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ScienceDirect
Procedia CIRP 38 (2015) 90 – 93
www.elsevier.com/locate/procedia

The Fourth International Conference on Through-life Engineering Services

The use of Job Aids for Visual Inspection in Manufacturing and Maintenance

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Abstract

Visual inspection is a task regularly seen in manufacturing applications and is still primarily carried out by human operators. This study explored the use of job aids (anything used to assist the operator with the task, such as lists, check sheets or pictures) to assist with visual inspection within a manufacturing facility that inspects used parts. Job aids in the form of inspection manuals were used regularly during the inspection process, and how accurately they were followed was dependent on a number of factors such as size of part, experience of the operator, and accuracy of the inspection manuals. If the job aids were well structured, well written and accessible, then the inspectors were seen to follow them, however for certain jobs inspectors were seen to change the inspection order making inspection more efficient. The findings of the study suggest that prior experience can help in designing efficient, easy to use job aids and that a collaborative approach to design as well as using pictorial examples for comparison purposes would improve the inspection process.

Peer-review under responsibility of the Programme Chair of the Fourth International Conference on Through-life Engineering Services.

Keywords: Visual inspection; job aids; visual aids

1. Introduction

Within a manufacturing facility, maintenance and overhaul may account for a large proportion of the work carried out by human operators due to the varied nature of the task. As the parts inspected have already been used, there is a certain amount of wear expected on the part. This makes the task more complex than inspection during initial production due to looking for defects on a worn and sometimes dirty part. For this study the visual inspection process during inspection maintenance was observed. The parts inspected range from small, straightforward parts taking a few seconds to visually inspect, to large, complex multi-faceted parts that can take up to a day to inspect. For larger, more complex parts the inspectors refer to job aids in the form of inspection manuals and standard operating instructions (SOIs), detailing every aspect of the inspection with a specific order and process to follow.

Currently most Visual Inspection (VI) is still carried out by human operators due to their ability to make decisions [1], adapt to unforeseen events [2], and use tactile senses [3]. A well-recognised and cited model in relation to VI is Drury's two stage model of inspection performance [4; 5]. This focuses on the 'search' and 'decide' components of VI. The 'search' process involves examining an object with reference to a pre-defined standard, and can extend to a multi-sensory approach involving (among others) touch and sound [3]. The 'decide' component involves deciding if the defect matches pre-defined criteria. This leads to the selection of the appropriate response about whether an item being inspected falls above or below these criteria. This can be criteria in the operators' memory or within an inspection manual. In either case the process will have been pre-defined and communicated using an inspection manual in a written form, before transferring to the operators' memory, through training and practice.

The search component has been found to be the major component in VI due to it being time consuming and error prone [4; 6]. Specifically in this example, the defects can be difficult to see due to the variation of the background 'noise' (the wear of the part) which can increase error rates [7]. Task

2212-8271
Peer-review under responsibility of the Programme Chair of the Fourth International Conference on Through-life Engineering Services.
doi:10.1016/j.procir.2015.08.056

complexity can have a significant effect on detection rates and performance. If a large number of faults are present, and are very similar in appearance or definition, detection rates can decrease [2]. Additionally the complexity of the part being inspected has been found to have an impact on detection rates [8], with performance declining as complexity increases.

When an inspector is asked to look for a large number of defects, cognitive demand can increase, and errors can occur. These errors are mainly in the form of missed defects [9]. An efficient and effective search strategy can help to overcome these errors and prevent defects from being missed. Somewhere in between the two extremes of visual search (a random strategy, and a systematic approach) lies human visual search behaviour [10], and studies have shown that the more systematic the approach, the better the performance of the operator [11]. Job aids can be used to train operators to adopt a systematic approach during the search phase and reduce errors [12]. Job aids should, as a minimum include information about defect type, location, and size [13]. Poorly written, inaccurate or inefficient inspection standards could increase cognitive strain and memory load because they increase the need for additional judgment and decision making [13]. Lack of clear definitions and instructions has been shown to encourage the development of personal criteria, which is not only at risk of being incorrect, but can also drift over time, leading to variability in performance [14].

Further, job aids are used to assist in improving the accuracy of both the ‘search’ and ‘decide’ components. These include additional lighting, magnifying glasses, and measurement tools. The focus in this paper will be on the use and design of written instructions used as job aids, such as in this case, inspection manuals. This paper describes how job aids are used to assist operators during the visual inspection process and identifies the key aspects that lead to the effective design and use of job aids within a complex, often unpredictable inspection environment.

2. Method

Data collection approaches included observations, walkthroughs, talk-throughs and interviews with inspectors to establish their VI approaches, as well as reviewing task documentation such as SOIs and inspection manuals to understand how these items are used by the inspectors to aid the VI process. Two researchers visited the maintenance facility over 10 days to gather data, which also included a two day validation visit. Data were collected during working hours and different shifts were accounted for. Due to its potential for in-depth analysis of individual task elements the Hierarchical Task Analysis (HTA) approach was selected for this study.

2.1. Task analysis

HTA has been recognised as one of the most commonly used and versatile methods for deconstructing and analysing manual activity [15]. This systematic approach is a top-down deconstruction process that forms a nested hierarchy of goals, sub goals, operations and plans. It records the observable behaviours that the operators carry out. The result of an HTA is a list of step by step actions providing a comprehensive description of the observable elements of the task. The basic decision making processes of the operator are also articulated in the form of plans, specifying the sequence of operations.

Task Decomposition (TD) was selected as a technique to extend the depth of analysis, expanding the HTA method to elicit more detailed task information including the unobservable cognitive aspects of task performance [16]. The operations of a HTA are broken down using TD to enable detailed information regarding the task and decisions made to be identified, providing a comprehensive analysis of a particular task [17].

3. Results and discussion

The findings were presented in the form of a HTA which described in sequence the physical task components of the VI task. A section of the HTA is shown in figure 1.

7	**Inspection.** ***Plan 7: 7.1 - 7.2, (depending on level)- 7.3 - 7.4 (if at a distance from computer the entire list of defects will be written down and then 7.4.1 – 7.4.2 – 7.4.3 - 7.4.4 would be carried out)***		
	7.1	***Follow inspection steps in the inspection manual***	
	7.2	***Level 1 and 2 hand clean parts***	
		7.2.1	*If cannot remove dirt and it isn’t coming clean contact engineer to send item for wash*
	7.3	***Inspect to the level dictated by manual***	
	7.4	***Write down a list of the defects found noting where they are. Plan 7.4: if at a distance from computer the entire list of defects will be written down and then 7.4.1 – 7.4.2 – 7.4.3 - 7.4.4 would be carried out***	
		7.4.1	*Match the defect on the component to the defects outlined in the manual*
		7.4.2	*Sentence these defects based on the sentencing criteria within the manual*
		7.4.3	*If find a defect that is not taken into account in the manual contact the engineer*
		7.4.4	*If find joined up defects assess them individually as outlined in the manual*

Figure 1 – Section of the HTA; following the inspection plan

The tasks were then decomposed under headings including purpose, cues, decision and variations to identify the key decisions made during the task.

Inspectors are told in the routing documentation exactly what inspection manual to work to and what level to inspect to. They then follow the inspection manual which outlines areas where attention has to be paid, and outline a step by step process for inspection, thus they do not inspect every area of every part.

3.1. Individual differences

The inspection manual will be visible on the computer in the inspection area while the part is inspected. If the part is small, the inspectors tend to read the inspection manual, inspect the part, then fill in the documentation afterwards. If the part is moveable, the inspectors may move the part closer to the computer and keep referring to the inspection manual while they inspect the part. For Large parts, some inspectors print off the relevant parts of the inspection manual and use it as a check list, whereas others inspect the part from memory and sit down at the computer afterwards and check through the list as part of the inspection process. Some inspectors may also write a list during inspection detailing any defects including measurement and placement. Inspectors were seen to rarely use any sort of measurement device, and instead relied on subjective judgment based on a mental comparison to previous defects. This was seen particularly with depth measurement for experienced inspectors.

Many of the parts arriving in the inspection bays are dirty and worn; especially if they are only having a partial disassembly and inspection. Less experienced inspectors were seen to clean the entire part prior to inspecting, whereas more experienced inspectors would clean the part as they went, inspecting at the same time, and therefore only clean the areas of the part that would need inspecting.

Individual differences may occur when inspectors have different levels of experience and also different product knowledge. Knowledge of how the parts fitted together or how they were produced was seen to create differences between inspectors in VI strategies. One inspector had varied experience working in different parts of the business, so had knowledge of where the potential problem areas were likely to be and the types of defects that were likely to occur. This meant he would look at these areas first. This type of information was shared between inspectors and commonalities form between inspectors as 'tricks of the trade' are passed down.

One inspector was observed to follow a pattern of inspection for one part slightly differently from the inspection manual because that was "how he had been trained to do it" and was more efficient than following the steps completely. Inspectors were seen to also regularly seek advice from one another, especially for less common defects or if someone had more experience on a particular part. This confirmation between inspectors was seen to lead to commonalities in inspection strategies.

3.2. The use of job aids

The inspection manual was regularly referred to and used, but for some large parts the steps were not followed in order. This may have been as a result of training, or through experience and finding more efficient ways of carrying out the task. A common practice observed was deviating from the inspection manual for large / complex parts. Inspectors would inspect one side first and complete all of the steps on that side, then flip the part and complete the inspection on that side. Following the inspection manual would result in constant flipping and turning of the part, so they streamlined the process. Each inspector had a slightly different order of doing things, and there were commonalities in terms of who they had been trained by, and length of time in the job. The process was carried out from memory, and was carried out exactly the same way each time. By changing the order of the inspection steps, the operators are reducing the potential for damage to the part that could potentially result from constantly flipping the part.

If an inspector is aware of an inspection step that could potentially result in the part being scrapped if it is present, this step is carried out first. This has the potential to save a lot of time, but the step may be near the end of the inspection list on the inspection manual. After carrying out this step, the inspectors then follow the steps laid out in the inspection manual.

If an inspector came across a defect that they were unsure of, or had not seen before, they may refer to the pictorial section of the inspection manual detailing all of the defect types in drawn form. However, these were generally viewed as not very useful in that they were only examples of the defects and were not part specific. For example, the edges of some of the parts were known for being damaged in a very specific way, which was very different to other parts, so the generic descriptions and drawings did not help to identify this. In this instance inspectors would draw on their learned knowledge or ask other inspectors for advice.

4. Conclusions and further work

During the inspection process the operators are looking for any defects, and are consistently comparing the component to their learned knowledge of what the object should look like. This knowledge is a combination of information gained from other inspectors, from the inspection manuals, and from repetition of the task. Through this process, the inspectors' knowledge is being constantly developed and extended. One way to ensure that the knowledge remains current and correct is to follow set inspection standards and provide examples of similar or known defects.

By changing the order of the inspection manual steps, the search strategies are often more efficient than the order laid out in the inspection manual and save considerable amounts of time, especially for complex parts. Experience and training lead to differences in inspection strategies that deviate from the inspection manual but can improve the process and lead to reduced damage and inspection times. One size does not fit all in this instance, and a collaborative approach when writing and updating the manuals, incorporating operator input should be common practice.

One potential improvement could be more flexible software allowing the inspectors to personalise their inspection manuals to suit their preferred practices. This would ensure that all of the steps are followed in order, reducing the potential for errors. By monitoring this and gathering information about preferred orders, future processes could be improved leading to the adoption of a systematic inspection strategy. Another potential improvement would be to allow annotated photographs of defects to be placed within the inspection manuals in their electronic form for reference purposes. This could ensure that shared knowledge is standardized, correct and accessible to all. An extension of this would be to develop a decision support system for the VI process based around this acquired knowledge and expertise which would assist in standardising the process, especially for complex parts.

Acknowledgements

This work was supported by the UK Engineering and Physical Sciences Research Council Centre for Innovative Manufacturing in Intelligent Automation.

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2015-10-27

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Elsevier

Rebecca L. Charles, Teegan L. Johnson, Sarah R. Fletcher. The use of job aids for visual inspection in manufacturing and maintenance. Proceedings of the 4th International Conference on Through-life Engineering Services, Procedia CIRP, Volume 38, 2015, Pages 90-93

http://dx.doi.org/10.1016/j.procir.2015.08.056