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HUMAN ERROR REDUCTION PROGRAM THROUGH CANONICAL ACTION RESEARCH (CAR) IN WAFER FABRICATION MANUFACTURING FACILITY

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ABSTRACT

In a wafer fabrication manufacturing facility, thousands of wafers are being processed daily. To manufacture the product, the wafers need to go thru hundreds of steps according to the technologies required. The cycle time to complete a standard product ranges from few weeks to few months, depends on the complexity of the technologies. Due to the difficulty and the complexity of the product, Computer Integrated Manufacturing system (CIM), is widely used as a manufacturing platform. As such, all the processes, equipment and wafers are fully integrated. Nevertheless, not all processes could be processed automatically. In the situation of the halfway processes wafer due to equipment or facility interruption, the wafer, need to be processed manually. Engineers or technicians will manually process the affected wafer according to the specification. The problem arises when; there is a human involvement that ends up with wafers misprocess. The potential revenue lost due to wafer misprocess is vast. Hence, this paper aims to discuss issues related to human error in manufacturing, specifically in Wafer Fabrication Manufacturing Facility. The paper presents partial input for the Canonical Action Research (CAR) that presently being exercised in order to minimize human error by developing a Small Group Activities (SGA) in the manufacturing facility.

Keywords: *Human error, wafer fabrication, manufacturing facility*

INTRODUCTION

Wafer fabrication manufacturing is one of the most complicated processes in the manufacturing industry (Z. Wang, Wu, & Qiao, 2007). The cost to build a wafer fabrication manufacturing facility is extremely high; as such, the average wafer selling price is costly. Any scrap wafer in the wafer fabrication manufacturing facility will be directly impacted to the potential loss of the revenue. There are many types of wafer scrap root caused; however, in general, it can be divided into the process, equipment, facility and human error issues. In a wafer fabrication manufacturing facility, human errors can cause one wafer, to a couple of thousand scrap wafers. The main objective of this paper is to implement a Human Error Reduction Program (HERP) thru Canonical Action Research (CAR) in order to reduce wafer scrap due to human error. The manufacturing area selected is Chemical Mechanical Polishing (CMP).

The reason CMP is selected is due to the majority of the steps are running in semi-automatic mode, and that involve human intervention. There have been many improvements done, including, the introduction of the new procedure, new semi-automated systems, and training to the employees, in that area. Nevertheless, human error still occurs. Without an understanding of the actual root cause of the human error, the problem cannot be easily solved. Hence, this paper aims to discuss issues related to human error in manufacturing, specifically in Wafer Fabrication Manufacturing Facility. By employing an action research approach, the study able to understand further the human error taxonomy. This study is significant to a wafer fabrication company because it will help to reduce wafer scrap that quickly contributes to high losses in the revenue.

Human Errors Review

According to Meister (1989), the root cause of the systematic human error can be investigated, whereas not for variable human error. The difficulty of systematic error is because it is only happened, out of a thousand times of the excellent practice. It also does not tell the interval of when the next error will be taken place. However, the study converges human error root cause, are due to hardware software, skills, experience, exposure, and motivations. The study revealed that the taxonomy of human errors could be divided into 1) the nature of the error (slip/mistake, omission), 2) the mission stage (takeoff, landing, installation, during non-standard practice,), 3) behavioral function such as decision making, monitoring, 4) procedural parts error, such as ineffective procedure written, equipment error or mechanical error, 5) presume (take a granted, skills, overconfidence), 6) error consequences. The researcher found that all the theories about human error, such as all the classification or the taxonomy mentioned are unlikely can improve the event of human error. However, the researcher did not suggest any method that can be used to reduce human error with all the elements discussed in his research. By incorporating human dependent failures in risk assessments, the actual risk could be estimated objectively (Hollywell, 1996). The research found that failing to consider the human dependent failures (HDFs) in a risk assessment could result in a severe underestimation of the actual risk. Large scale and sophisticated manufacturing companies such as in chemical, oil and gas, nuclear plant and others typically use excellent primary methods, such as quality, redundancy and diversity techniques to combat the human error. Fault Tree diagram was used in the research in order to analyze the human error on system reliability. The approach of poke yoke thru engineering works is suggested in minimizing human error.

There is a strong correlation between human error and the organizational culture (Fiedlander & Evans, 1997). Human is found to be the primary root cause of the industrial disaster. The industrial disaster was mainly due to people and their behavior (Granot, 1998). Three psychological elements were described in the study which is: 1) cognitive bias - overconfidence, 2) cognitive dissonance - tensions, stress 3) information processing and schema - error in planning, mistake (intentionally wrong judgment), lapse or slip. The research also found that management's decision to cut cost on the specific critical job that needs more people will tend to induce human error, however, with government standard and media's help by giving awareness to the community, human error could be reduced. The research on the decision analysis process in an automated environment revealed that a decision making an error in the automated environment such as software could be reduced by implementing a critique in it (Mezher, Abdul-Malak, & Maarouf, 1998). The researchers have classified four essential errors such as 1) cognitive biases (managers always assume it is correct, and find the evidence - overconfidence), 2) accidents (slip or lapse), 3) cultural motivations - repetitive, due to norm and culture, and missing knowledge. The researchers also found that there are four elements involves while doing judgment or decision. The fours are: 1) information that received is selective rather than comprehensive.2) information processing is the case by case and not do both in parallel, 3) limit memory, 4) human information processing is a capacity constraint.

The failure of the organization causes human errors involved rather than individual (Wreathall & Reason, 1992). Varieties of unsafe acts framework also have been developed, that potentially will improve the human error problem. The researchers revealed that unsafe acts are the real event that happened first before the human error take place. Unsafe acts mean a dangerous situation made by the operators or the human involved. A system that prevents that dangerous act is called the defense system such as engineering control, sensors, and auto lock off. According to the researchers also, psychological and sociological factors linked to the theory of motivation and unsafe acts can be divided into active and latent. Active unsafe acts will result immediately, whereas the latent unsafe acts will happen if there is another gate of the failure of the system. There are at least three varieties of unsafe acts such as 1) slips/lapses, 2) mistake and 3) circumventions. Slips/lapses are the events where the human that commit with the mistake has no intended at all or do not realize that he/she commits with the mistake. The mistake is where it is intended to do but with a wrong judgment, this due to lack of knowledge, exposure, experience, and others. Circumventions are the intention to do with a good reason, to do, for example, to overcome some organization barrier but yet committed to human error due to the lack of knowledge factors.

Human Factors Analysis and Classification Systems (HFACS) categorize the unsafe acts into errors and violation (Wiegmann & Shappell, 2001). Error is divided into a decision based, skill based and perceptual errors. Violation is divided into a routine (a small violation that has been done every day without notifying the seriousness of the violation), overlook (condoned by management) and exceptional (violations of the standard operating procedure). The HFACS framework also introduces preconditioned for unsafe acts, such as the environmental factors, condition of operators and personal factors. Unsafe supervision is divided into inadequate supervision, planned of inappropriate operations, failed to correct the problem and supervisory violations. A human to technological failure study has been carried out to know how accidents rooted in technology related to human error, and which may influence the judgment of organizational (Naquin & Kurtzberg, 2004). The researchers found that when the human error happened, people tend to target human rather than the technological factor. The hypothesis of the study showed that organizational accident happened due to the technological errors, will be less counterfactual thought, rather than the human error. Another hypothesis was that the judgment of organizational would be influenced by the counterfactual thought by the team member. HFACS was also used to determine the contributing factors to a transportation accident involving the operator and found that people always got the blame when they last handle, before when the accident happens. Bad Apple Theory was linked to the result of the study (Reinach & Viale, 2006). Zhao and Olivera (2006), studied error reporting in organizations, in order to understand the reason behind it. The objective of the research was to develop a framework and recognize error detection, situation assessment and choice of behavioral response. The researchers found that human error in the organization might impact the losses, low motivation, and stress to the staff that involves, and with negative publicity to the company. Despite the harmful impact the organization can learn from the mistake and could develop a continuous improvement plan to resolve a similar issue in the organization. The researchers also found several behaviors of the individual that commit the mistake such as 1) risky and discretionary behavior, (2) negative emotions and 3) error recognition. The researchers grouped error detection by two categories, 1) action-based, catching errors once it occurs and 2) outcome-based - realized after the outcomes. The cost of the damage, the reputation, and punishment towards are some of the factors that people will not report the human error, happened. Sharing the lesson, and learn from the mistake and develop an improvement plan could be potentially avoided. The researchers concluded that the organization that committed with lots of human error has some problem in the management itself and it shall be corrected.

Mars (1996), studied human factor failure in the structure of jobs and the implications for risk management. The researcher found that there are four archetypes of workers; 1) individualism where they usually are professional and expert, having a small group and do not like to follow procedure, 2) fatalism which is low autonomy and usually does routines job as subordinate, 3) hierarchy such as a job specialist and quite a big group, for example, maintenance crews and 4) enclave, which is the ordinary worker such as operators. The researcher also found that that there was a link between a way a job is organized, a way the workers view and justify their work, with the acceptable behavior and the way they carried it out. Furthermore, Chee, Sani, and Yu (2006), discussed methods to achieve zero human error in semiconductor manufacturing. The study proposed the usage of integrated computer integrated manufacturing (CIM) to reduce human error. The research scope was in the researcher's company, and the in house automation team was capable of modifying vintage Original Equipment Manufacturer (OEM) tools, in order to reduce human error. The improvement was made in the semiconductor packaging industry. In the wafer fabrication industry, the usage of CIM is quite normal.

Nevertheless, the human error still happening, and the implementation of CIM, it will not be able to solve the human error completely. Similarly, Razak, Kamaruddin, and Azid (2008) agreed with Chee et al. (2006), where although the semiconductor industries use the advanced manufacturing environment, the needs of human are always there, therefore the human error, still affecting some degree of the revenue. The Human Reliability Model (HRrM) framework was developed based on the performance shaping factors (PSFs).

In addition, the authors emphasized that origination to ensure maintenance personnel at the researcher workplace do perform the work correctly. However, only a few personnel involved, and it may not be able to generalize the whole picture of the model introduced.

Moreover, Liu, Hwang, and Liu (2009), mentioned that there is a minimal study on how the impact of human error in the manufacturing industry. According to the researchers, there is not much literature review that discusses the cost, especially in the semiconductor. This study breakdown details of human error and matches it with the cost. Impact cost due to human error can be classified into; 1) minor 2) medium 3) severe. The objective of the study was to provide some guidelines, to line managers' regards, the human error lost where the framework is to integrate with the risk assessment database and management program. The database was used as; 1) the data collection of the human mechanism, 2) estimation losses due to human error and 3) identifying the root cause of the human error.

Moriyama and Ohtani (2009) mentioned that although human error probability (HEP) and human error analysis (HEA) has been used for so long in other industry, there was no risk assessment tool for human error in the small industry in Japan. The researchers suggested a framework of cost estimation due to human error in the Japanese small - sized establishment. The framework was adapted from a framework from the previous researcher, called ALARP (As Low as Reasonably Practicable). It is integrated with risk assessments database and management program with data collection of the human mechanism. The framework also could be used to estimate losses due to human error. W. Wang and Zhao (2009) mentioned the gap between cognitive reliability and error analysis method (CREAM) and the hazard and operability study (HAZOP). The framework was to study deep in human behavior. CREAM was divided into observation error and error cannot be observed. HAZOP is the system being used in the weapon industry.

The researchers found that, although many sophisticated methods use in the weapon industry, human error events are still increasing. Li, Zhang, Chen, and Dai (2010), mentioned that although the new era of computerization and information technology (for example Computer Integrated Manufacturing, CIM) to reduce the human error in terms of the procedural and workflow, still the new problem happened which called the error of mechanism. This study found a model that could identify the cognitive process and cognitive skills needed for the abnormal state by analyzing potential operator errors. The expanded model of human error was based on three levels of human performance such as skill base, rule-based and knowledge base.
It was to identify the specific cognitive processes and skills that may be the source of errors. The model is called the NPP model. Moreover, the authors also stated that human errors factors can be divided into organizational factor, situational factor and individual factor. Cognitive human error can be divided into 1) monitoring and detection, 2) situation assessment, 3) response planning, 4) response implementation, 5) attention and 6) memory. However, no practical solution being discussed on how to improve human error.

Furthermore, Ma and Yuan (2011) examined the relationship between human error and aviation safety system. Around 70% to 80% of aviation accident happened because of human error. Due to the advanced technology systems, human errors in aviation are reduced. Six expert analyzers were chosen and gave their opinion regards 35 cases of aviation. The conclusion made by the researchers was with proper technology training, simulators and other advanced digital devices; the human error in aviation in China has dropped.

Myszewski (2012) also studied the management responsibility for human errors by focusing the error reporting in organizations. The researcher focused on determining the "effectiveness" of the prevention program made by the organization. The intensive human industry, such as the healthcare industry, was found to be critical. There are 3 main factors found by the researcher; 1) flaw of the management system, 2) lack of supervision by the supervisor or manager, 3) lack of focus given by the management to understand to root cause of the human error. The reduction of human errors, according to the researcher, is in the manager's control. The managers have a role in motivating and inspiring the workers to prevent human error. Three main components were found to be very important to reduce human error, such as 1) to understand the psychophysics of human error, 2) working environment and 3) human interaction between the environments.

Another study on human error in navigation officer on watch (OOW) shows there was a correlation between the attitude of the officer on watch (OOW) and the mistake is done during the accident (Yoshimura, Hikida, Itoh, Nishizaki, & Mitomo, 2012). The researcher commented that the cost of risk of wrong judgment by human cost soaring in society. Moreover, Miyamoto and Takahashi (2013) developed an automated reduction of human error based on cognitive analysis. The researchers found out that the root cause of the human error was because of the internal mental process. With the interface eye movement technique, fatigue can be predicted. Facial, skin temperature also can determine the level of tiredness of human. The researcher also found a difficulty in the process of collecting mental data thru the survey due to some questionnaire was found with a fake answer.

Similarly, Harvey (2013) focused on optimizing performance (OP) in the organization. The framework was inadequate considering, the symptoms, which are near missing event, waste, inefficiency, scrap, and lost in income. The elements that need to be fixed from the symptoms are leadership, culture, job scoping and other procedural. OP framework discussed on the 1) well defines tools that will minimize the human error, 2) search for traps that potentially makes an error: risk analysis, FMEA, others and 3) review the root cause of the error. The researcher found that the errors and violations can be differentiated, with error is equivalent to slip, unintentional lapse, another mistake due to lack of knowledge, whereas, the violation is the result of the error. OP is designed to minimize error frequency, by promoting One Point Lesson for error and violation made but not warning letter to those who commit a mistake. A framework for human error analysis in the offshore evacuation during evacuation emergency escape and rescue has been carried out by (Deacon, Amyotte, Khan, & MacKinnon, 2013).

According to the researchers, human errors cannot be eliminated, but it can be reduced with a good design in the working environment. The study was done to enhance the safety in offshore, and to make sure during the emergency, personnel could be safely evacuated. The researchers commented that human error studies are becoming more critical in the industry; also, there are many challenges to quantifying the problems. There are few systems to quantify human errors such as Success Likelihood Index Methodology (SLIM), Technique for Human Error Prediction (THERP) and Human Error Assessment and Reduction Technique (HEART). The study also emphasized that training and procedure will help to reduce human error. Many discussions about human errors are focusing on the root cause, i.e. lack of knowledge, environmental surroundings inefficient of the procedural, and others; nevertheless, there is not much discussion focus on change and the improvement plan that needs to be done in order to reduce human error. Table 1 shows the summary of human error root cost in various environments.

Table 1.

Human error root cause

Researcher	Year	Human Error Root Cause	Scope of Study
Meister	1989	1)slip/omission 2)non-standard practice 3)behavioral function 4)equipment error 5)over confidence 6)consequences error	General
Mars	1996	1)professional individual that do not like to follow procedure 2)fatalism with low autonomy do routines jobs as subordinate. 3)hierarchy job specialist (i.e. maintenance group) 4)Enclave (normal workers i.e. operators)	Risk management
Granot	1998	1)cognitive bias, i.e. overconfidence 2)cognitive dissonance, i.e. stress 3)planning error	Industrial
Friedlander & Evans	1997	1)organizational culture	Organization
Wreathall & Reason	1992	1)slip or lapse (not intended to do) 2)mistake (intended to do but wrong execution) 3)circumventions (intention to do with good reason, but wrong execution)	
Harvey	2013	1)non efficient management	
Chee et al.	2006	1)to use computer integrated system (CIM)	
Razak et al.	2008	1)to induce maintenance personnel to work perfectly by introducing Human Reliability Model (HRrM).	
Liu et al.		1)Impact cost classification due to human error; minor, medium, severe	

Canonical Action Research

Canonical action research (CAR) is one of the methods to reduce human error (Davison, Martinsons, & Kock, 2004). The CAR is consisting of 5 stages; 1) The Principle of the Researcher-Client Agreement (RCA), 2) The Principle of the Cyclical Process Model (CPM), 3) The Principle of Theory, 4) the Principle of Change through Action and 5) The Principle of Learning through Reflection. The most crucial element and the heart of the Action Research is the CPM. According to Davidson, Martinsons, and Kock (2004), CPM can be categorized into five stages; 1) diagnosis, 2) planning, 3) intervention, 4) evaluation, 5) reflection. The concept and principle of CPM never deviate from the cyclic process, which was introduced by Lewin in 1947 (Davison et al., 2004). To materialize the diagnosis stage in the CPM principle, a series of information gathering will be taken place.

Secondary data from the Quality Assurance department will be used as a guideline for the human error category and pattern. A qualitative research methodology, such as group interview method will be conducted, to obtain the suitable variables that will be converted into the action plan. The data will be collected by the unstructured, open-ended group interview, where the interview notes will be taken at the end of the session. An audiotape will also be used to record down for the reference. The meeting with the technicians will be done for all for production shifts. A few technicians that have been committed with human error misprocess will be selected for the interview. The interview session will be discussed in their experience of why and how the human error happened.

In the planning stage, and with all the input given, the data will be processed and compared with the literature. Human Factors Analysis and Classification Systems (HFACS) by Wiegmann and Shappell (2001) will be adapted. HFACS is widely used by another researcher too in their studies in order to identify and confirm the human error root cause. In the intervention stage, the committee will be decided which and what improvement plans will be practically implemented in the CMP production floor. After all the improvement plans are agreed among the steering meeting members, training will be conducted to all the Manufacturing Engineer and the Assistant Manufacturing Engineer for all CMP Manufacturing Department shifts.

The execution process will be conducted and controlled by the Manufacturing Engineer as the Supervisor. The researcher will be monitored closely if there is a complaint or any suggestion for the improvement plan will be revised accordingly. The evaluation process will be taking place for one quarter or three months. At the end of the evaluation period, all the Manufacturing Engineers will be meeting, and input from the floor will be discussed again. If there is any human error situation happened again during the evaluation period, some other tactics will be changed, and it needs to implement again. Figure 1 below shows the CPM process.

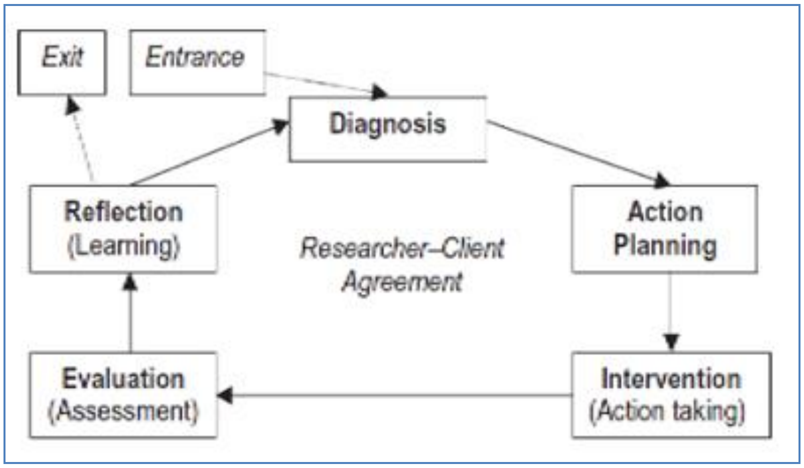

Figure 1. *CAR process model*

CONCLUSIONS

The Canonical Action Research (CAR) model is expected to support the success of the Small Group Activities (SGA), in order to reduce the human error in the wafer fabrication manufacturing facility. The elements of the improvement plan are then compared to the underpinning theories of human behavior and organizational behavior. The improvement plan will then documented as the standard operating procedure in a wafer fabrication company.

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