Analysis of Per-Item and Per-Lot Paced Visual Inspection for High Target Probability Conditions

Rajeev M. Sahasrabudhe, Shannon R. Bowling, Mohammad T. Khasawneh, Anand K Gramopadhye, and Brian J Melloy
Advanced Technology Systems Laboratory
Department of Industrial Engineering
Clemson University
Clemson, South Carolina 29364-0920

Abstract. Inspection, a necessary component in manufacturing to ensure process and quality control, has two main components, visual search and decision-making. The human element, while not perfect, cannot be eliminated from the inspection process because of the inherent advantages that a human inspector has to offer. Since some type of pacing is generally incorporated into the manufacturing setting for cost effectiveness, discovering how speed and rigidity affect the accuracy of inspection is essential. Therefore, this study attempts to explore the relationship between time limits imposed on inspectors and the amount of flexibility they have in performing the inspection task.

Introduction

Inspection, a process that attempts to locate faulty or defective items, is necessary in order to maintain customer satisfaction, but it also must be kept efficient to reduce the associated costs. Inspection tasks can be performed by using automated inspection machines or visually by humans inspecting items for defects.

In the past humans have performed a majority of the inspection tasks. But because even the most effective human inspector is not completely reliable, attempts have been made to automate the inspection process. Regardless of these attempts, inspection continues to be done mainly by human inspectors because of superior human decision-making ability in such areas as the ability to adapt to unforeseen events and the ability to judge (Thapa, et al., 1996).

Thus, human factors has been the motivation behind several studies dealing with the subject’s ability to perform inspection tasks (Drury 1973) with the aim of improving human performance in visual inspection to make it more reliable.

Inspection can be successful only if its two components, visual search and decision-making are performed accurately and effectively (Drury, 1978; Sinclair, 1984). The search component is more time-consuming and error-prone than the decision-making one. Also it is difficult to pace a visual inspection task when both speed and accuracy are equally important. (Morawski, Drury & Karwan, 1992). Thus, it is important to research inspection tasks using various pacing strategies to determine which one yields the best performance.

Pacing, an integral aspect of many inspection tasks, is widely used in industry as it reduces the variability of the work-in-progress and limits the number of items stored in a queue or a stockpile. Three types of pacing have been discussed in literature: unpaced, self-paced and machine-paced; also pacing can be on a per-lot basis or a per-item basis for a particular lot of items. Since some of these terms have been used interchangeably, often their use has not been consistent.

Therefore, for the purpose of this study, a machine-paced task is defined as one for which a fixed time has been allocated for detecting a defect. The same amount of time is allocated whether or not a defect is detected. This type of pacing offers such obvious economic advantages in industry settings as minimization of work-in-progress, maximization of floor space and simplification of the organization of supplying components to the right place at the right time (Belbin & Stammers, 1972). For a self-paced task, a maximum time limit is set, although the inspector may chose to go onto the next task before it has been reached.

According to a study conducted by McFarling & Heimstra (1975), self-paced inspection appears to be beneficial for both performance and motivation. Their results suggested that a “self-paced situation may be structured to encourage accuracy rather than speed and still realize a reasonable level of total task completion time”. Also self-paced inspection is generally regarded as better suited for an inspector than machine paced inspection, due to the additional degree of control it affords (e.g., Drury, 1975; Eskew and Riche, 1982). Finally, unpaced inspection places no time limit on the inspector.

Previous research has focused on the speed and structure of pacing. However, little attention has been placed on how the degree of pacing control is structured. Per-item pacing sets a certain amount of time for each individual item, as seen in inspection on a conveyor line or indexing machine (Kochar & Jaisingh, 1980). It represents a structured condition, eliminating the possibility of some items being missed. Per-lot pacing sets a certain amount of time for the inspection of an entire lot of items, such as when an inspector works from a bin in an industry. Although less structured, per-lot pacing has been observed to compensate for the variability of inspection times between individual items. Since each pacing condition offers certain advantages, further research is suggested.

Current related studies (Garrett, Melloy, Gramopadhye, 2000) have been conducted where pacing conditions have been investigated for low defect probabilities. Their findings suggested that performance was similar for both per-lot (self-paced) and per-item (machine paced) conditions as far as
accuracy was concerned. Similar findings were also reported by Coury and Drury (1986), albeit, for the decision making component of the inspection task. Also the levels of speed; which is the time allowed for either an item or a lot; was a significant factor for the performance measures, which was consistent with previous studies. They concluded in their study that for practical reasons a per item pacing condition is more favorable in majority of industrial settings. It would be interesting to study whether their findings could be applicable for a scenario where the defect probability is high.

Generally for a high defect probability inspection task the search times will tend to dominate, as the number of items without a defect are negligible. Therefore a high probability of defect occurrence may tend to have effects that are different than when the defect probability is low, on human performance.

Moreover if the results tend to suggest that there is a significant difference between the accuracy levels of the two pacing conditions then pacing on a per-item basis may not be the best suitable strategy to adopt when the defect probability is high. To address this issue, this study examined the visual search component of an inspection task, focusing on the effect of per-item v/s per-lot pacing on visual inspection performance for high defect probability.

Methodology

Subjects
This study was conducted using ten student subjects from the Industrial Engineering Department at Clemson University. Student subjects were used in lieu of quality control inspectors based on Gallwey & Drury's (1986) findings that no significant differences exist between student subjects and inspectors on simulated tasks.

Equipment
Dell Optiplex GX 110 personal computers with Windows NT workstation 4.0 operating systems and Intel Pentium 733 MHz processors were used for this study. The viewing screen was a 17-inch color monitor at a resolution of 800*600 pixels.

Stimulus Material
The experiments for the actual study were conducted using an inspection simulator, which is a program developed using Visual Basic 5.0 software. Screens with a set of eight ASCII characters (W, N, M, V, Y, K, Z) as the background characters were randomly generated for each trial. The subject’s task was to search for the target character 'X' amidst the background characters (see Fig. 1). The density of the background characters was kept at 40% which was consistent with the study of Garett et. al. (2000). Unlike Garett’s study, which considered a low-defect probability situation, this study used a defect probability of 0.96. The number of characters in the eight positions adjacent to the target character has a large effect on the performance in a search task Monk & Brown (1975). Therefore to eliminate any embedded effect, the numbers of characters adjacent to the target character were controlled so that no more than four of the adjacent positions to the target character would contain a background character.

Once the subjects had located the target subsequent to their visual search of the screen they had to use a scroll mouse to point and click on the target, which would be highlighted in red color on clicking. In the per-lot trials as discussed earlier the subjects had the liberty to click on the next screen button to proceed to the next screen. This meant that the subjects could use more than or less than the time appropriated for each screen from the total available time for the lot.

For the per-item trials wherein each screen was timed, the subjects could not move onto the next screen once they had identified a target on a particular screen. They would have to wait till the allotted time for that screen was used up and then the next screen would automatically show up. The machine paced trials screens did not have the ‘next screen’ button to avoid confusion. For both the trials the time elapsed per screen and the total time elapsed was always displayed to the subjects.

Experimental Design and Procedure
The experiment utilized ten subjects who were selected from the student population of both graduate and undergraduate students. The experimental design used for this study was a Latin Square design, with blocking for both subjects and sequence of trials. The two main factors studied were level of control and speed. The two levels of control investigated were per-lot pacing and per-item pacing. Five pacing levels (one corresponding to the mean, three below the mean and one above) had to be established for each individual subject. To determine these pacing levels each subject was tested on a set of 75 unpaced screens to determine his or her mean inspection time and to construct an inspection time distribution. From the inspection time distribution the pacing levels were determined as seen in Fig. 2. The mean inspection time (in seconds) was plotted on the inspection time distribution to find the corresponding percentage. Once this initial percentage had been established the three faster pacing levels were found by dividing this percentage by four. This
resulted in three equal percentages that were then plotted on the inspection distribution to determine the three corresponding inspection times. The slowest speed level was established by using the maximum search time. The purpose of the pilot study was to ensure that the task was of sufficient difficulty to impact accuracy. Before the actual study each subject was asked to complete a set of 25 screens each in both the per-lot and per-item pacing modes to train them on the simulator and any concerns that they had were answered after the training screen sets.

In the actual study each subject completed ten trials, one at each of the five speed levels of the two pacing conditions. The order of the trials were randomized to balance any carry-over effect, and the last treatment condition in each sequence of trials was repeated for each subject to balance any learning effects. After completion of the study, each subject was thanked and compensated for their time.

Figure 2: Cumulative Inspection Time Distribution

Results

The data was analyzed using a Latin Square design. Separate analyses of variance (ANOVA) were conducted on the following performance means: percentage detected (accuracy), mean inspection time, mean stopping time, and mean search time. Adjusted measures were calculated by considering only the viewed screens, while total measures were calculated by considering all 25 screens. Table 1 shows a summary ANOVA indicating only the F value. Following the ANOVA, a post hoc analysis was conducted on the significant effects for total percentage detected (accuracy) using Tukey's test, shown in Table 2.

Accuracy

The main effects of speed $F(4,72) = 21.77$, $p < 0.01$ and control $F(4,72) = 4.10$, $p < 0.05$ were found to be significant on accuracy. The interaction effect for accuracy, that of speed x control, $F(4,72) = 2.59$, $p < 0.05$ was also found to be significant. On the other hand, only the main effect of speed was found to be significant $F(4,72) = 12.59$, $p < 0.01$ for the adjusted accuracy. The main effect of control and the interaction effect of speed x control were not found to be significant. The post hoc analysis conducted using Tukey's test for honestly significant difference revealed that there was no significant difference between the accuracies at speeds 1&2 and speeds 4&5. Speed level 3 was different from all others, which indicates that at the speed level 3 there was a significant increase in accuracy and as the subjects moved from speed level 3 to speed level 4 again there was a significant difference in accuracy.

Table 1: Summary ANOVA table

<table>
<thead>
<tr>
<th>Source</th>
<th>Speed</th>
<th>Control</th>
<th>Speed x Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>21.77 *</td>
<td>4.10 *</td>
<td>2.59 *</td>
</tr>
<tr>
<td>Adjusted Accuracy</td>
<td>12.59 *</td>
<td>1.87</td>
<td>1.61</td>
</tr>
<tr>
<td>Total Mean Inspection Time</td>
<td>17.22 *</td>
<td>1.34</td>
<td>0.64</td>
</tr>
<tr>
<td>Adjusted Mean Inspection Time</td>
<td>22.60 *</td>
<td>4.40 *</td>
<td>1.96</td>
</tr>
<tr>
<td>Total Mean Stopping Time</td>
<td>18.55 *</td>
<td>1.67</td>
<td>1.70</td>
</tr>
<tr>
<td>Adjusted Mean Stopping Time</td>
<td>25.83 *</td>
<td>11.00 *</td>
<td>1.63</td>
</tr>
<tr>
<td>Mean Search Time</td>
<td>17.16 **</td>
<td>6.45</td>
<td>1.42</td>
</tr>
</tbody>
</table>

Table 2: Tukey's Individual Differences Test

<table>
<thead>
<tr>
<th>Speeds</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.155</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0155</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.7929</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.7929</td>
<td></td>
</tr>
</tbody>
</table>

Speed

For all three total speed measurements, mean inspection time, mean stopping time and mean search time, the interaction effect was not found to be significant. Yet for total mean inspection time the main effect of speed $F(4,72) = 17.22$, $p < 0.01$ was found to be significant, despite the main effect of control being not significant. Likewise, the main effect of speed for total mean stopping time $F(4,72) = 18.55$, $p < 0.01$ was found to be significant, while control was not, and for mean search time, the main effect of speed $F(4,72) = 17.16$, $p < 0.01$ was found to be significant and control was not found to be significant.

For the adjusted mean inspection time the main effects of speed $F(4,72) = 22.60$, $p < 0.01$ and control $F(4,72) = 4.40$, $p < 0.01$ were found to be significant. The interaction effect of speed x control was not significant. In the case of the adjusted mean stopping time the effects of speed $F(4,72) = 25.83$, $p < 0.01$ and control $F(4,72) = 11.00$, $p < 0.01$ were found to be
significant whereas the interaction effect was not found to be significant.

Discussion

The objective of this study was to compare and contrast the effects that per-lot and per-item pacing have on inspection performance where there is a high target probability, under different speed pacing levels. After the subjects were adequately trained, all performance measures were found to be sensitive to the speed of the pacing level. Although overall no statistically significant difference was found for between the per-lot and per-item pacing for accuracy, yet for the slower speeds (levels 4 & 5) the per-lot pacing yielded higher accuracies than the per-item pacing. This is remarkably different from the earlier study by Garrett et.al. (2000) where the authors found that although the difference was not statistically significant the accuracies for the per-item condition were higher than those of the per-lot. Given this, the most salient findings are discussed for both accuracy and speed factors.

Interestingly, per-lot and per-item conditions were found to be statistically similar for the accuracy measures, although it was hypothesized that they would be different under stressed conditions. This is consistent with an earlier study by Coury and Drury (1986) and Garrett et. al. (2000) that found pacing rigidity to have little effect on subject performance. Coury and Drury hypothesized that performance deteriorates when the inspector’s resource limits are exceeded and the level of effort necessary to complete the task successfully can no longer be maintained, which was then demonstrated in the current study. Coury and Drury’s findings however, were based on a decision making task which did not exceed the capacity of the inspector’s processing system, established by the fact that subjects maintained accuracy. In this study, it appears that each subject’s capacity level was reached as can be seen in Figure 3 at the faster pacing levels. The accuracy at these pacing levels is much lower than at the other pacing levels, (67.37% and 65.38% for per-lot and per-item respectively at the fastest speed level). However, despite the drop-off, it should be underscored that even when capacities are stressed, there is still no significant difference between the two control conditions of per-lot and per-item for the same speed level. Therefore, even though this study investigates only the visual search process of inspection, since the findings are consistent with those of Coury and Drury, who found no difference in rigidity levels while investigating decision making, it may be appropriate to hypothesize that the previous findings may actually apply to a much broader range of inspection tasks that have both search and decision making components.

Since subjects did not allocate their time in order to be able to view all 25 screens, adjusted accuracy, as measured by adjusted percentage detected, was higher than the accuracy or percent detected when considering all 25 screens at the faster speeds for the per-lot condition. Although not statistically significant there was however a difference in the performance of per-item and per-lot for the adjusted accuracies at the faster speed levels with the per-lot yielding better accuracies than the per-item condition. At the slower pacing levels, the time available approached that for a completely unpaced task, and therefore performance was very similar on both the per-lot and per-item condition.

![Figure 3: Total Percentage Detected](image)

The number of search times and stopping times are a function of both defect rate and accuracy, and both contribute to the total time allocated for a task. If the accuracy is constant, as the defect rate increases, more search times and fewer stopping times will be included in the total time. This would decrease the total time used since stopping times tend to be longer than search times, and would in this case favor a per-lot inspection (Garrett et.al. 2000). Considering the fact that this study was conducted for a very high target probability (96%), a per-lot pacing condition seems to be best suited and the results also indicate this. Moreover as it is not necessary to save on the overall time allocated to the task by truncating long individual stopping times as the percentage of stopping times would be very low, hence making per-lot the more practical type of pacing for industry.

The effect of the gained flexibility in time allocation for the per-lot condition of the control variable was more pronounced at the fastest speed. This follows rationale intuition that the added flexibility would have a less prominent effect when more than ample time is given for the task.

The response variables that reflected the performance measure of speed were total and adjusted mean inspection time; total and adjusted mean stopping time and mean search time. For all of these measures, speed was a significant factor. As would be expected, as speed was increased, the response variable times decreased.

When looking at the actual times for mean stopping time and the adjusted mean stopping times, it appears that under the per-item condition, the subjects were cut off, while they spend more time per screen under the per-lot condition. This human tendency to take longer when given more flexible time constraints caused them to be unable to finish all screens under the per-lot condition.
There was a significant effect of speed on mean search time and no significant effect of control. In other words, the search times were significantly affected by whether the subjects were performing the task under a slow or a faster speed level. The per-item search times were consistently lower than those at per-lot, and since both methods achieved approximately the same accuracy level, per-item would appear to be the more efficient method. Also the subjects used more of their available cognitive resources in the per-item condition to be able to maintain accuracy levels with less time, which is consistent with classic resource allocation theory.

Thus the most salient finding of this study was that the per-item pacing strategy seems to be appropriate for a high defect probability since there is no significant difference in the accuracies yielded using either pacing strategy.

Conclusions

Speed levels were always a significant factor for each performance measure. This confirms previous studies that have shown that the amount of time given for an inspection task is critical to performance. The most important deduction from this study was that even though the accuracy for per-lot and per-item were found to be statistically similar, per-item would be more favorable in most industry settings because of the possible reduction in the overall inspection time. Additional research need to be conducted in order to generalize findings to inspection tasks with varying degrees of both visual search and decision making components.

References