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Automated Verification of Raw Material. (Scrap reduction)

Literature Review

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Abstract: Human error is an important aspect in production quality. The occurrence of human error in a manufacturing environment impacts on quality, productivity, operational efficiency, operational and economic results. Contributing factors, such as product design, process design, organisational structures, training methodologies and working hour patterns, influence the risk factors for operations staff with a direct influence on the quality of a product or process. This paper presents a literature review concerning human error in manufacturing processes with the aim of investigating, by analysis, the current status in manufacturing environments and highlighting the research and practice gaps. A review was conducted using three databases (Emerald, Research Gate and Science Direct) using a set of relevant keywords in order to identify and review papers that presented evidence on the relationship between human error and quality results. XX papers were identified for review and then examined using a pre-determined methodology. This facilitated the classification and critical assessment of the selected papers as belonging to: process and product design contributions; organisational factors as error contributions; methodologies for human error analysis; error consequences; industrial sectors. The analysis explores the importance of considering human error and human factors in industry because varying error types occur during the processes with measurable effects on the quality and operations outputs. Certain engineering environments had more research available, specifically Aviation, Mining, Construction and Heavy industries. This suggest that there is a greater focus on human error in these areas, which could be defined as “high-risk”, where the impact(s) of human error may be more pronounced. In the sectors of Automotive and electronics manufacturing there were less studies on effects of human error, and fewer still focusing on the possible underlying causes of human error.
This review suggest that there is scope for additional research in the automotive and electronics manufacturing sectors, as demonstrated by the research gap.

1.0 Introduction

The scope of this project is to evaluate the causes and effects of human error during a manufacturing process and develop robust mechanisms to reduce or eliminate the risks.

Human error is the single largest contributor to scrap costs at laser etch. Incorrectly loaded raw material is undetected at point of failure. Each occurrence of “wrong material” has multiple costs associated with it.

- Direct cost of the raw material (PCB).
- Associated consumption of additional assembly parts (SMD).
- Cost of manufacturing, (labour, and equipment costs, manufacturing time).
- Lost order fulfilments though delays, rescheduling.
- Material shortages through incorrect ERP transactions.

Failure to achieve a right-every-time methodology is a critical point of failure in a multi-stage, high speed manufacturing process.

Occurrences are unpredictable yet occur periodically. This suggest that there may be more than one root-cause, or most likely a systematic failure in the various process steps from raw material storage to consumption.

While steps have been taken to action perceived points of failure, no defined study has been conducted on the process. Current methods have increased the workloads on operations staff, thus efficiency losses have occurred as a by-product of the additional inspection steps.

This document attempts to discover a correlation between existing published works and the issues raised by the core project. The study focused on works that relate to the areas of human error, published between 2005 and 2018, divided into 2 primary elements.

- Human Error – causes, measurements and quality tools to understand occurrences.
- Human Error – changes to product, process and systems design to reduce occurrence.

An analysis of the literature identified several consistent findings.

Errors were related to the fatigue of Operations staff (physical, cognitive, psychological, biomechanical, muscular, emotional, and social).

Initiatives included changes to work practices, providing additional resources to operation staff to help them perform their roles, and awareness training to address changes to process flow.

Many improvements involved training, shared workload, and communications. Research and operations focused on the areas of: a) training and experience, b) communications, c) fatigue, d) Human Machine Interaction (HMI), e) manual detection (poke-yoke).

Significantly the use of newer methodologies, such as participatory ergonomic design, shows promise. The involvement of end-users earlier in product and process design had demonstrated benefits. The use of computer modelling and full-scale mock-ups is an advanced approach that considers the impacts for poor process and product design on the real-world performance of these systems – as factors that affect the risk of human error.

This review concluded that, historically, much research was conducted that explained why Human errors occurred. Similarly, many initiatives were implemented, but the underlying causality was unchanged. There appears to be an acceptance that if humans are involved in a process, human errors are an inevitable result, particularly in manufacturing environments where shift-work is the norm and fatigue is an accepted consequence of long working hours.

This mind-set will continue to be prevalent until underlying causal dimensions typically associated with human errors are better documented and understood. Fatigue is often cited as a main causal dimension, yet current process and product design mythologies underestimate the impacts of poor design on being a contributor to fatigue and the incidence of human error occurrence.

2.0 Method:

The text presented here is a literature review of a body of work dealing with the areas of human error, causes and effects. The aim is to identify and examine research papers that presented evidence on the relationship between human errors and production (manufacturing) operations, and postulate techniques or methods to influence the effects and occurrences of human error.

Four initial questions were addressed in this study:

1. Is there a body of research established in the areas of human error in production?
2. Can the contributing factors for human error be defined or categorised?

3. What are the main effects or consequences of human error?
4. How is human error evaluated and integrated to a manufacturing environment?

This research used the following sequence:

- Identification of research databases and keywords definition.
- Literature search and paper selection through specific inclusion/exclusion criteria.
- Deep reading of the papers and discussion of the trends / commonality (if any).

2.1 Searching for papers:

For the purpose of this study 3 main research databases were chosen; Emerald, Research Gate and Science Direct.

A search for suitable papers was conducted on each of the databases using the following keywords: (both single string and joined searches)

“Human error”, “Human reliability”, “Error proofing”, “Risk assessment”, “Quality”, “Manufacturing”, ”Electronics”, ”Automotive”, “Assembly”, “Error probability”, “Ergonomics”.

2.2 Filtering results:

The search took place in October/November 2019, for papers published after 2008. However the volume of returned results was excessive. A filtering of the search to only include articles from specific areas (namely engineering) that had the search terms in their title or abstract, reduced the number of hits. Only articles where the full text was available were included, where necessary the papers were requested from the authors.

Suitable papers were then downloaded where possible or stored in the online document repositories, before a more detailed reading occurred to assess how the documents met the questions outlined above. Papers that failed, or inadequately answered question 2, 3 & 4 were subsequently excluded. This stage involved the reading of the full text, or as much as was required to form an opinion on its eligibility. In a number of cases older papers were cited, where specific papers were cited on more than one occasion the original paper was accessed (if available), and assessed to determine relevance. Thus there are papers from before 2008 that are also included.

2.3 Condensing the results:

Each of the remaining papers was read in full, the key points were noted. These points, and the paper as a whole were categorised into the following broad divisions.

- Do the papers conclude a link between product/process design and human error?
- Do the papers propose methods or techniques to reduce human error?
- Do the papers conclude a link between quality and human error?
- Do the papers discuss a measurement methodology to assess risk factors?

The final selection of papers form the basis of this review. XX papers are referenced.

3.0 Review:

Across almost all areas of manufacturing there are still many tasks that have yet to be automated. While automation is certainly replacing human effort in many areas *humans are an essential part of operations systems that are difficult to replicate (unlike technology) and hence improving their performance could eventually lead to sustainably competitive operations systems (Ahmad and Schroeder,2003; Onyema, 2014*).

Understanding human error is therefore a key consideration when processes are being developed. Failure to correctly identify and mitigate against the key failures associated with human (manual) actions and activities, as well as failure to systematically eliminate or reduce the environmental factors that contribute to human errors may lead to an unstable process, with an increased incidence of quality related defects.

Much effort has been devoted to the areas of ergonomics, the primary focus has been Human Resource centred; specifically in optimising productivity (throughput), reducing headcounts, and maintaining a safe working environment. *There is a whole discipline of Human Factors (HF) (to be considered as synonymous with Ergonomics), which is devoted to optimizing the design of the human-system interaction to improve system performance and operator wellbeing (IEA, 2014).*

While laudable, this strict application of ergonomic principles has not translated in the realms of human-proof engineering. There is a dearth of research from the engineering community and this *discipline has not been widely attended to in engineering and management research literatures (Dul et al., 2012).*

A possible explanation for this is that historically Human Resource lead ergonomic policies were primarily concerned with health and safety. Dul and Neumann, 2009, cite a prior review of 97 business and management journals, *93% of the journals had no human factor contributions at all (Dul,2003). Thus the strategic potential of ergonomics has not been widely considered at the company level in either research or practice (Dul and Neumann, 2009).*

More recent studies, and indeed advances in technologies have necessitated a re-think on the roles human play in processes. The impacts of human factors in production engineering is now being studied more frequently. An area of process mapping and analysis focusing on the specific impacts of humans is developing as illustrated below in Fig 1.

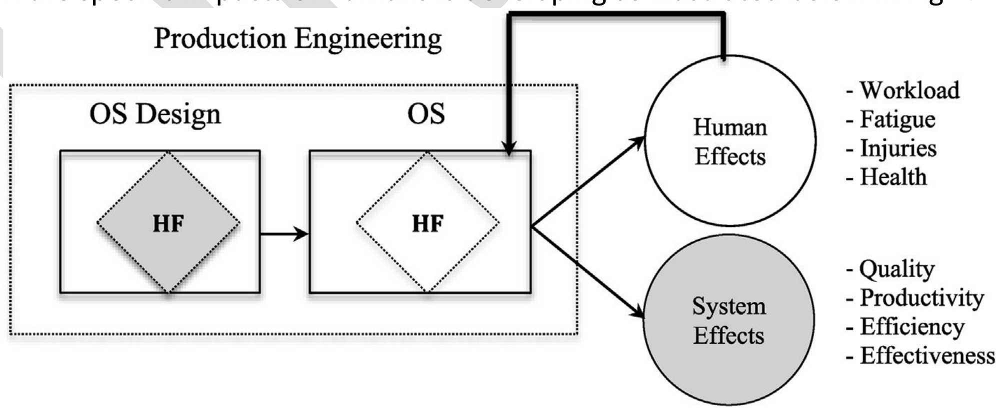

Fig. 1. A framework illustrating how HF within the OS have both human and system effects (adapted from Rose et al., 2013).

Fig. 1 illustrates a cascade of design and management choices that ultimately determine the mental and physical demands on the system operator. The effects of these demands can include learning and competency, or fatigue, discomfort and injury. These human effects will have a feedback effect on operator performance in the next cycle of production. If the

Human Factors are not attended to in the Operations System design and management decisions, then a negative spiral can occur. (Kolus, Wells, Neumann, 2018)

Additionally research is now focusing on the effects on quality by human error, specifically where operation systems and/or ergonomics are seen as contributors to the causes of human error, and by extension contributors to the actual quality reduction.

Process system flow and design is a focus of research by *Kolus, Wells, Neumann, (2018), which builds on previous research by Neumann and Medbo (2009, 2016), Givi et al., (2015), Di Pasquale et al., (2015).* The underlying causal factors are examined by probing 3 research question.

- *Is there a relationship between human factors and quality performance in operations?*
- *What are the human factor design characteristics that may cause poor quality?*
- *Is there a relationship between human effects (e.g., fatigue) and quality performance? (Kolus, Wells, Neumann, 2018)*

During their research it was found that the highest percentage of published papers were concerned with the automotive (26%) and electronics (20%) industries.

Both of these industries have undergone immense technological changes, where miniaturisation, automation, increased competition and cost reductions have driven major improvements in production metrics, and an overall improvement in quality metrics. However the same production improvements may not have been adequately designed to factor in the human elements in the process chain, thus the higher number of research papers to address the issue encountered.

The deep-level analysis concluded that significant quality risk factors were attributed to human factors.

A breakdown into four key groupings of Product – Process – Workstation – Individual identified the associated human factors. (Table 1)

Category of QRF	QRF	Description of QRF
Product	Load	Load in physically exerting tasks (e.g. posture)
	Difficulty	Task difficulty (e.g. visibility)
	Task characteristics	Factors related to task (e.g. static vs. dynamic work)
	Complexity	Knowledge demanding, memory intensive and many choice options (e.g. no. of components in assembly)
Process	Instructions	Work procedure (e.g. method of inspection)
	Management	Managerial activities and policies (e.g. waging policy)
	Training	Training programs and certificates (e.g. training for a specific technique)
	Time/pace	Factors related to time or work pace (e.g. rest time)
	Relations	Relations between stakeholders (e.g. relation between workers and management)
	Production	Type of production system (e.g. batch production)
Workstation	Tools	Types and features of tools (e.g. weight of tools)
	Space/search	Factors related to work space and layout (e.g. worker movement)
	Conditions	Work environment (e.g. illumination)
Individual	Professional	Professional factors of individuals (e.g. skills)
	Personal	Personal factors of individuals (e.g. age)

Table. 1. A description of identified Quality Risk Factors (Kolus, Well, Neumann, 2018).

Two types of human effects were identified in the analysis: workload and/or fatigue. Results showed that there is an association between Quality Risk Factor and workload, namely physical, cognitive, psychological, biomechanical, muscular, cardiovascular, emotional, and social (as reported in the studies).

Physical workload was the most frequently identified effect, followed by psychological and muscular workload. Thirty-four Risk Factors were identified as increasing physical workload in (of which 14 belong to product design, 10 to workstation design, 9 to process design and 1 to individual factors). Results indicated that physical workload in manufacturing was associated with load, difficulty, task characteristics, tools and space about 70% of the time. The increase in muscular workload was associated with load, task characteristics, tools, space/reach and management 100% of the time. In addition, biomechanical and cardiovascular workloads were solely associated with product-related Risk Factors (i.e., load and task characteristics), while social workload was associated with process-related Risk Factors. Psychological workload was associated with 17 Risk Factors of which management, load, difficulty, task characteristics and tools accounted for 69%.

Results also showed that there is an association between Quality Risk Factor and fatigue. The increased risk of fatigue in manufacturing was accounted for by 46 Risk Factors of which 57% were not associated with a specific type of fatigue. Visual fatigue was associated with 11, among which task difficulty, inappropriate time/pace and tools constituted 82%. Muscle fatigue was equally associated with load, tools and space. In addition, results indicated that poor instructions and work procedures might increase risks of physical and mental fatigue. It is worth mentioning that a linkage between workload, a fatigue precursor, and poor quality was identified. High physical and psychological workloads were associated with poor quality in about 26% and 12% of the studies, respectively. *(Kolus, Wells, Neumann, 2018)*

Delving further into the reported quality failures there is evidence that while "*Human Error*" is the defining mode of failure there is correlation between the occurrences of a failure and key groupings of Product – Process – Workstation – Individual. The study, based on the reports of numerous other studies found that *the majority of the reported factors impacting quality were related to process design (37%) followed by product design (27%). Similarly, factors causing work errors were ranked as factors related to product design (36%) followed by process design (32%).(Kolus, Wells, Neumann, 2018)*

Thus, as is the understanding of this project, the authors assert that human error is directly affected by poor process design and poor product design.

A study by Sundin et al. (2004) explores the use of computer based simulations to understand the assembly process in the automotive manufacturing business. The aim of the study was to understand how product design and specifications, coupled with existing workplace ergonomics contributed to the final assembly times. This study found that poor ergonomics, reach, stretch and obscureness occurred due to product design and process design. *The conclusion is that a different participatory ergonomics approach, termed participatory ergonomics design, PED, has a potential for facilitating communication and co-operation.* Sundin et al. (2004)

However the use of computer modelling is secondary to the inclusive elements of the PED approach. The involvement of product and process engineers from the different manufacturing plants, as well as the involvement of experience production operators in mock-up simulations was influencing in the final product and process designs. *The approach has a potential to improve assembly productivity and ergonomics and offer a better understanding among product designers and production engineers in product development processes.* Sundin et al. (2004)

Participatory ergonomics in the workplace is not a new occurrence, but historically it was been restricted to end-users (operators) trying to improve their existing workspaces – after the workspaces and process have been designed and implemented – by definition a retrospective involvement. *Nagamachi(1995) states that participatory ergonomics ''is the workers' active involvement in implementing ergonomics knowledge and procedures in their workplace''. According to Nagamachi, participatory ergonomics starts by organising a project team to solve ergonomic problems in workplaces.*

Wilson and Haines (1998) further say that the definition, at its most basic, consists of 'stakeholders' contributing to an ergonomics initiative or sharing ergonomics knowledge and methods. They also say that 'stakeholders' are a broader category than 'workers', including anyone affected by the process or consequent change.

However, not all persons involved are affected by the process or consequent change; they are instead affecting a change. (Wilson, J.R., Haines, H.M. ,1998)

From the study conducted at the Volvo manufacturing plant, and specifically with the inputs from the end-users (Assembly operators) design changes were introduced. *Design changes decreased assembly times, work related physical stress among the workers and the amount of corrective rework otherwise necessary in several operations. Sundin et al. (2004)*

What these studies show is that where there is an active engagement with the end users, process or product improvements reduce the likelihood of the underlying causes of human error. Production process or product changes that result in less fatigue, stress and or ergonomic issues for operators result in greater quality and efficiency. The report also cites improvements in production efficiencies. *In the body plant only, materials handling and rework time were estimated by the company to show a reduction by 10–15%.*

Additionally the study found that *future assembly problems were detected early, deeply involving the design department in the participatory ergonomics process, leading to a more effective and ergonomic production system. Sundin et al. (2004)*

The recommendations of the study are demonstrated by the illustration below:

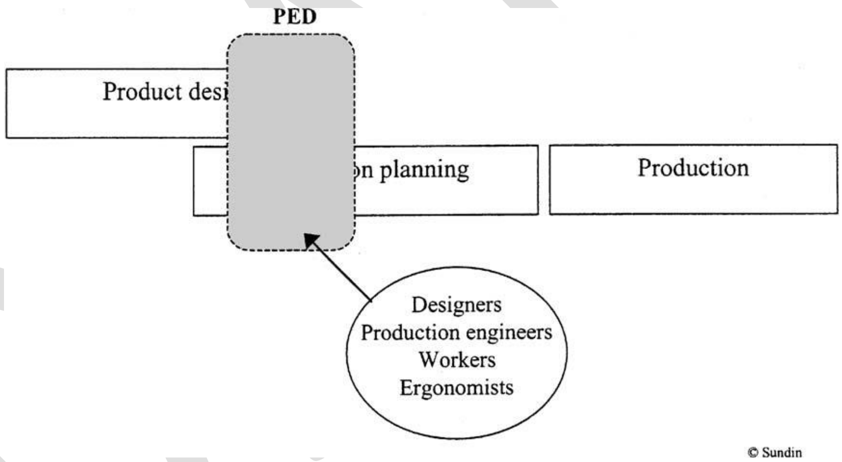

Fig. 2. Participatory ergonomics design, PED, as carried out in the case study described. Sundin et al. (2004)

A robust Participatory Ergonomics Process in the Pre-production phase can encapsulate any required changes to product design and production planning elements – before any detected problems are committed to production.

<u>Taxonomy of Human Errors.</u>

Much research focuses on the underlying causes of human error, as discussed above. A second strand of research focuses on the understanding of these different types of human errors, with a view to categorisation. Significant work by Nakajo T, Kume H. (1985) and expanded on by Sondermann JP. (2013) continues to form the basic taxonomies for human error understanding. However, before beginning to work with the breakdown of human errors it is important for research to agree on a methodology for assessments.

The German standard VDI 4006: Human reliability - Methods for quantitative assessment of human reliability offers a consistent approach.

Böllhoff et al. (2016) reference the VDI standard for human error probability as the: *"Capability of human beings to complete a task under given conditions within a defined period of time and within the acceptance limits", whereas an error is a "human action which exceeds the defined acceptance limits". Accordingly, the human error probability (HEP) and human reliability probability (HRP) are indicators for the relative occurrence of errors and respectively faultless actions and defined as:*

$$HEP = \frac{number\ of\ observed\ errors}{number\ of\ the\ possibilities\ for\ an\ error} = \frac{n}{N}$$

$$HRP = 1 - HEP$$

As with any formulaic discussion the quality and veracity of the inputs determine the outputs. Therefor in any study due regard to data clarity and integrity must be measured. *One major issue with the quantitative evaluation of human error is the availability of reliable data. They can for example be determined via field study, experiment, statistics, and estimation by experts or interviews. Generally, data which has been derived from measurements should be preferred over subjective estimations. Böllhoff et al. (2016)*

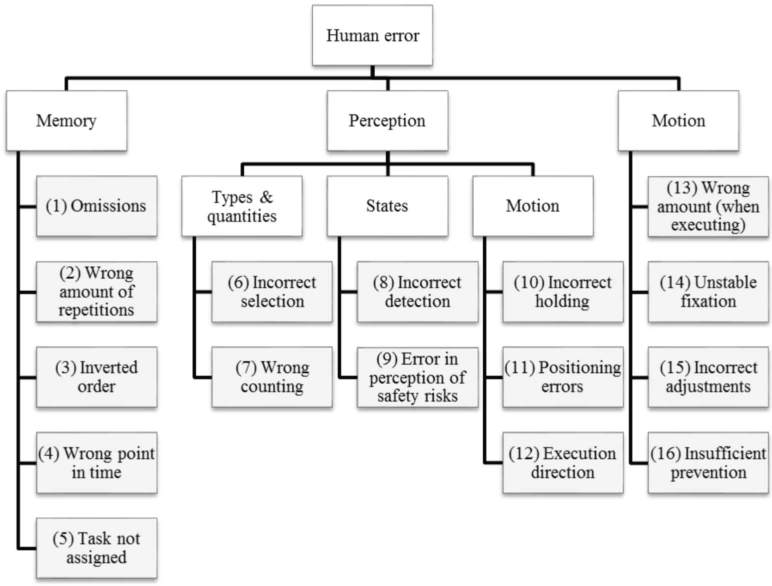

Fig. 3. Classification of human error according to Nakajo T, Kume H. (1985), Sondermann JP. (2013)

Using the taxonomy chart above the key findings for this project is that the identified problems in the current process are present in each of the core classifications of Memory, Perception and Motion. Thus similarities may be present in the researched solution proposals and the solutions developed for this project. Of specific interest are both the use of Poke-Yoke as a preventative measure and improved detection rates at the non-critical beginning of the process.

The conclusion therefore must be that analysis, understanding and accurate reporting of the process and its failures is an important first step in developing a solution to reduce or eliminate the occurrence of incorrectly loaded raw material.

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