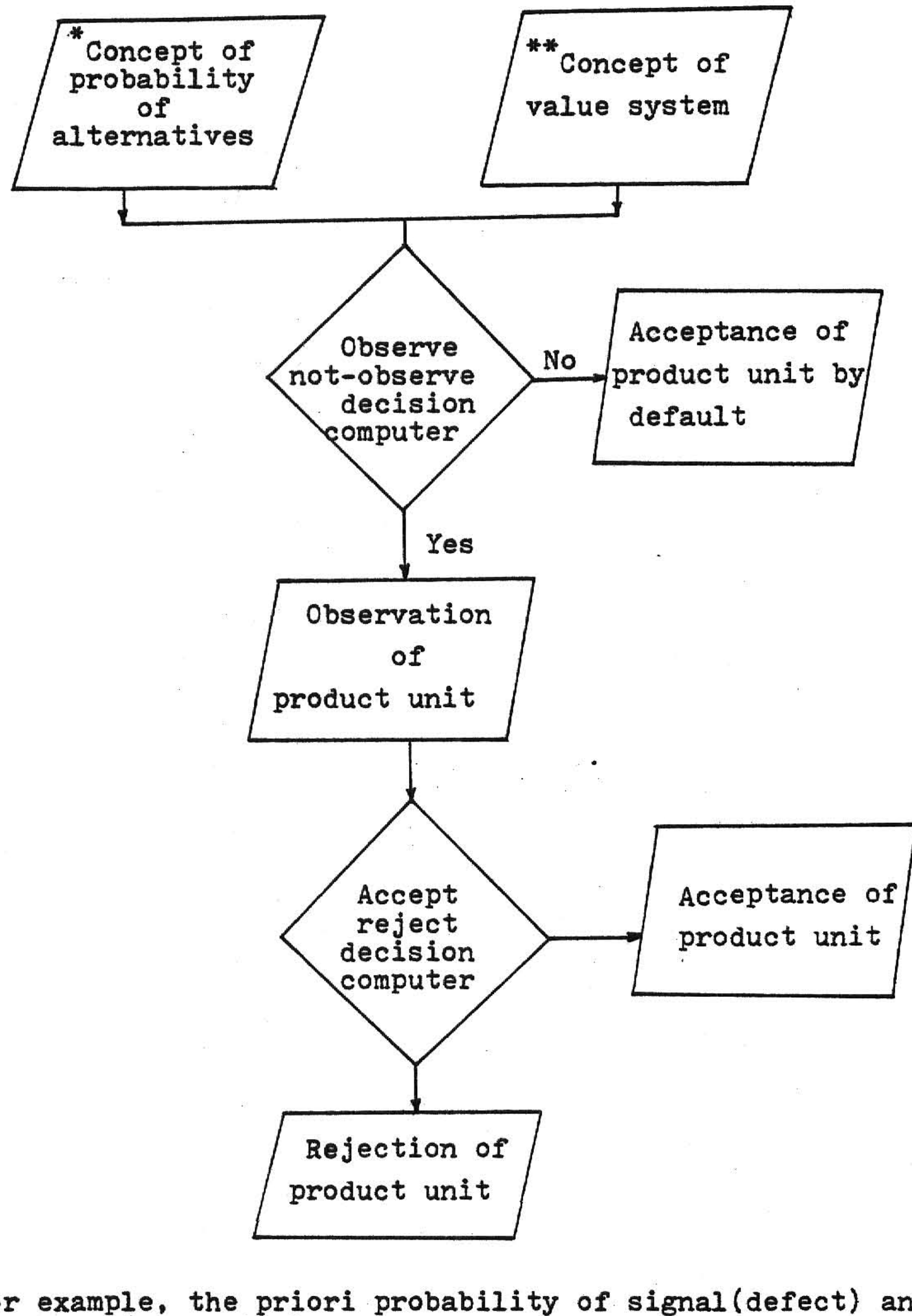


* For example, the priori probability of signal(defect) and nonsignal(effective) events.

** For example, the cost to the inspector of rejecting a good item or of accepting a bad item.

Figure 1. Flow chart of decision processes in inspection (cited from Smith and Barany, 1970)

two types of error: (1) Type I error: classifying acceptable parts as rejectable; and (2) Type II error: classifying rejectable parts as acceptable. For convenience a Type I error is often called a "false alarm" and a Type II error is called a "missed signal". The "signal" in this case is the particular defect which renders the items rejectable.

There is a method for combining information on these two types of error by using the "Theory of Signal Detection". Considerable success has been achieved in recent years by treating the human operator, in a signal detection system, as if he were making a statistical decision of whether a signal is present or whether "noise" alone is present. The work described in Swets (1964) shows how such a treatment is an accurate description of human performance in a variety of experimental signal detection tasks. A diagram of the decision situation is shown in Figure 2. It is assumed that the human operator can assess the amount of activity generated in his nervous system by the particular item being observed. This amount of activity is not a single value, but varies to some extent even during the viewing of one particular item and more so during the course of viewing a batch of items. The variation in activity level is assumed to be a normal probability distribution. If there is no defect then the probability distribution is that of noise alone. If an item with a defect occurs giving a signal of a particular strength, there will still be noise added to it and the distribution will shift to the right as shown by the "Signal + Noise" distribution. The separation of the two

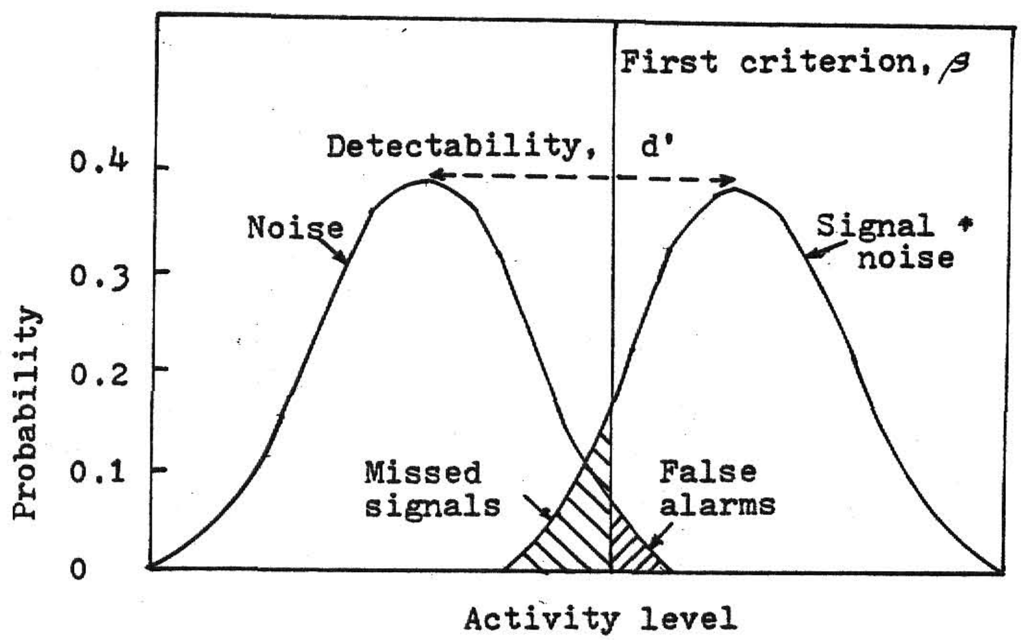


Figure 2. Decision situation, first criterion. (cited from Drury and Sheehan, 1971)

distributions depends on the strength of the signal, and the detectability of the signal is the ratio of this separation to the standard deviation of the distributions. This parameter is usually symbolized as <u>d'</u>.

It is apparent that the two distributions overlap to certain extent; if the random variation of noise reaches a large value or the random variation of signal plus noise reaches a small value, then the amount of nervous activity will be the same. The operator must "draw a line" somewhere, ie choose a criterion level (B) such that any level of activity above the criterion will cause him to say "signal present" and reject the item as faulty. In Figure 2 he has chosen a high criterion and so has few false alarms, that is he rarely rejects good items. The price he pays, of course, is that he misses a fair portion of bad items. Figure 3 shows a low criterion where the situation is reversed: he detects more bad items but reject more good items.

In practice the human operator can choose from a continuous range of criteria between these two extremes. Each criterion line will, by the point at which it cuts the two distributions curves, define a pair of values: probability of correct detection (on the signal + noise curve) and probability of false alarm (on the noise curve). For a constant value of detectability d' a curve of one against the other can be plotted. A series of such curves is shown in Figure 4. The two parameters, d' and the criterion line position, can be varied independently.

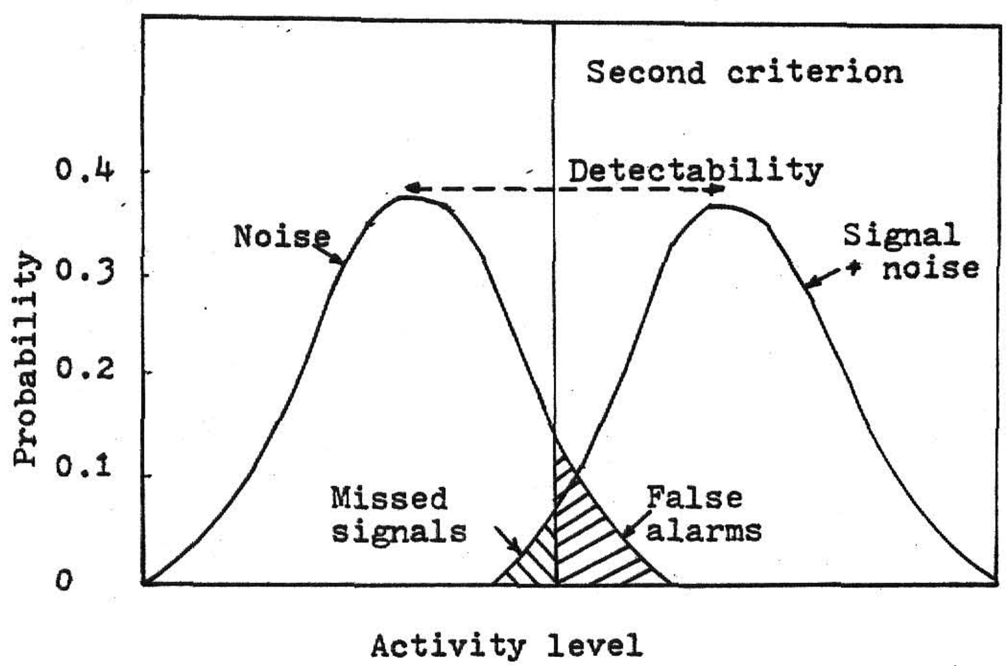


Figure 3. Decision situation, second criterion (cited from Drury and Sheehan, 1971)

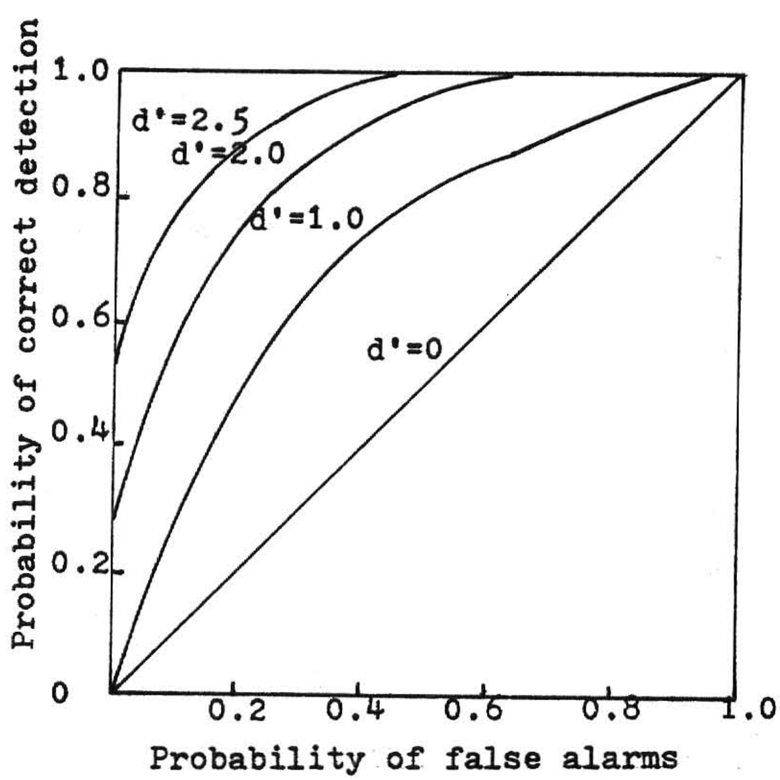


Figure4 . Performance curves on a signal detection task, (parameter of curves is detectability). (cited from Drury and Sheehan, 1971)

Thus for a fixed value of d' we can choose an economic trade off between correct detections and false alarms.

Thus d' is a measure of the difficulty of the task and is largely outside the control of the inspector. It can only be improved by altering the task conditions, for example, by adjusting the illumination or changing the conveyor velocity to make the task easier (d' is increased). The criterion line position, on the other hand, may be chosen and varied explicitly or implicitly by the inspector and is often influenced by several factors which may bring pressure upon him, for example, the cost to the inspector of rejecting a good item or the cost of accepting a bad item. For a fixed value of d', the inspector can choose an economic trade off between correct detections and false alarms.

The factors which may affect d' in any industrial inspection task are: (1) Individual factors (2) Physical and environmental factors (3) Task factors (4) Organizational factors. So the design variables of inspection should include:

(1) Individual factors

(2) Physical and environmental factors

  (a) Noise and temperature

  (b) Illuminance level, glare and contrast

(3) Task factors

  (a) Time to view

  (b) Conveyor belt velocity (angular velocity)

  (c) Percentage of lot defectives

(d) Type of pacing

(e) Display arrangement

(f) Target complexity

(g) Window width (exposed area)

(4) Organizational factors

(a) Training

(b) Rest pauses

Individual Factors

Individual factors can be devided into two categories: inter-operator differences and intra-operator differences. Intra-operator differences — such as illness, drug effects and fatigue — are not readily subject to industrial control. Inter-operator differences, on the other hand, can be more practically regulated or selected for in the industrial situation. Past research has been concerned with differences such as abilities and aptitudes.

Physical and Environmental Factors

Noise and temperature. The environmental variables of noise and temperature above certain high levels have been shown to affect performance. The NIOSH (National Institute for Occupational Safety and Health) 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 (Wet-Bulb-Globe Temperature) for unimpaired mental performance for an exposure time of 240 minutes. This value can be viewed as an approximate guideline for the upper temperature limit in designing inspection tasks. It should also be noted that the NIOSH Criteria Document recommended 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.

Noise in industrial settings is common. Since it has been shown to induce long-duration and detrimental psysiological effects at high levels of exposure, noise is considered to be an environmental stressor. Noise may be continuous or intermittent. Continuous noise sources have been previously investigated (Fox and Haselgrave, 1969). A series of studies by Warner (1969), and Warner and Heimstra (1971, 1973) have investigated the effects of various intermittent noise parameters on visual target detection performance. Results indicated that no differences in detection times were found below 90dB (decibels) for any level of task difficulty. The OSHA (Occupational Safety and Health Administration) also set a standard of no more than 90dB unless personal hearing protection was provided.

Illuminance level, glare and contrast. Illuminance level as a variable affecting visual acuity has been studied by a number of investigators, including McCormick and Niven (1952), Tinker (1949), Schlaer (1937), Westheimer (1965), and Faulkner and Murphy (1973). Most of the studies cited support the point of view that above a given point **further** increase in illumination level increases neither task performance nor visual acuity appreciably. In Table 1, the recommended illumination levels are liste

TABLE 1.

Recommended Illumination Level for Inspection Tasks
(Cited from Harris and Chaney 1969)

Type of Work	Foot-Candles
Unmagnified visual, functional, and dimensional product inspection.	100
Large area magnification for inspection of small details frequently requiring low power magnification.	200
Microscopic examination of materials, surfaces, and finishes usually requiring spot illumination.	500
Highly magnified examination of materials and small details always requiring high intensity special lighting	1000

Glare is usually defined as any brightness within the field of vision which causes discomfort or interference with vision. There are two types of glare to be recognized. Direct glare refers to the effect of a light source within the visual field; reflected glare refers to the effect of surfaces which reflect light coming from outside the visual field. Research has indicated that direct glare may be reduced by (a) advoiding bright light sources within 60 degrees of the center of the visual field, (b) using shields, hoods, and visors to keep direct light out of the viewer's eyes, (c) using indirect lighting, and (d) using several low-intensity lights instead of one high intensity light. Reflected glare may be reduced by (a) using working surfaces and tools that diffuse reflected light, (b) using a diffused light source, and (c) positioning light sources and work so that light is not reflected toward the eye (from the sides).

Contrast is defined as the relative brightness difference between the target and the target background and is expressed as a percentage. Blackwell (1959) shows curves for a given detection accuracy for particular values of target size, background luminance, and target contrast. He found that contrast had to be high for low illuminance levels. Therefore, if the illuminance level, the glare, and the target contrast are satisfactory, this can be eliminated as a potential problem area.

Summary of physical environment is shown in Table 2.

TABLE 2.

Summary of Physical Environmental Variables
(Cited from Lin's study, 1979)

Temperature	NIOSH (1972), the environmental temperature should not exceed 87°F on WBGT scale	
Continuous noise	Fox and Haselgrave (1969)	No difference in detection times were found below 90 db intensity for any level of task difficulty. And should not exceed the OSHA standard of 90 db unless personal hearing protection is provided
Intermittent noise	Warner(1969) Warner and Heimstra (1971, 1973)	
Illuminance	Harris and Chaney(1969)	in Table 1.
Glare	Harris and Chaney (1969)	Direct glare may be reduced by (a) avoiding light sources within 60 degrees of the line-of-sight, (b) using shields, hoods, (c) using indirect lighting (d) using several low-intensity lights. Reflected glare may be reduced by (a) using working surfaces and tools that diffuse reflected light (b) using a diffused light source (c) positioning light sources
Contrast	Blackwell (1959)	Contrast should high for low illumination levels and low for high illumination levels

Task Factors

Time to view. Fox (1964), Perry (1968), Sinclair (1971) performed studies concerning the effect of mean time allowed per item on P1 (correct acceptances) or P2 (correct rejections). They found that as mean time allowed per item increases, P1 will decrease while P2 will increase. This can be interpretated by Signal Detection Theory which suggests that in any given situation the inspector balances one error against the other.

Drury (1973) found a general relationship between inspection time and accuracy of performance regardless of whether the tasks were conveyor paced or not. This is illustrated in Figure 5. There is an exponential increase in the hit rate (P2) as the time available for inspection is increased. The curve levels off below P=1.0 at a value depending on the fault conspicuity as reflected by the signal detection theory parameter of sensitivity(d'). The probability of correct acceptance decreases approximately linearly (false alarms increase).

Grahan and Cook (1937) and Niven and Brown (1949) found time to view in the range of 0.1 to 0.2 second in static visual acuity tests had an effect on performance, but not for longer times. Cochran, Purswell and Hoag (1973) found that inspection performance was significantly affected for a viewing time of 0.25 second, but not at level of 0.50 second. Thus the time to view may possibly be reduced to less than 0.5 second without affecting performance, but levels of 0.25 second or less are likely to affect inspection performance significantly.

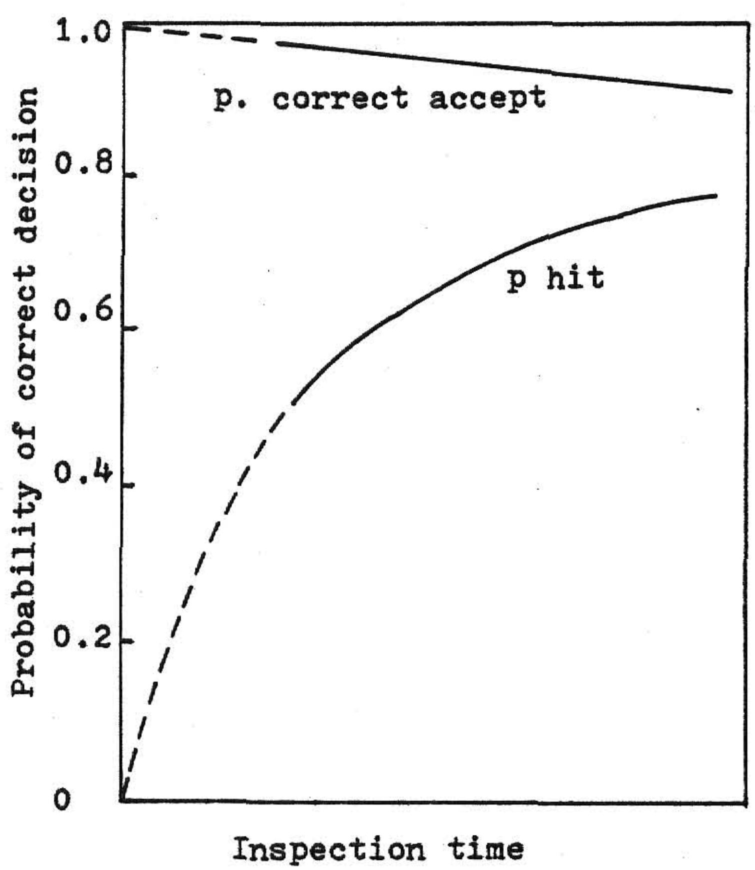


Figure 5. Generalised relationship between inspection time and accuracy of performance (cited from Drury, 1973)

A summary of time to view results is shown in Table 3.

<u>Conveyor velocity</u>. The angular velocity of a target as it passes before the observer will have an effect on the observer's ability to perform accurately if the angular velocity exceeds a certain level. Westheimer (1954, 1965) found that angular velocity had an important effect on dynamic visual acuity when the angular velocity was high, but not when it was low. He found that the eye can move smoothly up to about 40 degrees per second. Ludvigh and Miller (1949, 1958) have authored numerous articles on dynamic visual acuity. In their study, angular velocity was varied from 10 degrees per second to 170 degrees per second. They found that the visual acuity of moving targets decreased rapidly as the angular velocity increased. Studies of Burg and Hulbert (1959, 1961) also support the findings of Ludvigh and Miller: the visual acuity suffers at values of 10 degrees per second or above. William and Borrow (1963) found that under 8 degrees per second of angular velocity, the inspection performance was not affected by the conveyor speed. It only depended on search time per item.

A summary of angular velocity results is shown in Table 4.

<u>Percentage of lot defectives</u>. For conveyor paced conditions, the percentage of lot defectives has been found to have more effect on inspection performance when the defect rate is higher. Fox and Haslegrave (1969) found that at 0.5%, 1% and 2.5% defect rates, there were no performance differences in terms of defects detected. Dorris, Hoag and Kasivis-wanathan (1977) found that

TABLE 3.

Summary of Time to View

Fox(1964), Perry(1968) and Sinclair(1971)	As mean time allowed per item is increased P1(correct acceptances) will decrease while P2(correct rejections) will increase.
Drury(1973)	As mean time allowed per item is increased P1 will decrease approximately linearly while P2 will increase exponentially.
Grahan and Cook(1937) Niven and Brown	Time to view in the range of 0.1 to 0.2 second in static had an effect on performance but not for longer times.
Cochran, Purswell and Hoag(1973)	A viewing time of 0.25 second had an effect on performance but not at level of 0.5 second.

TABLE 4.

Summary of Angular Velocity

Westheimer (1954)	The eye can see smoothly up to about 40 degrees per second
Ludvigh and Miller (1949, 1958)	Angular velocity was varied from 10 °/sec-170 °/sec found that visual acuity of moving targets decreased rapidly as the angular velocity increased
Burg and Hulbert (1959, 1961)	Showed that visual acuity suffers at values of 10 °/sec and above

at 8%, 20% and 32% defect rates, the probability of rejecting an item decreased with a decrease in defect rate.

A summary of percentage of lot defectives results is shown in Table 5.

Display arrangement. Search time will be changed if display arrangement is changed to a certain degree. In a previous study, Purswell and Greenhaw (1972) found that more closely spaced targets at a lower velocity were superior to targets spaced farther apart at a higher velocity. Errors increased with increased throughput. Drury and Clement (1978) found that it was more efficient to search densely packed items rather than spaced items. But Williges and Streeter (1971) found that the display arrangement seemed to have little effect on inspection performance.

Since previous studies were not enough in this area the effect of target arrangement required more studies. Basically, there are two types of inspection arrangement; (1) horizontal inspection - an inspection which does not require up and down eye or head movement, (2) vertical inspection - an inspection which does require up and down eye or head movement. From subjective judgment, two-row and four-row conditions were classified into horizontal inspection while eight-row conditions were classified into vertical inspection.

Target complexity. Different complexities of targets will change the durations of fixation, concentration of attention and thus change the time required for inspection. Harris (1966)

TABLE 5.

Summary of Percentage of Lot Defective

Author	Percentage of lot defective	Measures	
		Defects detected(hit)	False alarm
Fox and Haslegrave (1969)	paced: 0.5%, 1%, 2.5%	Defects detected were not affected by defect rate	Varied widely among subjects
Dorris, Hoag, Kasiviswanathan (1977)	paced: 8%, 20%, 32%	The probability of rejecting an item decreased with decrease in defect rate	

used 62 experienced inspectors to inspect 10 different items of electronic equipment covering a wide range of complexity. Inspection performance was found to have an almost perfect inverse relationship with equipment complexity and the effect couldn't be overcome by extending the amount of inspection time allotted. McFarling and Heimstra (1975) studied the inspection of simulated printed circuits varying in circuit complexity. They found that inspector's performance decreased on the more complex circuits.

Exposed area (window width). There were few reports on this factor. The change of exposed area would change the flexibility of inspection. The flexibility of inspection is defined here as the number of items exposed to the inspector at one time. The more items exposed, the more flexible the task is. Also flexibility is classified into horizontal flexibility (which only increased exposed items horizontally) and vertical flexibility (which only increases exposed items vertically). Drury and Clement (1978) reported that the exposed area has a significant effect on search time. Further research is required on this.

Organizational Factors

Training. For more difficult inspection tasks, training may improve the performance to certain degree. Chaney and Teel (1967) performed a study to evaluate the effectiveness of a 4-hr. training program for experienced machine-parts inspectors. They found that training resulted in a 32% increase in defective detected.

Rest pauses. 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 mental parts. The average 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 6. These are consistent with the results of Mackworth and Hoag and provide a direct comparison between one group of "inspectors" which had frequent rest breaks and the other group which received no breaks.

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.

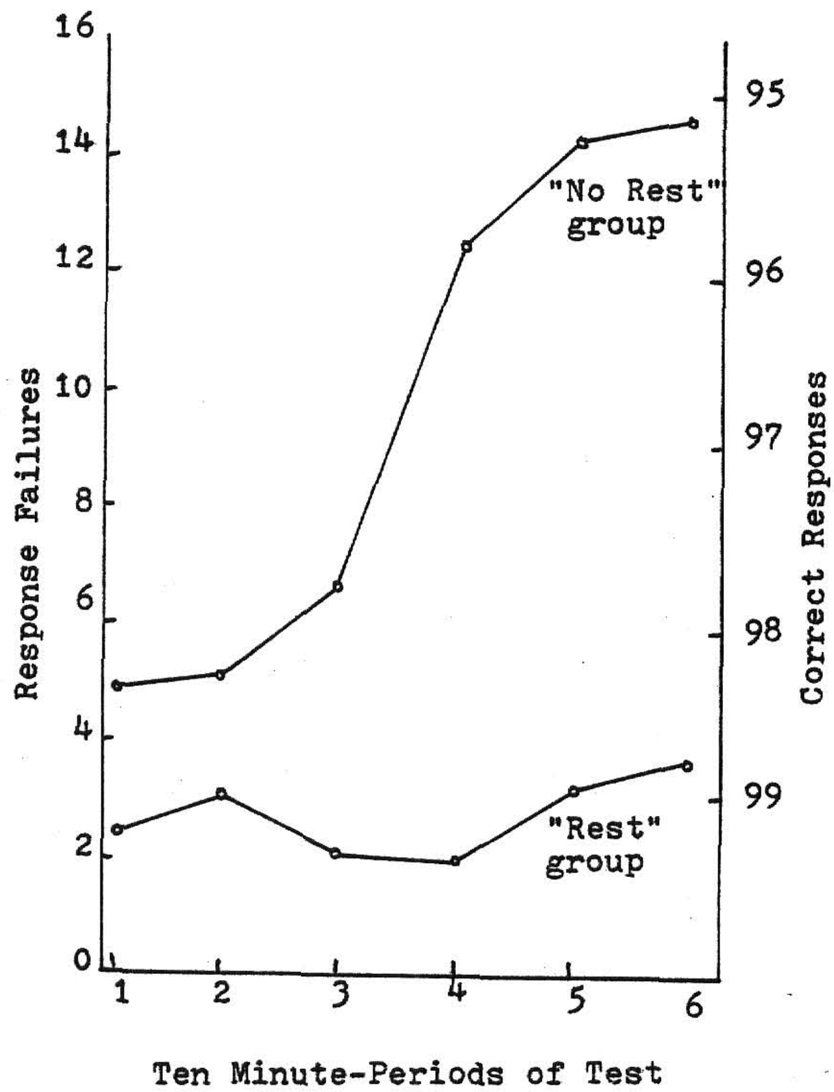


Figure 6. Mean response failures for "rest" and "no rest" groups in successive ten-minute periods of testing time (Colquhoun, 1959)

PROBLEM

From previous studies, it is known that angular velocity, time to view, window size and target arrangement have effects on inspection tasks. However, it is not possible to combine all the factors and choose the most efficient strategy for inspection performance. The importance of flexibility, the arrangement of tasks, the interaction between defect size and speed, and the differences between horizontal and vertical inspection have not been studied. In this study, the following hypotheses will be tested:

The first hypothesis is that the optimal strategy which gives the best performance is basically determined by the inspection rate (which is defined as items inspected per unit time). If the inspection rate is low, the performance is better.

The second hypothesis is that the more flexibility an inspection task has, the more efficient it is while the inspection rate is fixed.

The third hypothesis is that horizontal inspection is better than vertical inspection while targets exposed and inspection rate are fixed.

The fourth hypothesis is that if defect size is small, it's better to inspect more rows at a slower angular velocity than to inspect fewer rows at a higher angular velocity when the inspection rate is fixed.

METHOD

Task and Design

Targets used in this experiment were black circles, 3/8" diameter. Some circles had defective white spots with 1/64" (2.2 minutes of arc) or 1/128" (1.1 minutes of arc) diameter as shown in Figure 7. Targets were arranged in four types: one row, two rows, four rows and eight rows, as shown in Figure 8 and 9.

The distance between any two adjacent targets was one inch. The defective rate was kept at 20% with an equal number of two different defect sizes. Targets were fed from one end of the conveyor.

The subject sat at a conveyor with about 15" distance from the conveyor to eyes (as shown in Figure 10). There were 30 experimental combinations for each subject to go through. Before the experiment, he was asked to read the informed consent in Figure 11. Before each test, he had a practice period until he was familiarized with the inspection method. Each test was about 5 minutes long. There was a five minute break after every thirty minutes of inspection. During the experiment the subject inspected all the targets exposed (240 targets/test) and marked the defective items with a pencil. The sequence of experimental combinations was random.

There were three variables: (1) Conveyor speed at 4.7°/sec, 9.4°/sec and 18.8°/sec levels. From Westheimer's (1954) study,

Complete (accept)

Defect (reject)

Figure 7. <u>Target used in inspection task</u>

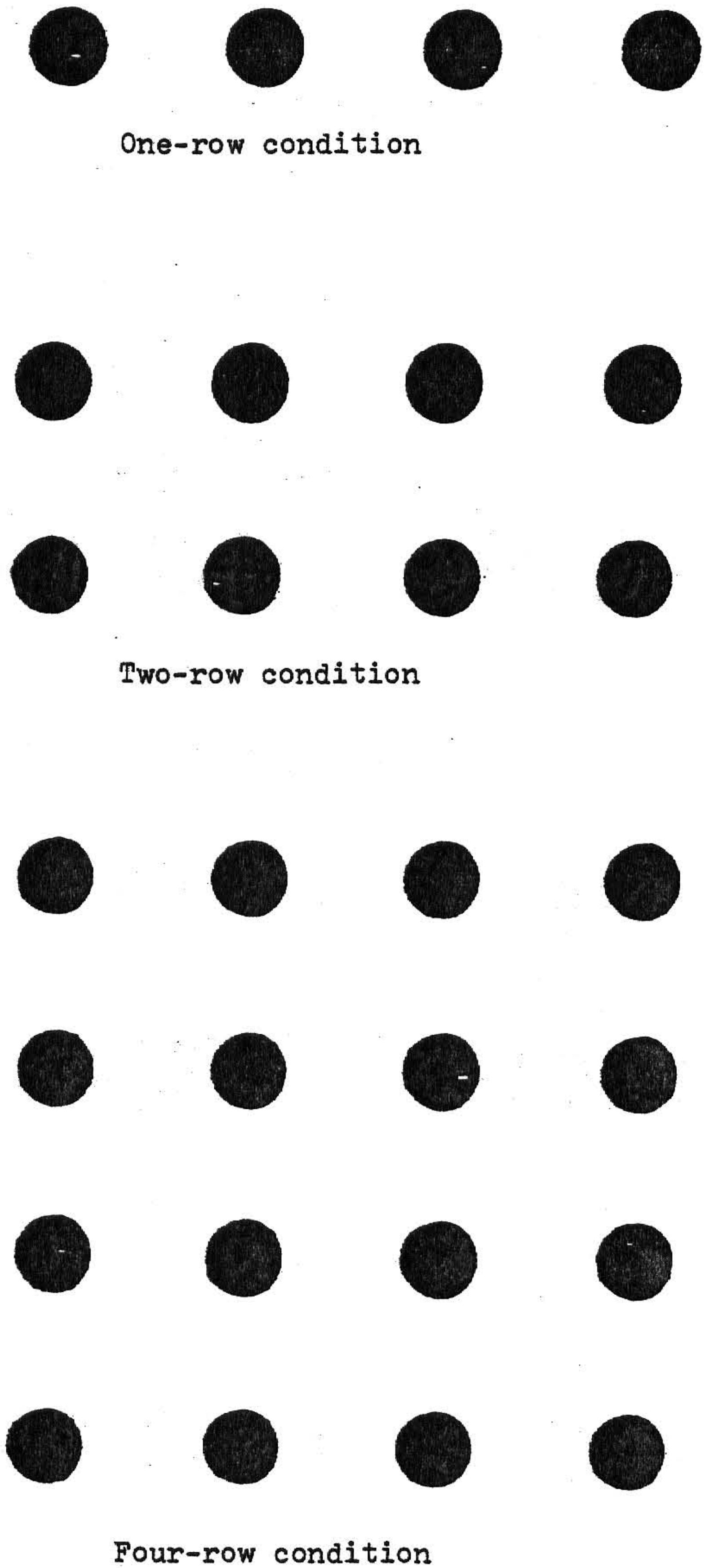


Figure 8. <u>Target arrangement for one-row, two-row and four-row conditions</u>

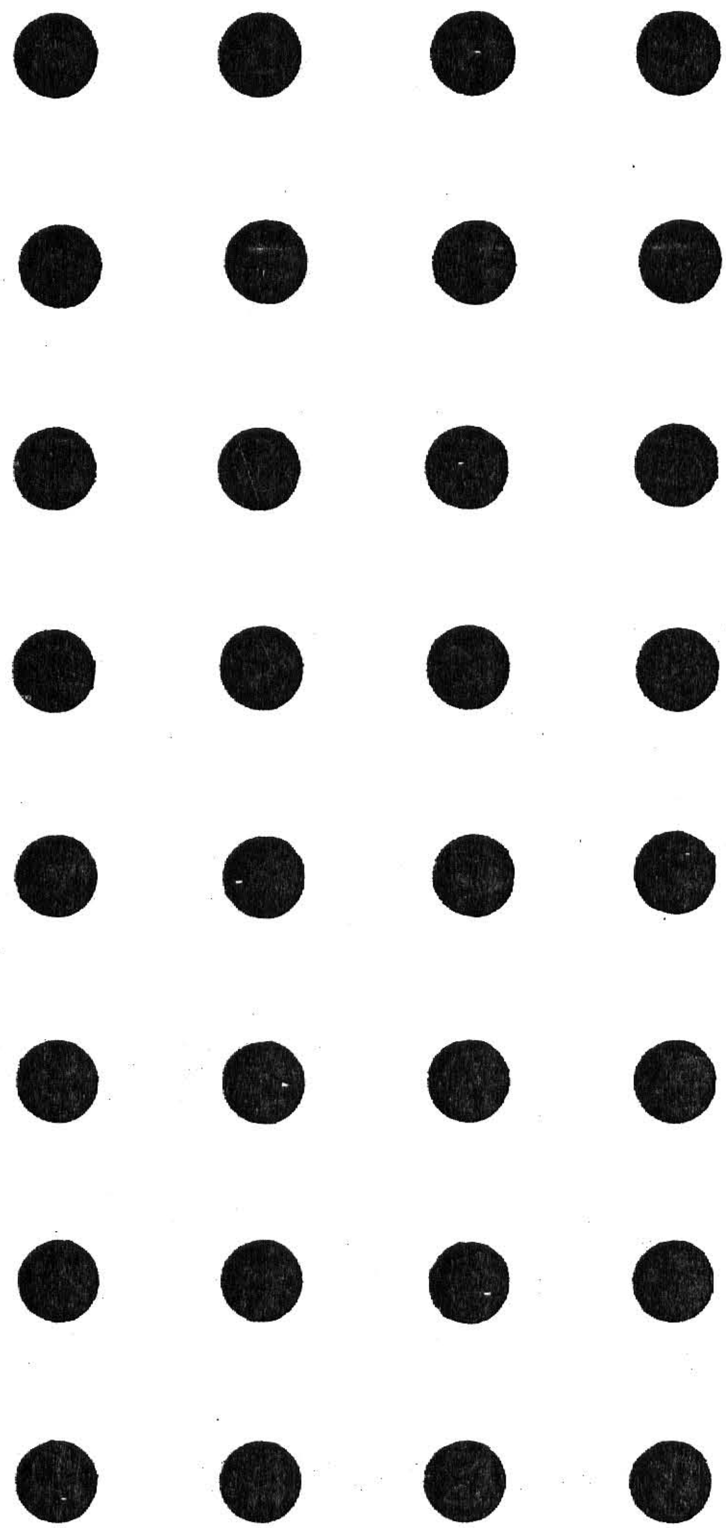


Figure 9. Target arrangement for eight-row condition

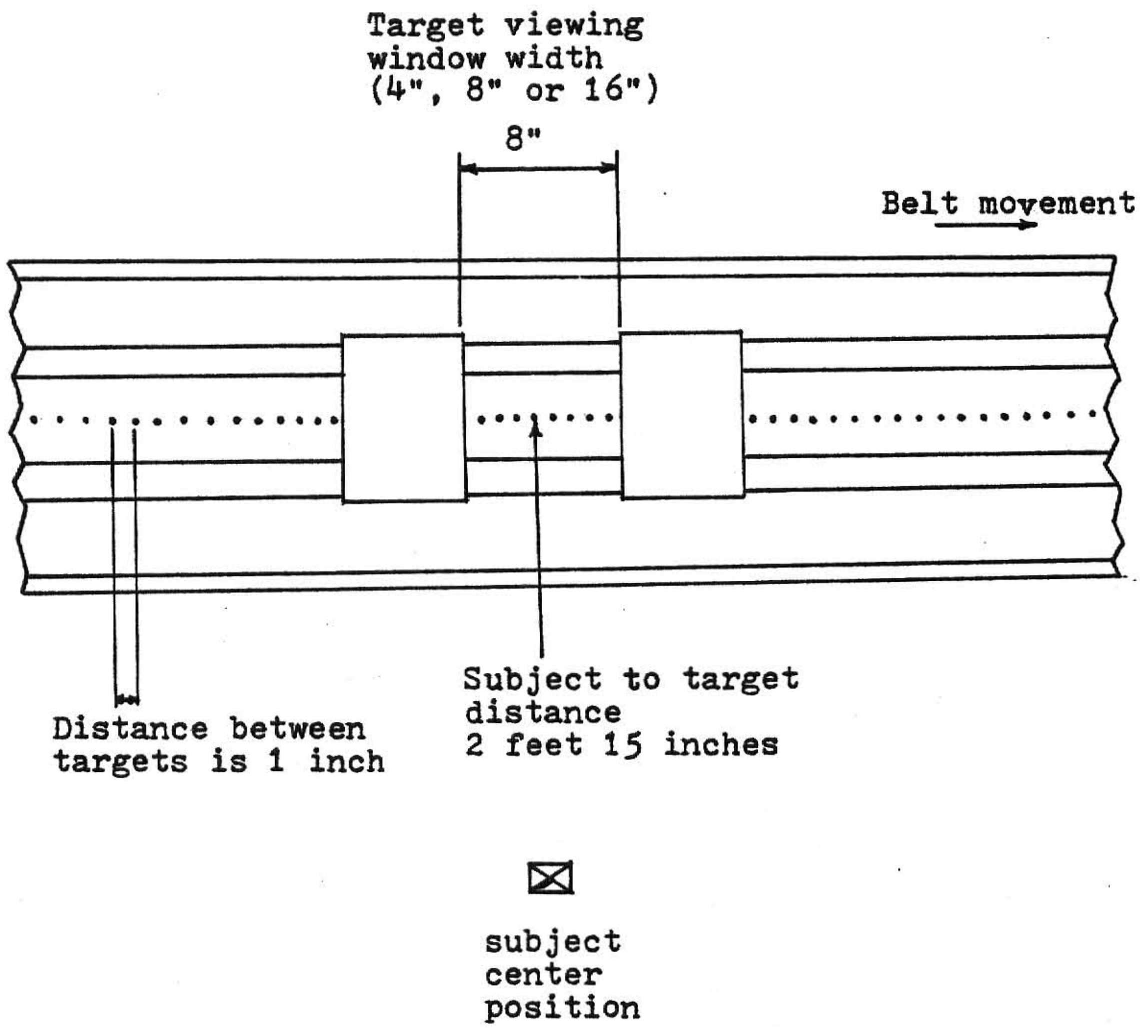


Figure 10. Diagram of experimental situation for one-row situation

INFORMED CONSENT AND INSTRUCTIONS

The purpose of this experiment is to determine how correctly you can detect defects in moving targets. Your job will be to look at targets and mark the defective ones. If any of the blacked circles contain a white dot, it's a defective one. There are 27 sets of tests and targets will be presented to you in different arrangements. You will be asked to inspect all the targets presented to you in the given period of time. When you detect the defective targets passing in front of you, mark it with pencil. Otherwise just let it go.

Thank you very much for your cooperation. If you have any questions or comments, please feel free to ask me.

There are no dangers or risks involved in this experiment. However, you are free to stop at any time. I will appreciate if you will complete the experiment. If you are ready for the experiment, please sign the consent form.

NAME :

DATE :

Figure 11. Informed consent form

the eye could see smoothly within this range. (2) Window size of 4", 8" and 16". These values were within reasonable working span of the subject. (3) Number of rows with one-row, two-row, four-row and eight-row conditions. Since the conveyor width was about 11", the eight-row condition which spaned 8" was about the maximum number of rows which could be studied. The three variables give inspection rates ranging from 0.9 items/sec to 14.3 items/sec and made the tests reasonable. The experimental combinations were shown in Table 6.

During the experiment, all the other factors which might affect the inspection performance were fixed: the illuminance was 110 foot candles in the inspection area; the contrast of the target is 51%; the noise level varied from 70 to 82 decibels; the temperature was 75°F; the target density (which was defined as total number of targets divided by total area of target span) was 1 item/in^2.

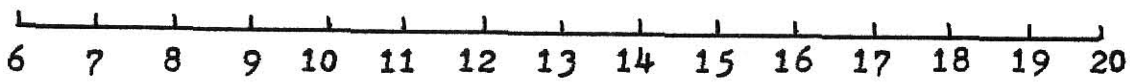
Scoring of performance was based on correct acceptances (and false alarms), hits (and misses) and the Borg scale rating. The correct acceptances were defined as the percentage of good items presented in a lot which were accepted. Hits were defined as the percentage of defective items presented in a lot which were detected. The Borg scale rating was the subject's rating for the difficulty of the tests. In the case of physical work, the values are close to one tenth of a person's heart rate. It was shown in Figure 12.

TABLE 6.

Experimental Combinations

Speed / Window size / Rows	18.8 °/sec(600rpm)			9.4 °/sec(300rpm)			4.7 °/sec(150rpm)		
	4" (16°)	8" (32°)	16" (64°)	4"	8"	16"	4"	8"	16"
1	.56	.56	.56	-	-	-	-	-	-
2	*.28	.28	.28	.56	.56	.56	1.12	1.12	1.12
4	.14	.14	.14	.28	.28	.28	.56	.56	.56
8	.07	.07	.07	.14	.14	.14	.28	.28	.28

* Entries are the average viewing time per item in seconds.



7 = very very easy

9 = very easy

11 = fairly easy

13 = somewhat hard

15 = hard

17 = very hard

19 = very very hard

Figure 12. <u>Borg scale rating</u>

Apparatus

The Doll straight belt conveyor with a variable speed-drive where the belt moved smoothly over a supporting platform was used as shown in Figure 13. The conveyor belt was a textured gray. The belt was shrouded by two wooden structures to control the window size.

The straight line conveyor was 11.25 inches wide and 10 feet 3 inches long. The conveyor was located in a laboratory.

Subjects

Eight subjects were recruited from acquaintances among KSU students ranging from 20 to 35 years. All of them were males and were paid. Each one had at least 20/20 by the Titmus Vision Tester. The subjects' information is shown in Table 7.

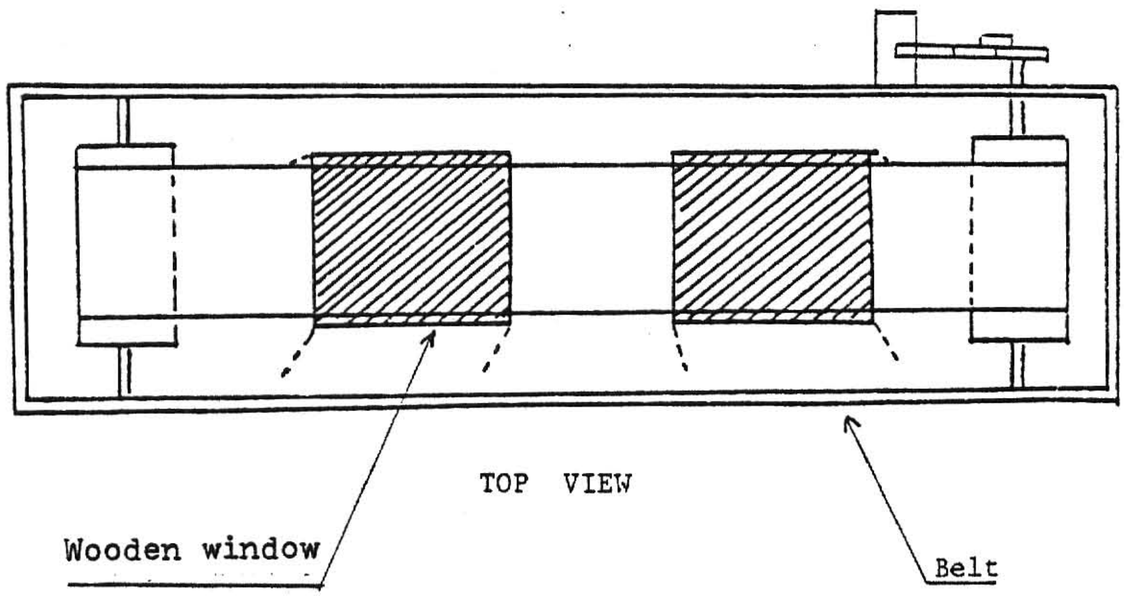


Figure 13. Straight conveyor.

TABLE 7.

Subject Information

Subject number	Sex	Age	Eye vision	Major
1	Male	28	20/20	Physics
2	"	26	"	Industrial Engineering
3	"	23	"	I.E.
4	"	25	"	Chemical Engineering
5	"	29	"	Architecture
6	"	22	"	I.E.
7	"	28	"	Architecture
8	"	30	"	I.E.

RESULTS

Effects of Conveyor Velocity, Window Size and Number of Rows

There are three variables (conveyor velocity, window size and number of rows) with 30 tests for each subject. The measures of the inspector's performance are correct acceptances, percentage of defects detected, and the Borg scale rating. Table 8 gives the data and mean value for each test. In order to have more comparison concerning the effects of window size and number of rows, one-row condition at 18.8 °/sec is added. In this case, two ANOVA tables are needed: one is three-way analysis excluding one-row conditions; the other is two-way analysis including one-row conditions.

Analyzing the data, the following results are found:

Hits. The analysis of variance (Table 9) shows that all the four variables (conveyor velocity, window size and number of rows & subject) have significant effects on hits. The interactions between conveyor speed and window size, speed and number of rows, window size and number of rows, or speed and window soze and number of rows also have significant effects on hits. Table 11-15 show Duncan's test for speed, window size and number of rows effects. Table 16-19 use LSD test to separate all the significant interaction means. Table 10 also shows the significant effects of window size, number of rows and subjects on hits under 18.8 °/sec condition.

Correct acceptances. The analysis of variance (Table 20)

TABLE 8.

Means for 30 test combinations

Speed	Row	Window size	Total subject	Mean hits	Mean correct acceptances	Mean Borg scale rating
18.8 °/sec	8	4"	8	0.1980	0.9951	20
		8"	8	0.2685	0.9971	18
		16"	8	0.3281	0.9973	19
	4	4"	8	0.4248	0.9964	17
		8"	8	0.5626	0.9965	16
		16"	8	0.6148	0.9986	16
	2	4"	8	0.6850	0.9946	15
		8"	8	0.8100	0.9963	13
		16"	8	0.8465	0.9979	13
	1	4"	8	0.8204	0.9970	12
		8"	8	0.8933	0.9971	12
		16"	8	0.9350	0.9993	11
9.4 °/sec	8	4"	8	0.4088	0.9978	17
		8"	8	0.4558	0.9993	17
		16"	8	0.5575	0.9986	15
	4	4"	8	0.8258	1.0000	13
		8"	8	0.8439	1.0000	13
		16"	8	0.8776	0.9985	13
	2	4"	8	0.9610	0.9978	11
		8"	8	0.9714	0.9978	10
		16"	8	0.9688	0.9980	10
4.7 °/sec	8	4"	8	0.6223	0.9971	14
		8"	8	0.6798	0.9979	13
		16"	8	0.7680	0.9979	12
	4	4"	8	0.9296	0.9985	10
		8"	8	0.9453	0.9993	10
		16"	8	0.9115	0.9993	9
	2	4"	8	0.9896	0.9993	9
		8"	8	0.9741	0.9903	8
		16"	8	0.9714	0.9979	8

TABLE 9.

Analysis of Variance for Hits (Excluding one-row condition)

Source of variation	DF	Mean square	F value	PR>F
Speed (S)	2	2.1802	498.82	0.0001*
Window size (W)	2	0.1433	32.79	0.0001*
Rows (R)	2	3.5113	803.35	0.0001*
Subject	7	0.1361	31.15	0.0001*
S x W	4	0.0285	6.47	0.0001*
S x R	4	0.1231	28.17	0.0001*
W x R	4	0.0133	3.62	0.0073*
S x W x R	8	0.0088	2.00	0.0478*
Error	182	0.0044		
Total	215			

TABLE 10.

Analysis of Variance for Hits under 18.8 °/sec Condition (Including one-row condition)

Source of variation	DF	Mean square	F value	PR>F
Window size (W)	2	0.1856	34.57	0.0001*
Rows (R)	3	1.8263	340.25	0.0001*
Subject	7	0.0783	14.58	0.0001*
W x R	6	0.0033	0.61	0.7225
Error	77	0.0054		
Total	95			

TABLE 11.

Duncan's Multiple Range Test for Hits with Different Speeds (excluding one-row condition)

Grouping	Mean(hits)	Observations	Conveyor speed
A	0.8657	72	4.7 °/sec
B	0.7633	72	9.4 °/sec
C	0.5265	72	18.8 °/sec

* Group with the same character is not of significant different

TABLE 12.

Duncan's Multiple Range Test for Hits with Different Window Size (Excluding one-row condition)

Grouping	Mean(hits)	Observations	Window size
A	0.7605	72	16"
B	0.7235	72	8"
C	0.6716	72	4"

TABLE 13.

Duncan's Multiple Range Test for Hits under 18.8 °/sec Condition (Including one-row condition)

Grouping	Mean(hits)	Observations	Window size
A	0.6811	32	16"
B	0.6336	32	8"
C	0.5320	32	4"

TABLE 14.

Duncan's Multiple Range Test for Hits with Different Rows (Excluding one-row condition)

Grouping	Mean(hits)	Observations	Number of rows
A	0.9086	72	2
B	0.7706	72	4
C	0.4763	72	8

TABLE 15.

Duncan's Multiple Range Test for Hits under 18.8 °/sec Condition (Including one-row condition)

Grouping	Mean(hits)	Observations	Number of rows
A	0.8829	24	1
B	0.7805	24	2
C	0.5340	24	4
D	0.2649	24	8

TABLE 16.

LSD Test for Speed X Window Size Effect on Hits
(Excluding one-row condition)

Grouping	Mean(hits)	Observations	Interaction	
			Speed	Window size
A	0.4359	24	18.8 °/sec	4"
B	0.5470	24	18.8	8"
C	0.5965	24	18.8	16"
D	0.7318	24	9.4	4"
D	0.7570	24	9.4	8"
E	0.8013	24	9.4	16"
F	0.8472	24	4.7	4"
G F	0.8664	24	4.7	8"
G	0.8836	24	4.7	16"

TABLE 17.

LSD Test for Speed X Row Effect on Hits
(Excluding one-row condition)

Grouping	Mean(hits)	Observations	Interaction	
			Speed	Rows
A	0.2648	24	18.8 °/sec	8
B	0.4740	24	9.4	8
C	0.5340	24	18.8	4
D	0.6900	24	4.7	8
E	0.7805	24	18.8	2
F	0.8491	24	9.4	4
G	0.9288	24	4.7	4
H	0.9670	24	9.4	2
H	0.9784	24	4.7	2

TABLE 18.

LSD Test for Window Size X Row Effect on Hits (Excluding one-row condition)

Grouping	Mean(hits)	Observations	Interaction	
			Rows	Window size
A	0.4097	24	8	4"
B	0.4680	24	8	8"
C	0.5512	24	8	16"
D	0.7267	24	4	4"
E	0.7839	24	4	8"
E	0.8013	24	4	16"
F	0.8785	24	2	4"
G	0.9185	24	2	8"
G	0.9289	24	2	16"

TABLE 19.

LSD Test for Speed x Row x Window Size Effect on Hits

Grouping	Mean (hits)	Observations(N)	Inspection rate items/sec	Interaction		
				Speed	Row	Window size
A	0.1980	8	14.3	18.8 °/sec	8	4"
B	0.2685	8	14.3	18.8	8	8"
B	0.3281	8	14.3	18.8	8	16"
C	0.4088	8	7.1	9.4	8	4"
C	0.4248	8	7.1	18.8	4	4"
C	0.4558	8	7.1	9.4	8	8"
D	0.5575	8	7.1	9.4	8	16"
E D	0.5626	8	7.1	18.8	4	8"
E D	0.6148	8	7.1	18.8	4	16"
E F	0.6223	8	3.6	4.7	8	4"
F	0.6798	8	3.6	4.7	8	8"
F	0.6850	8	3.6	18.8	2	4"
G	0.7680	8	3.6	4.7	8	16"
H G	0.8100	8	3.6	18.8	2	8"
I H G	0.8204	8	1.8	18.8	1	4"
I H G	0.8258	8	3.6	9.4	4	4"
I H	0.8439	8	3.6	9.4	4	8"
I H	0.8465	8	3.6	18.8	2	16"
I J	0.8776	8	3.6	9.4	4	16"
J	0.8933	8	1.8	18.8	1	8"
J K	0.9115	8	1.8	4.7	4	16"
L J K	0.9296	8	1.8	4.7	4	4"
L J K	0.9350	8	1.8	18.8	1	16"
L K	0.9453	8	1.8	4.7	4	8"
L K	0.9610	8	1.8	9.4	2	4"
L K	0.9688	8	1.8	9.4	2	16"
L K	0.9714	8	0.9	4.7	2	16"
L K	0.9714	8	1.8	9.4	2	8"
L K	0.9741	8	0.9	4.7	2	8"
L	0.9896	8	0.9	4.7	2	4"

TABLE 20.

Analysis of Variance for Correct Acceptances
(Excluding one-row condition)

Source of variation	DF	Mean square	F Value	PR>F
Speed (S)	2	0.00007162	2.28	0.1051
Window size (W)	2	0.00002253	0.72	0.4892
Rows (R)	2	0.00006712	2.14	0.1208
Subject	7	0.00007708	2.50	0.0178*
S x W	4	0.00003485	1.11	0.3531
S x R	4	0.00000862	0.27	0.8940
W x R	4	0.00002983	0.95	0.4362
S x W x R	8	0.00002380	0.76	0.6404
Error	182	0.00003139		
Total	215			

shows that only subjects have a significant effect on correct acceptances. But in Table 21, under 18.8 °/sec condition, none of the variables has a significant effect on correct acceptances.

Borg scale rating. The analysis of variance (Table 22 and 23) shows that all the four variables (conveyor speed, window size, number of rows and subjects) have significant effects on the Borg scale rating. But there are no interaction effects. Table 24-28 show Duncan's test for effects of speed, window size and number of rows.

TABLE 21.

Analysis of Variance for Correct Acceptances under 18.8°/sec Condition (Including one-row condition)

Source of variation	DF	Mean square	F value	PR>F
Window size (W)	2	0.00004951	2.24	0.1133
Rows (R)	3	0.00001157	0.52	0.6715
Subject	7	0.00002656	1.27	0.2777
W x R	6	0.00000286	0.13	0.9923
Error	77	0.00002210		
Total	95			

TABLE 22.

Analysis of Variance for Borg Scale Rating
(Excluding one-row condition)

Source of variation	DF	Mean square	F value	PR>F
Speed (S)	2	609.78	324.76	0.0001*
Window size (W)	2	22.03	11.73	0.0001*
Rows (R)	2	476.28	253.66	0.0001*
Subject	7	15.59	8.30	0.0001*
S x W	4	0.99	0.53	0.7155
S x R	4	4.20	2.24	0.0668
W x R	4	0.41	0.22	0.9287
S x W x R	8	1.30	0.69	0.6965
Error	182	1.88		

TABLE 23.

Analysis of Variance for Borg Scale Rating under 18.8 °/sec Condition (Including one-row condition)

Source of variation	DF	Mean square	F value	PR>F
Window size (W)	2	17.3750	8.58	0.0004*
Rows (R)	3	235.7882	116.47	0.0001*
Subject	7	17.5699	8.68	0.0001*
W x R	6	0.6528	0.32	0.9234
Error	77	2.0245		
Total	95			

TABLE 24.

Duncan's Multiple Range Test for Borg Scale Rating with Different Speeds. (Excluding one-row condition)

Grouping	Mean(Borg)	Observations	Speed
A	16.17	72	18.8 °/sec
B	13.17	72	9.4
C	10.35	72	4.7

TABLE 25.

Duncan's Multiple Range Test for Borg Scale Rating with Different Window Sizes (Excluding one-row condition)

Grouping	Mean(Borg)	Observations	Window size
A	13.83	72	4"
B	13.10	72	8"
B	12.75	72	16"

TABLE26.

Duncan's Multiple Range Test for Borg Scale Rating under 18.8 °/sec Condition (Including one-row condition)

Grouping	Mean(Borg)	Observations	Window size
A	15.84	32	4"
B	14.84	32	8"
B	14.41	32	16"

TABLE 27.

Duncan's Multiple Range Test for Borg Scale Rating with Different Rows (Excluding one-row condition)

Grouping	Mean(Borg)	Observations	Rows
A	15.92	72	8
B	12.97	72	4
C	10.79	72	2

TABLE 28.

Duncan's Multiple Range Test for Borg Scale Rating with Different Rows under 18.8 °/sec Condition (Including one-row condition)

Grouping	Mean(Borg)	Observations	Rows
A	18.79	24	8
B	16.21	24	4
C	13.50	24	2
D	11.63	24	1

DISCUSSION

In this study, the measures of performance are percentage of hits, correct acceptances and the Borg scale ratings. Since the average percentage of correct acceptances is very high (0.9978), it can be inferred that the detectability d' is large which means defects are easily found so correct acceptances doesn't give much information on the performance of different tests. Also the Borg scale rating is about proportional to the percentage of hits in each test. So in this study, the percentage of hits is a better measure of performance. In the discussion of hypotheses, the percentage of hits will be used as a measure of performance.

From this study, the effects of conveyor velocity, window size and number of rows are found:

Effect of Conveyor Velocity on Performance

Hits. From Tables 9 and 10, the percentage of hits is significantly different for each individual. This can be explained by the differences in the choice of criterion line in Figure 2 and the differences of individual skill and motivation. The percentage of hits decreases when the conveyor velocity is increased from 4.7 °/sec to 18.8 °/sec as shown in Figure 14.

Research (Westheimer, 1954, 1965) found that angular velocity under 40 °/sec didn't have an important effect on dynamic visual acuity. Also, William and Borrow (1963) found

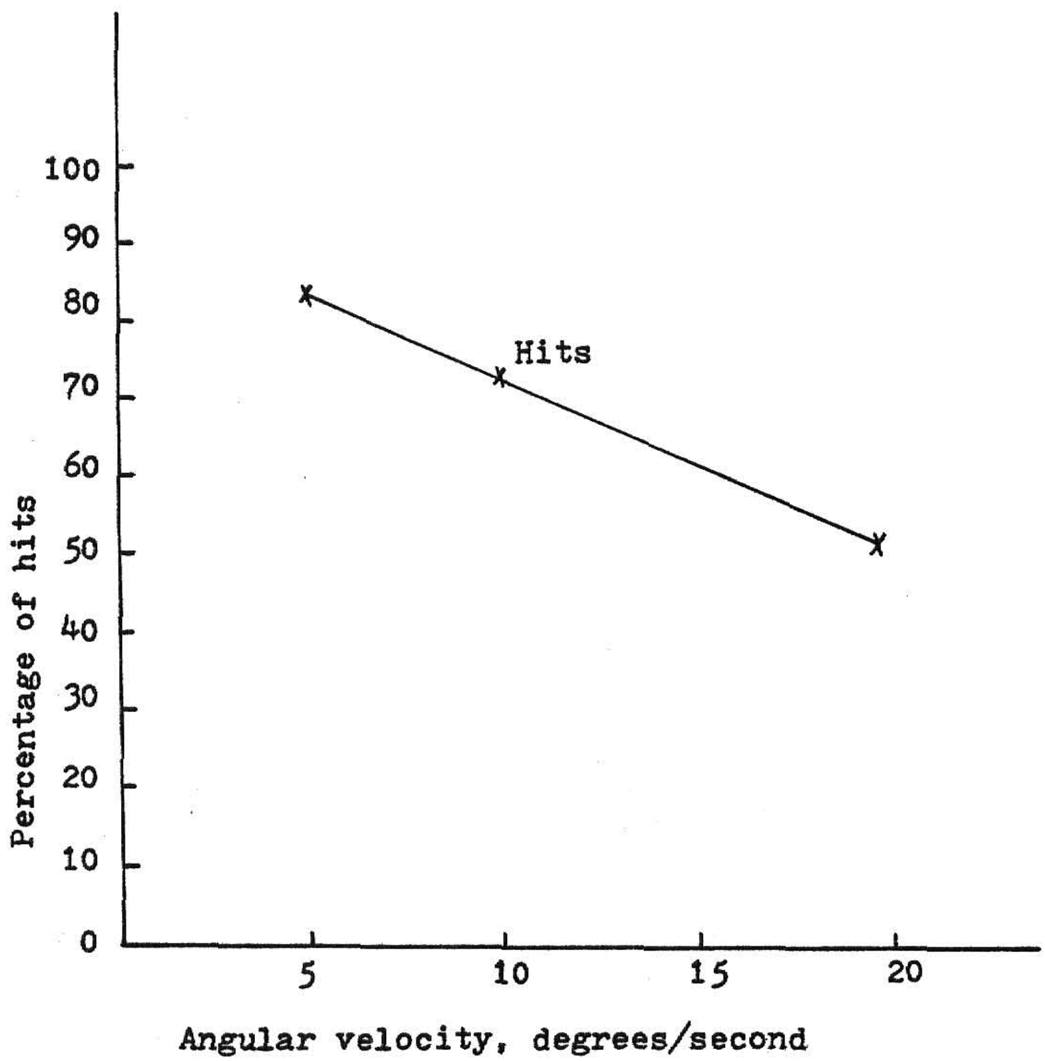


Figure 14. Mean value for hits across velocity level

that at low angular velocity (under 8 °/sec), the inspection performance was not affected by the conveyor speed, it only depended on search time per item. These findings agree with this study.

Correct acceptances. The percentage of correct acceptances is not significantly affected by the increase of conveyor velocity as shown in Table 20 and 21. Or it can be stated that the decrease of viewing time per item doesn't have significant effect on correct acceptances.

Drury (1973) found (Figure 5) that the decrease of inspection time would result in a linear decrease in the percentage of correct acceptances. This finding doesn't agree with this study. It can be explained by "Theory of Signal Detection": in this study, the detectability d' is large (by inference), so the probability of correct acceptance is high. There is no speed effect.

Borg scale rating. The increase of conveyor velocity increases the Borg scale rating linearly as shown in Figure 15. This can be interpreted as: increase of conveyor velocity results in the decrease of viewing time per item and makes the task more difficult. The Borg scale rating is proportional to the percentage of hits: when the task is easier, the percentage of hits is higher and vice verse. In Figure 15, the Borg scale ratings range from 10 to 16 with mean value equal to 13.23 which means the average of tests is somewhat hard. Since

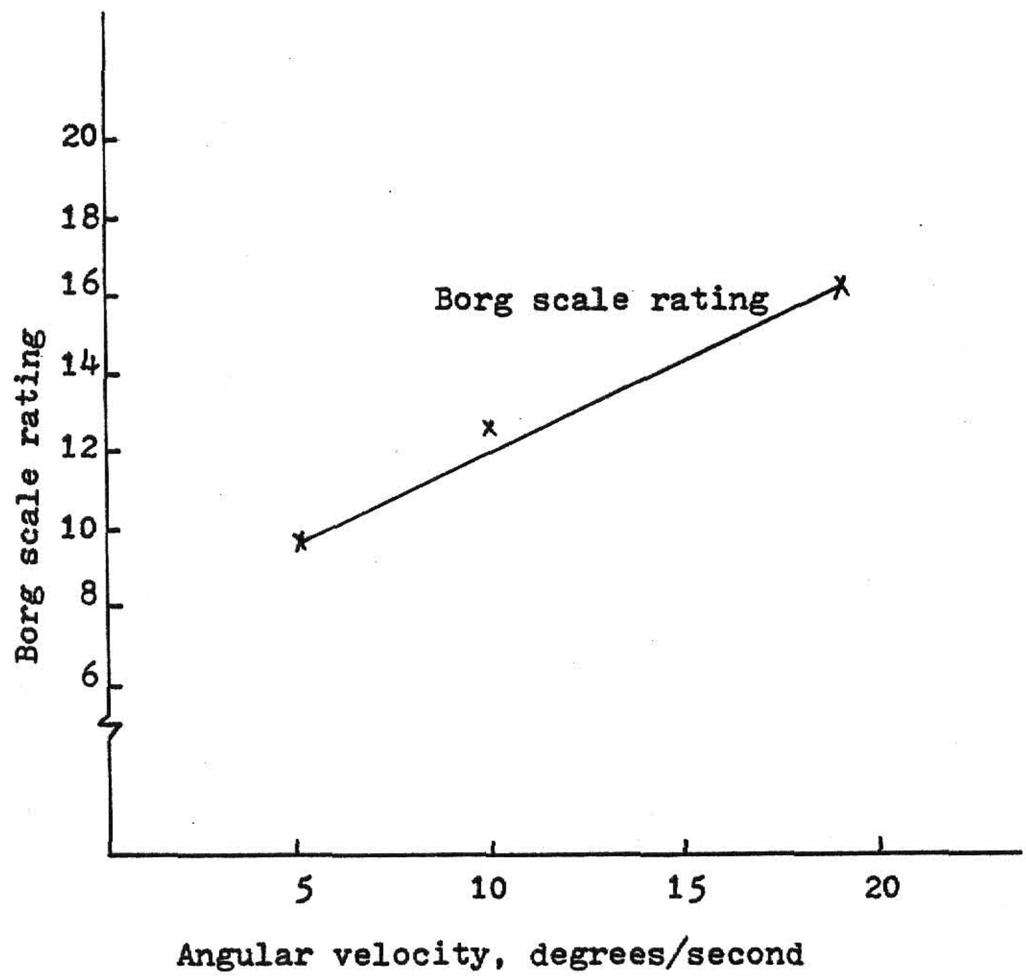


Figure 15. Mean value for Borg scale rating across velocity level

in this study, the percentage of defects and defect sizes are fixed, the Borg scale rating is basically affected by different viewing times per item.

Effect of Window Size on Performance

Hits. The percentage of hits increases significantly as the window size is increased from 4" to 16" as shown in Figure 16. The increase of window size doesn't increase viewing time per item; it only increases the inspection area and allows more flexibility of inspection. Thus if the inspection task is more flexible, the performance is better.

Research (Drury and Clement, 1978) found that the exposed area had a significant effect on search time. This agrees with the study: as the window size (exposed area) is increased, the inspection task is more flexible and takes less total search time to find defects.

Correct acceptance. The increase of window size from 4" to 16" doesn't have significant effect on the percentage of correct acceptances. This can be interpreted as: since the detectability d' is large, the probability of correct acceptance is high and window size effect is not significant under this condition.

Borg scale rating. The increase of window size decreases the Borg scale rating as shown in Figure 17. This can be interpreted as: the increase of window size makes the inspection task more flexible and easier to do.

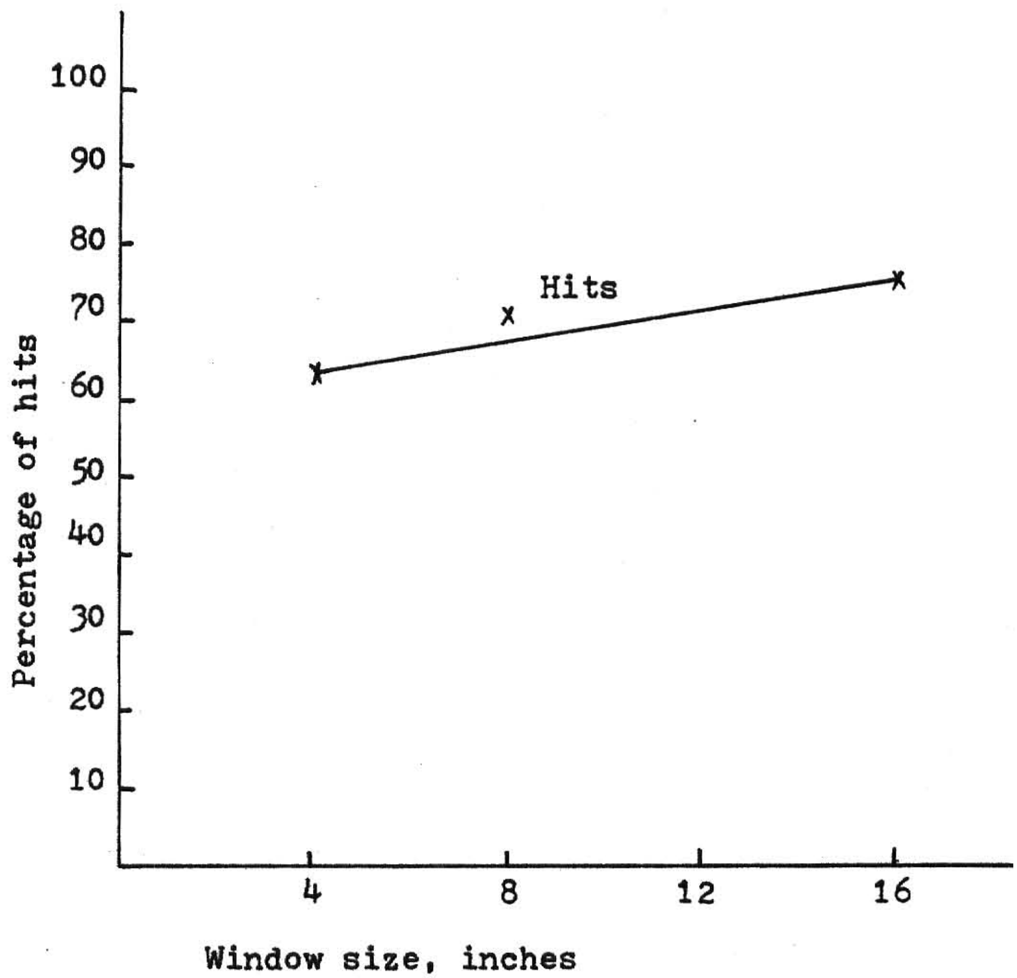


Figure 16. Mean value for hits across window size

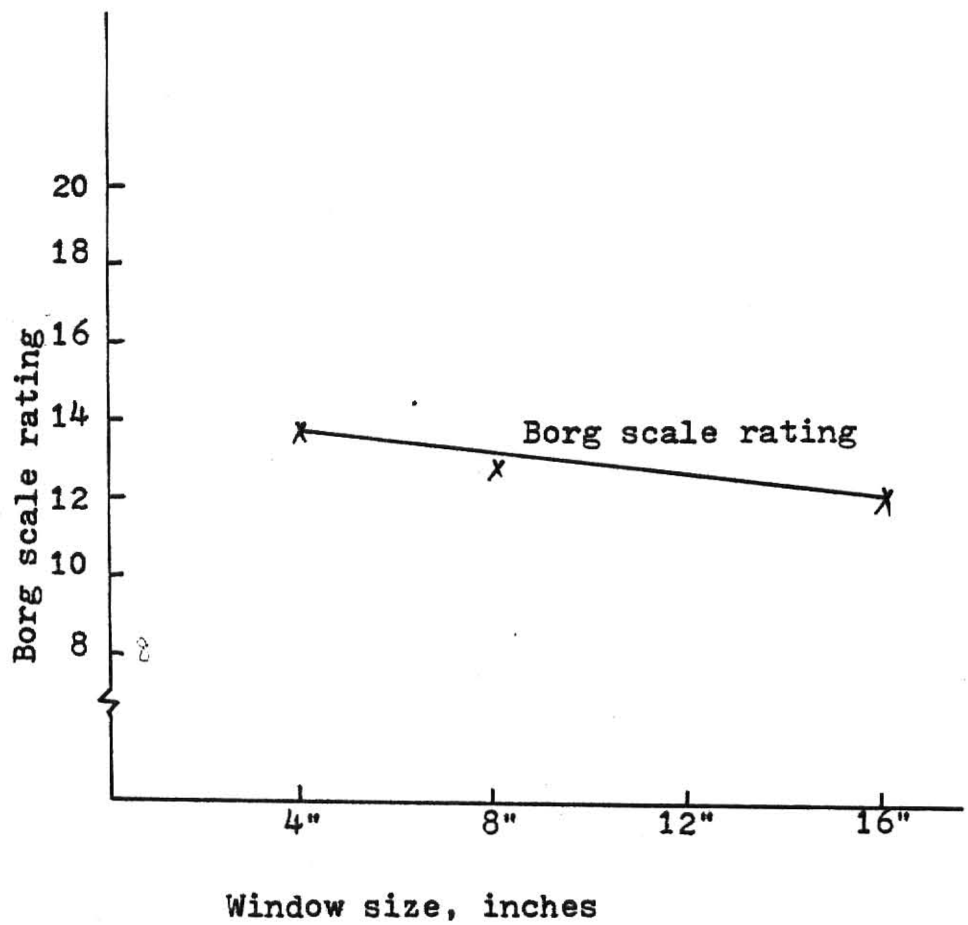


Figure 17. Mean value for Borg scale rating across window size

Effect of Number of Rows on Performance

Hits. The percentage of hits decreases linearly as the number of rows are increased from 2 to 8 as shown in Figure 18. The increase of the number of rows means the decrease of viewing time per item. This agrees with Drury's (1973) finding about the increase in hit rate as viewing time is increased.

Correct acceptance. The increase of the number of rows doesn't have significant effect on the percentage of correct acceptance. This is because the detectability d' is large, so the probability of correct acceptance is high. The change of the number of rows doesn't have much effect on it.

Borg scale rating. The increase of the number of rows increases the Borg scale rating as shown in Figure 19. This can be interpreted as: increase of number of rows results in the decrease of viewing time per item and makes the task more difficult.

The Interaction Effect of Conveyor Velocity, Window Size and Number of Rows

From Figure 20, 21 and 22, the interaction effect of each two factors can be seen.

Optimal Strategy

The first hypothesis is that the optimal strategy which gives the best performance is basically decided by the inspection rate. From the experimental results (Table 19), the percentage of hits is higher when viewing time per item is longer.

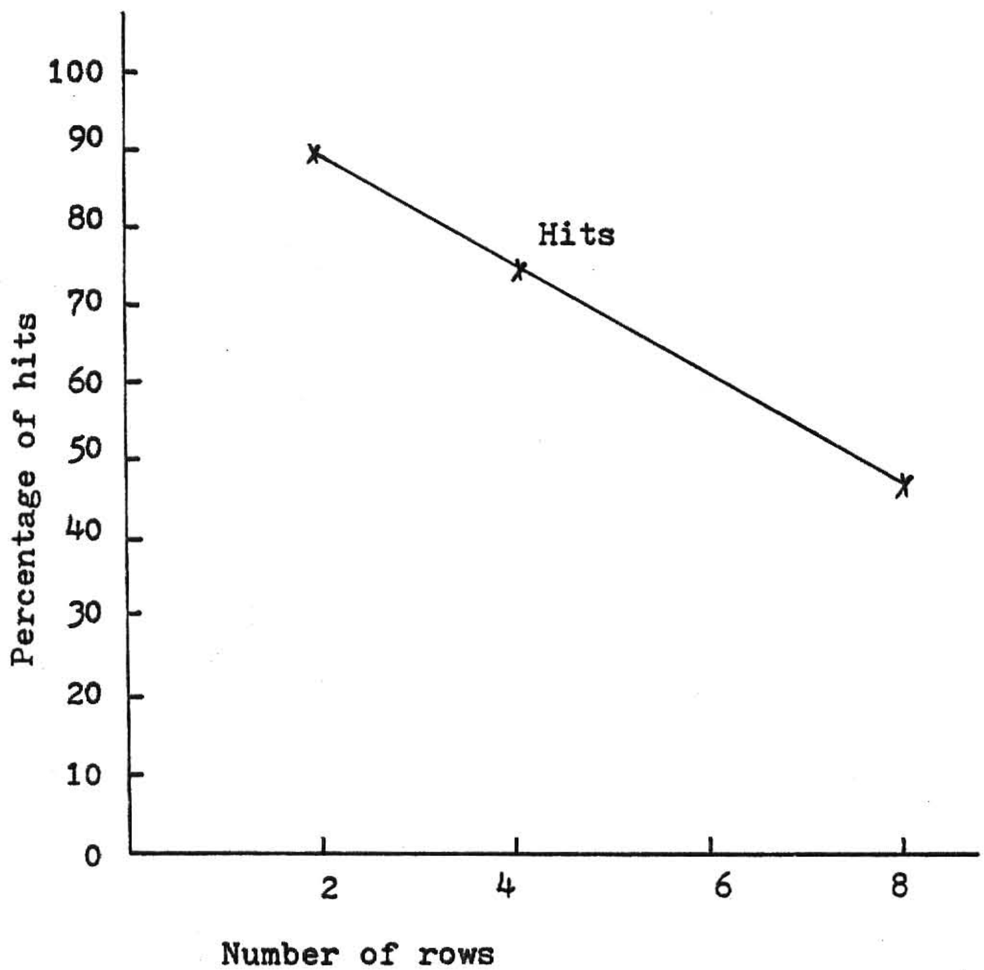


Figure 18. Mean value for hits across number of rows

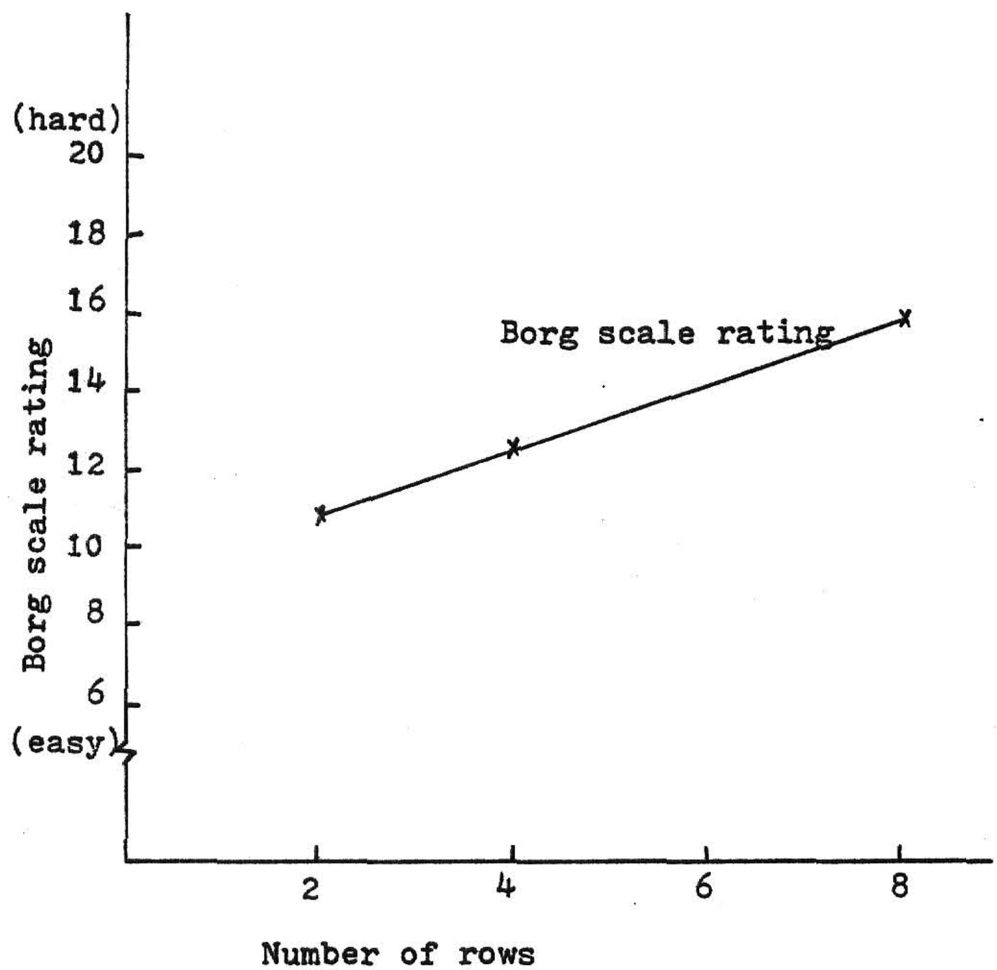


Figure 19. <u>Mean value for Borg scale rating across number of rows</u>

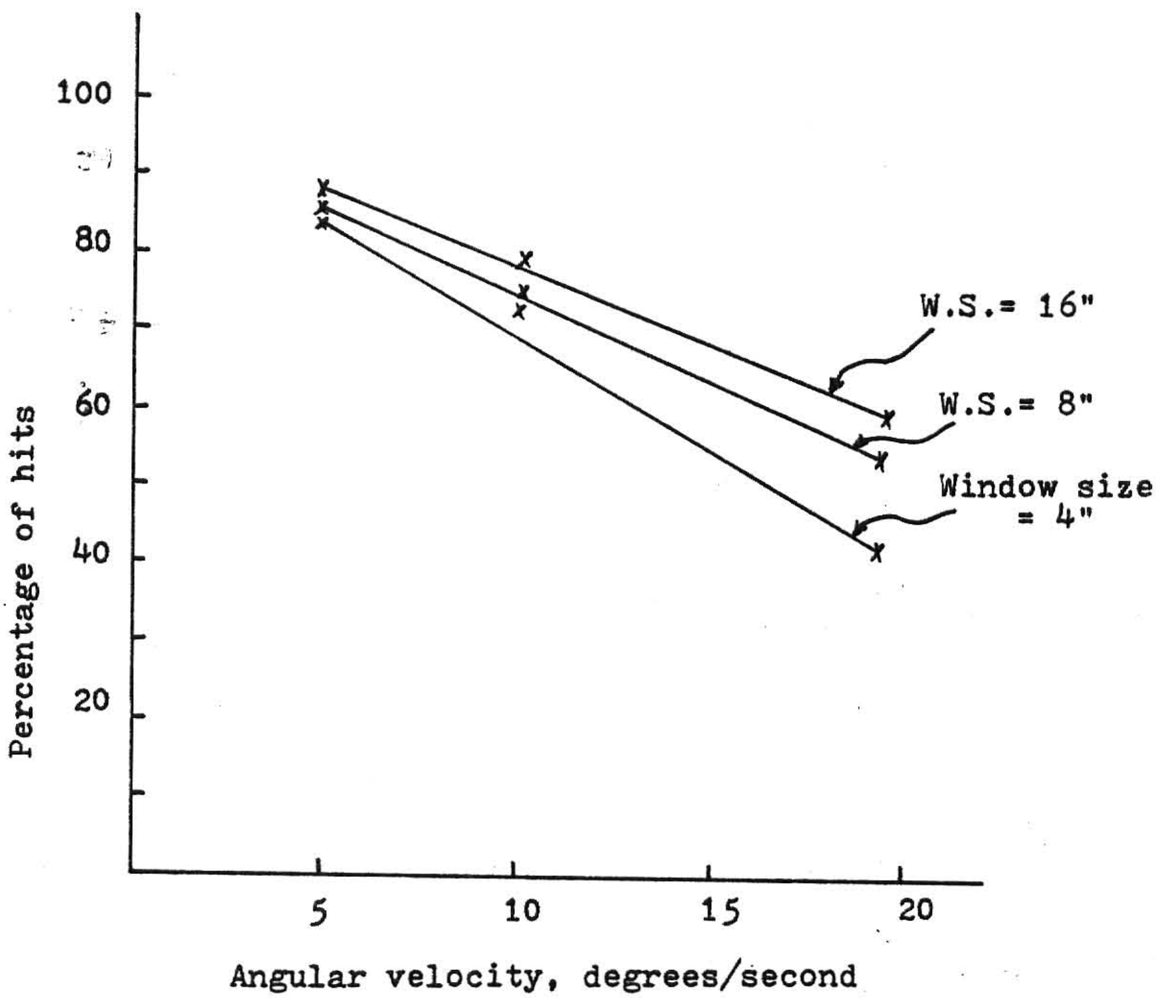


Figure 20. <u>Mean value for hits across velocity level with different window size</u>

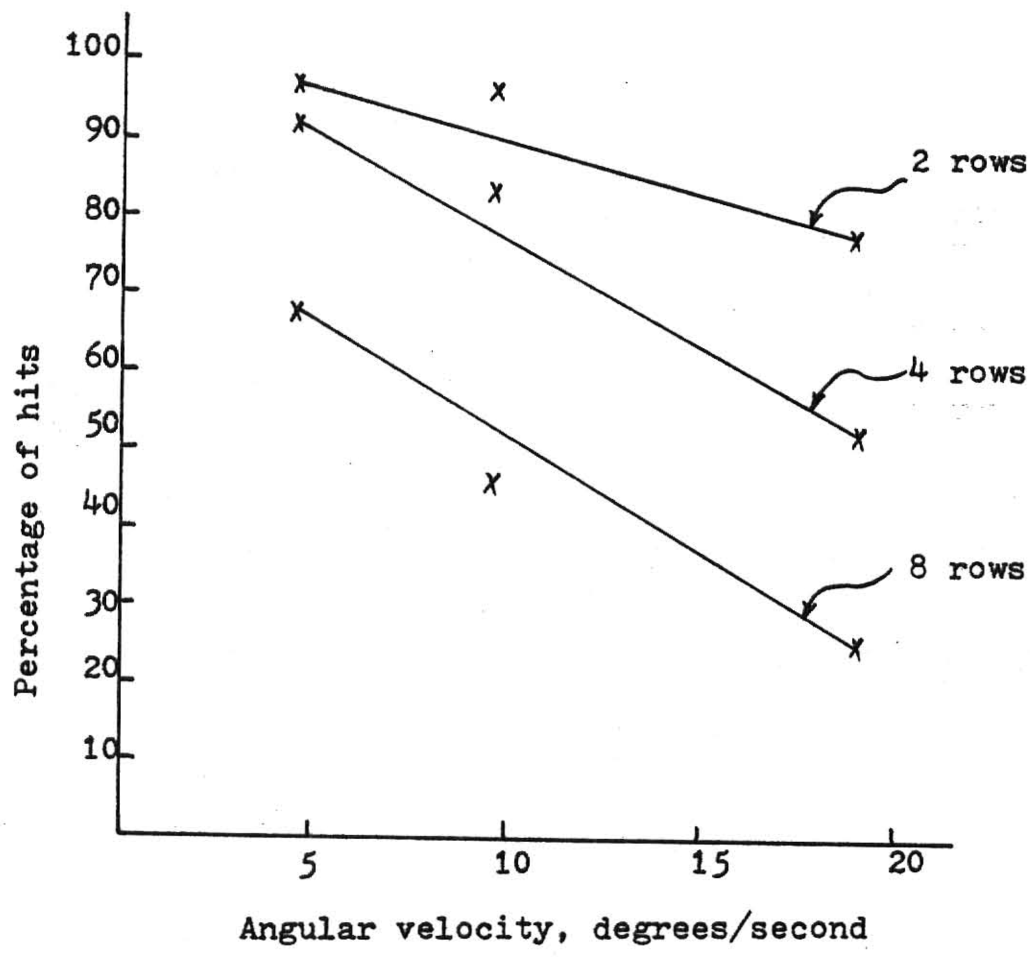


Figure 21. <u>Mean value for hits across velocity level with different number of rows</u>

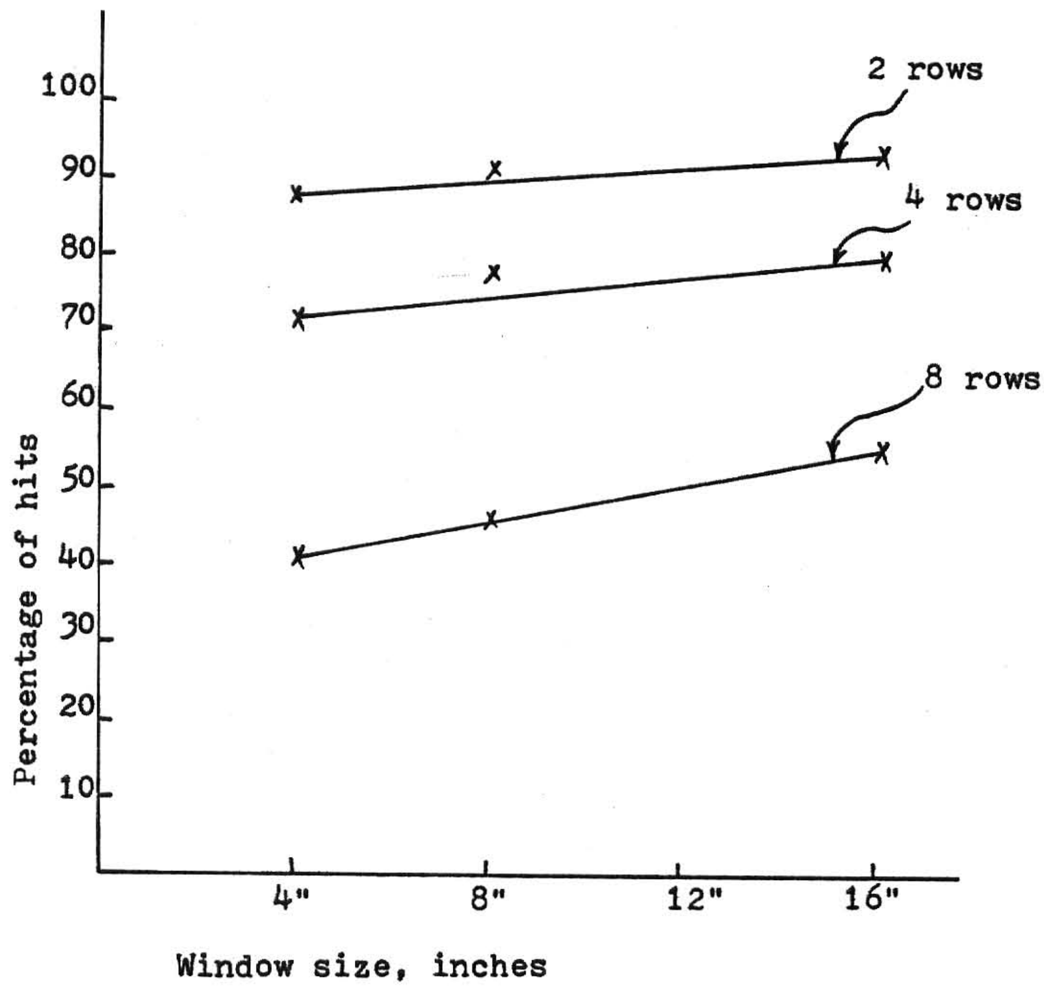


Figure 22. Mean value for hits across window size with different number of rows

This agrees with William and Borrow's (1963) finding which stated that the inspection performance depends on viewing time per item when the conveyor speed is not high.

Flexibility in Inspection

The second hypothesis is that the more flexible an inspection task is, the more efficient it is while viewing time per item is fixed. From Table 12 and 13, the window size effect is significant while increasing from 4" to 8" or 8" to 16". The increase of window size will expose more items to the inspector which will increase the horizontal flexibility of inspection, so this hypothesis is correct.

But from Table 29, the increase of vertical flexibility (fixed inspection rate and window size, changing only the number of rows) doesn't always increase performance. Especially when the number of rows are increased from 4 to 8, the performance decreases significantly. This part will be discussed in the nest hypothesis, i.e. horizontal versus vertical inspection.

Research (Drury and Clement, 1978) found that the exposed area had a significant effect on search time. This agrees with the study of horizontal flexibility. As the horizontal area is increased, more items exposed to the subject, the subject is more flexible in distributing search time among good items and bad items and reduces the total search time in finding the defects. But the increase of vertical area to a certain level might introduce the difficulty of vertical inspection and make the performance worse.

TABLE 29.

Effects of Vertical Flexibility under Different Inspection Rates

Inspection rate	Grouping	Mean (hits)	Observation (N)	Interaction: Window size	Interaction: Row	Interaction: Speed	Items exposed
7.1 items/sec	A	0.4248	8	4"	4	18.8 °/sec	16
	A	0.4088	8	4	8	9.4	32
	B	0.5626	8	8	4	18.8	32
	A	0.4558	8	8	8	9.4	64
	B	0.6148	8	16	4	18.8	64
	B	0.5575	8	16	8	9.4	128
3.6	C	0.6850	8	4	2	18.8	8
	F E D	0.8258	8	4	4	9.4	16
	C	0.6223	8	4	8	4.7	32
	E D	0.8100	8	8	2	18.8	16
	F E	0.8439	8	8	4	9.4	32
	C	0.6798	8	8	8	4.7	64
	F E	0.8465	8	16	2	18.8	32
	F	0.8776	8	16	4	9.4	64
	D	0.7680	8	16	8	4.7	128
1.8	G	0.8204	8	4	1	18.8	4
	I	0.9610	8	4	2	9.4	8
	I H	0.9296	8	4	4	4.7	16
	H	0.8933	8	8	1	18.8	8
	I	0.9714	8	8	2	9.4	16
	I	0.9453	8	8	4	4.7	32
	I	0.9350	8	16	1	18.8	16
	I	0.9688	8	16	2	9.4	32
	I H	0.9115	8	16	4	4.7	64

The third hypothesis is that horizontal inspection is better than vertical inspection while the number of target exposed and average viewing time per item is the same. From Table 30, the four-row and two-row conditions (horizontal inspection) are significantly better than eight-row conditions (vertical inspection). When inspection rate is 7.1 items/sec, four-row conditions are better than eight-row conditions. When inspection rate is 3.6 items/sec, two-row and four-row conditions are not significantly different, but they are significantly better than eight-row conditions. When inspection rate is 1.8 items/sec, two-row and four-row conditions are not significantly different. This is because up to four-row condition, the vertical span of targets is still within the effective inspection range of eyes, so it doesn't require much up and down eye(or head) movement and it's more efficient, while the eight-row condition, the vertical span of targets is outside the effective inspection range of eyes, so it requires more up and down eye (or head) movement and it's less efficient. These findings agree with the hypothesis.

Research (Williges and Streeter, 1971) found that the display arrangement seemed to have little effect on inspection. This disagrees with the study. When targets are arranged in a way that only horizontal inspection is required, it's more efficient than one which required vertical inspection.

TABLE 30.

LSD Test for Percentage of Hits with Different Target Arrangements

Grouping	Mean (hits)	Arrangement (Row x column)	Inspection rate items/sec	Test Speed %sec	Row	Window size
A	0.6148	4 x 16	7.1	18.8	4	16"
A	0.5626	4 x 8	7.1	18.8	4	8
B	0.4558	8 x 8	7.1	9.4	8	8
B	0.4088	8 x 4	7.1	9.4	8	4
C	0.8776	4 x 16	3.6	9.4	4	16
C	0.8465	2 x 16	3.6	18.8	2	16
C	0.8439	4 x 8	3.6	9.4	4	8
C	0.8258	4 x 4	3.6	9.4	4	4
C	0.8100	2 x 8	3.6	18.8	2	8
D	0.6798	8 x 8	3.6	4.7	8	8
D	0.6223	8 x 4	3.6	4.7	8	4
E	0.9741	2 x 8	1.8	9.4	2	8
E	0.9688	2 x 16	1.8	9.4	2	16
E	0.9453	4 x 8	1.8	4.7	4	8
E	0.9296	4 x 4	1.8	4.7	4	4

Number of Rows versus Conveyor Velocity

The fourth hypothesis is that if defect size is small, it's better to inspect more rows at a slower speed than to inspect fewer rows at a higher speed. From Table 31, when the inspection rate is 7.1 items/sec, the average performance of four-row conditions at fast speed (18.8 °/sec) is better than eight-row conditions at middle speed (9.4 °/sec). From Table 31, when the inspection rate is 3.6 items/sec, the four-row conditions at middle speed (9.4 °/sec) are better than two-row conditions at fast speed (18.8 °/sec). But the performance of eight-row conditions at slow speed (4.7 °/sec) are the worst ones. From Table 31, when the inspection rate is about enough (1.8 items/sec), two-row conditions at middle speed (9.4 °/sec) are not significantly better than four-row conditions at slow speed (4.7 °/sec). But they are better than one-row condition at fast speed (18.8 °/sec)

From the above results, the fourth hypothesis is not always true, it depends on the average viewing time per item (or inspection rate). Also, the number of rows can only be increased to certain limit, while exceeding that limit (about four-rows in this study) the difficulty of vertical inspection will be introduced and overwhelm the advantage of inspecting more rows at a slower speed.

Summary of Results

The strategy which gives the best performance is basically decided by the inspection rate. Decreasing the performance

TABLE 31.

Number of Rows versus Conveyor Velocity under 7.1 items/sec of Inspection Rate

Inspection rate	Grouping	Mean (hits)	Observations(N)	Interaction Speed	Interaction Row	Interaction Window size
7.1 items/sec	A	0.4088	8	9.4 "/sec	8	4"
	A	0.4248	8	18.8	4	4
	A	0.4558	8	9.4	8	8
	B	0.5575	8	9.4	8	16
	B	0.5626	8	18.8	4	8
	B	0.6148	8	18.8	4	16
3.6	C	0.6223	8	4.7	8	4
	C	0.6798	8	4.7	8	8
	C	0.6850	8	18.8	2	4
	D	0.7680	8	4.7	8	16
	E D	0.8100	8	18.8	2	8
	F E D	0.8258	8	9.4	4	4
	F E	0.8439	8	9.4	4	8
	F E	0.8465	8	18.8	2	16
	F	0.8776	8	9.4	4	16
1.8	G	0.8204	8	18.8	1	4
	H	0.8933	8	18.8	1	8
	I H	0.9115	8	4.7	4	16
	I H	0.9296	8	4.7	4	4
	I	0.9350	8	18.8	1	16
	I	0.9453	8	4.7	4	8
	I	0.9610	8	9.4	2	4
	I	0.9688	8	9.4	2	16
	I	0.9714	8	9.4	2	8

rate will result in the increase of performance.

The performance of inspection is increased when horizontal flexibility (change of window size) of inspection is increased. The window size is better at least up to 16" wide.

Horizontal inspection (no more than four inches of vertical span) was better than vertical inspection (more than four inches span or four-row condition).

When the inspection rate was too high (3.6 items/sec), it was better to inspect more rows (not exceeding four rows) at a slower speed than fewer rows at a higher speed.

Future Research

Further research is needed to determine the different effects of randomly and orderly arrangement of targets on inspection and the effect of sparse or densely packed arrangement on inspection.

The difference in eye (and head) movement between vertical inspection (more than four rows) and horizontal inspection (less than four rows) also needs further research.

The interaction between conveyor velocity and task difficulty (defect size) also requires more research.

Practical Implications

1. For any inspection task, the inspection rate should be slow enough to give adequate viewing time per item in order to achieve the optimal performance. The inspection rate can be decided by the average time to inspect a good item and

a bad item and the average percentage of defective rate in a production line.

2. The inspection task should be designed in a way that the inspector has more flexibility to allocate inspection time over more items while the inspection rate is fixed. This can be achieved by increasing the inspection area and the density of targets to expose more items within the inspector's effective working area.
3. In order to use horizontal inspection (which is more effective) if the vertical span of targets is too wide, it's better to divide the conveyor line into two or more sections and let each inspector only inspect one section while the inspection rate is fixed.
4. In general, it's better to inspect more densely packed items at a slower speed than more sparsely spaced items at a higher speed while the inspection rate is fixed.

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INSPECTION STRATEGY - CONSIDERING CONVEYOR SPEED, WINDOW SIZE AND TARGET ARRANGEMENT

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ABSTRACT

This study investigated the effects of conveyor velocity, window size and number of rows on the inspection task. There were three velocities (4.7 °/sec, 9.4 °/sec and 18.8 °/sec), three window sizes (4", 8" and 16"), and four kinds of rows (one, two, four and eight rows). Eight subjects were tested and each one was assigned all the 30 tests. Measures were hits, correct acceptances and the Borg scale ratings. Hits and the Borg scale ratings were affected by all the three variables while correct acceptances were not. Hits were the best measure of performance in this study. It was found: the performance was a function of inspection rate, the increase of inspection rate resulted in the decrease of performance; the flexibility of inspection task had an effect on performance; "horizontal inspection" was better than "vertical inspection"; in general, it was better to inspect more rows at a slower speed than fewer rows at a higher speed.