Journal of Business Strategies, Vol. 15 No.1, 2021, pp 59–82 *DOI:10.29270/JBS.15.1(21).04*

PREVENTION OF PRODUCTION LOSSES IN PAKISTANI POWER GENCOs DUE TO OPERATOR ERRORS-A QUALITATIVE ASSESSMENT

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ABSTRACT

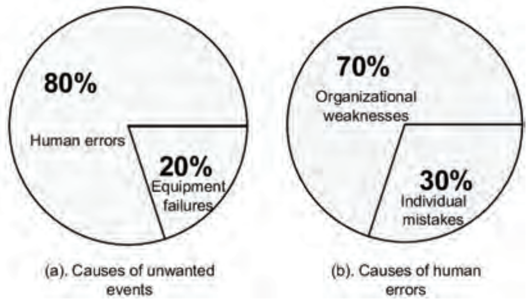
In this paper, we report on performing qualitative assessment of leading sources of human error, and its bearing on the nature and scale of production losses in power generation sector of Pakistan. Once identified, mitigation techniques and management controls are explored, to avoid their (re-) occurrences. The data collection included conducting two focus groups, five individual interviews and across the industry large-scale survey, which consists of 3780 responses from 108 participant. From the obtained results, causes of human error could be narrowed down into three prominent areas that include organizational, personal and environmental factors. Prominent among the organizational issues found, are bad procedures, insufficient operator knowledge, and poor teamwork. Similarly, the personal factors set identified skill level, motivation, experience, work attitude and self-discipline as key parameters. Results also indicated that workplace lighting is a significant environmental factor that must be taken care of. For the prevention strategy, participants pointed out to improve training, job planning, in-house incident reporting and learning management system, with assurance of management commitment as a key factor. The paper concludes with recommendations to the generation stations and to the national power regulator.

Keywords: *Operator Error, Production Loss, Power GENCOs, Qualitative Assessment.*

INTRODUCTION

Human (operator) error has been a source of great concern in industries and businesses alike and especially in power generation sector where a minor lapse by an operator may lead to losses amounting to billions. The contribution of operator error that is analyzed in a comprehensive study reported in DOE-HDBK-1028-2009 (2009) is illustrated in Fig. 1.

Figure 1: Occurrence of unwanted events, and contribution caused by human error in industry. Reproduced from DOE-HDBK-1028-2009 (2009)



The contribution caused by human error in industry is well established, however, it is yet to be explored for specific industry types such as power generation for instance which is a high-risk industry as well. Furthermore, the relationship between the human error and revenue loss especially for Pakistani power generation companies (GENCOs) needs to be explored.

In the current study, we report on performing qualitative assessment of leading sources of operator errors and ways to prevent their occurrence, for Pakistani GENCOs. In fact, the study contributes to identify operator errors that are being perceived or experienced as precursors to production (or revenue) losses. Secondly, once identified, prevention techniques and management controls are explored and recommended to avoid their occurrences. In this regard, this study significantly contributes to the current body of knowledge with case studies and data analysis performed in the Pakistani perspective.

Three major questions were formulated for this research:

(a) Is there any direct relationship between the production (or revenue) loss and operator errors?

(b) Are there any formal mechanisms/tools/techniques that are being practiced in local industry to prevent occurrence of operator errors?

(c) What strategies would be effective to prevent the operator errors and thus eventually avoid the production losses?

Our research methodology is based on a three-step procedure. First, we conduct two focus group sessions with operation & maintenance (O&M) personnel groups, respectively. Based on the focus group results and integrating these results with evidences reported in literature, we formulate interview and survey questionnaires, separately.

For individual interviews, five (05) number of interviews were conducted with industry practitioners. Furthermore, survey questionnaires are distributed to the target survey participants from where large number of individual responses were obtained.

The results obtained through interviews and survey questionnaires were analyzed and recommendations are made to address the reported problem.

From the first focus group (related to Operation department personnel of the sampled organization), the participants reported different situations that they experienced during their work experiences. Their experiences and verbal reports were documented and transformed to survey questionnaires. The second focus group was related to maintenance department personnel of the sampled organization. They reported few situations where failures or loss of production occurred. Their experiences and verbal reports were also documented and transformed to survey questionnaires. Next, individual interviews were conducted with five (05) number of industry professionals. Finally, data was collected through survey questionnaires from more than 100 industry professionals. Two parts of the survey questionnaire included queries regarding organizational, personal and environmental factors. Third part include probing perceived solutions and final part include probing for the awareness on error prevention tools in the industry.

LITERATURE REVIEW

Power Sector in Pakistan

The power sector in Pakistan comprises of multiple entities (S. Khan and H.F. Ashraf, 2015) that includes Ministry of Water & Power, Pakistan Atomic Energy Commission (PAEC) run nuclear power plants, private sector power generation companies (commonly known as IPPs), and transmission & distribution companies (e.g., K-Electric). The scope of this research is limited to selected entities from Generation Companies (GENCOs), i.e., PAEC's nuclear power plants, K-Electric and few other power generation units.

Inefficiencies in Power Sector

On January 9, 2021, the national power grid breakdown plunges Pakistan into darkness (NEPRA Report, 2021). The event occurred in the mid night at Guddu Thermal Power Station due to an apparent human error (not timely and procedurally removing earthing from the repaired breaker).

The inefficiencies in power sector are of three types. First one is those which arise from management and policy issues. Second one are those which relate to equipment and machinery issues. Third one are related to human performance. The first two types of inefficiencies are beyond the scope of this research work. However, this work probes the causes leading to production losses and management controls to prevent issues arising due to human performance.

Since the power sector in our case is also limited to generation companies (GENCOs) and does not include transmission or distribution set up so there is dire need to address the in-efficiencies caused due to human errors that could save billions of rupees in terms of money and production availability and this research deals with these issues.

Human Factors as Risk to Production Processes

Frank B. Gilbreth (1911), known as an early advocate of scientific management and pioneer of time and motion study, studied bricklaying, and consequently, scaffold was invented that increased the productivity of labor by almost three times. In 1945, human factors engineering was formally recognized as a specialized domain in engineering as well. Thus, the role of human factors in production processes and industry is not only inevitable but of critical nature too.

In modern times, even with higher levels of automation, human factors are considered very important for production process sustainability and safety in nuclear power plants (Carvalho, 2008). Some researchers termed these as soft factors (Vogt et al., 2010) and quasi-technical inputs (Leenstra, 2017) in production.

Homburg et al. (2003) were the first to put emphasis on soft factors. The context was the Aloha Boeing 737 fuselage failure accident in 1988 that attracted the attention of impact of human factors (Johnson & Hackworth, 2008). Contrary to equipment, human factors are very unpredictable and varying (Xie & Guo, 2018) thus are considered a concern or risk at workplace (Sobhani et al, 2017).

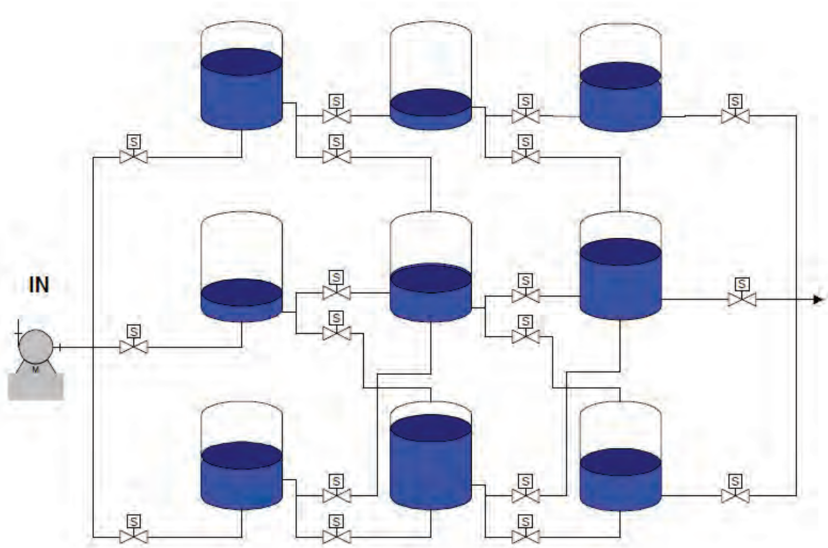
Orme and Venturini (2011) highlighted the significance of human factors in power plant production processes and mentioned that they may risk operational and maintenance activities. The identified causes of production risk include procedure usage, fatigue, knowledge, experience, time pressure (Sheikhalishahi et al., 2017), turnover (Vaurio, 2009), efficiency of implementing orders (Bevilacqua & Ciarapica, 2018), mental pressure (Jou et al., 2011), maintenance planning (Krishnasamy et al., 2005), ergonomic work conditions, discomfort, pain, stress, reduced visual, hearing, smell and tactile abilities (Govindaraju et al., 2001), equipment failures (Lavasani et al., 2015), monitoring systems (Chang et al., 2010), land, labor (Tiedemann & Latacz-Lohmann, 2013), and weather (Karki et al., 2012).

Causes of Human Error

It is worthwhile to discuss two relevant studies on human error causes in industrial operations and maintenance context. One is NASA Simulation study, and other is EPRI switching study.

NASA Simulation study (Morris & Rouse, 1988) which was also reported by Bilke (1998) with the recommendation of establishing of error database at plant level. The study itself is based on observing and recording responses of process operators on likely causes of error during operation. The operators were controlling a simulation known as *PLANT* as shown in Figure 2. The results of that interesting study were that operator with less control on what is happening was more careful in taking the next step.

Figure 2: NASA Simulation Study Setup. Reproduced from Terry Bilke (1998).



Actually, the operators could control the fluid flow in the tanks through a network of interconnected piping and valves. Other operations include starting and switching off the pumps through computer commands. Production was the primary goal in the process.

The results of this interesting study was that operator with less control on what is happening was more careful in taking the next step. In fact, the key findings were to relate the error occurrence with the workload reported subjectively by the operators at various stages of operation. Another interesting finding was that complex failure scenarios yield more errors than the simple failure scenarios, i.e. 10.1% for simple failure scenarios to 12.2% for complex failure scenarios.

The second study by Electrical Power Research Institute (EPRI) in which switching safety study was conducted, probing operating errors that included more than 400 events reported by the utilities. Common errors include planning the task, communication with team members and execution by the control room personnel (dispatcher) and field operators.

Table 1 illustrates the distribution of errors committed by the dispatchers as well as field operators.

Table 1: Contributors of Errors. Reproduced from EPRI Report.

	Dispatcher	Field Operator	Both	Maint. & Testing
# of Errors	163	175	29	34
Omission	33%	25%	34%	32%
Wrong Sequence	17%	6%	10%	0%
Wrong Action	18%	22%	14%	41%
Wrong Equipment	31%	47%	41%	12%
Fail to Check	53%	20%	71%	33%

An interesting finding of the report was that the field operators were more prone to slips. i.e. a physical action different than intended (DOE-HDBK-1028-2009). The report strongly suggests workload control and training on switching safety and error in the qualification curriculum.

Human Error & Loss of Production

In an interesting study reported by Bertha Ngereja, and Bassam Hussein (2019), the authors compared the soft factors (which often are intangible) in the two contexts (i.e. developed economies versus developing economies and especially in African context) in order to provide an understanding of whether they have the same level of importance, regardless of their differences in economic, social and environmental aspects. The authors reported to have conducted 17 semi-structured interviews to identify the critical soft factors for optimum performance of maintenance operations at a natural gas processing plant in Tanzania. The results show that soft factors included top management engagement, oversight, trainings, ergonomics, collaboration, safety and security, recognition programs, education and career growth being the of significance. Furthermore, the authors also found conformity between developing and developed countries in these soft factors' importance, however, the difference exists due the level of the emphasis developed countries place on implementation.

Operator errors are strong precursors of financial and revenue losses in many industries and especially in power generation sector. In Pakistan, power generation from thermal as well as nuclear reactors is being an emerging area of attention, where financial viability is related to smooth and safe operation of the plant. However, there are threats to safety as well as to revenue generation (productivity) during the non-productive periods of the plant caused by operator errors. The three significant studies found regarding this area are reported here:

Diao and Ghorbani (2018) investigate production risks caused by human factors in thermal power plants and management methods to address identified human factors through a cross-sectional inductive study. The authors reported carrying out 18 semi-structured interviews with front-line, middle, and senior managers from four thermal power plants in China. Fault tree analysis and causal network analysis were used. The results show that working attitude, safety consciousness, creativity, and awareness of environmental protection as essential human factors potentially influencing production risks.

Sheikhalishahi et al. (2017) have reported results of their study using HFEA (Human Factor & Effect Analysis) in maintenance activities. This is a rare study that found relevance of human error with operational cost (inclusive of productivity losses, workforce lost time and spare part cost). Their results indicated operator's fatigue and procedure usage being the big contributor among other factors. They also reported compared error provoking factors earlier reported by Reason and Hobbs (2003) versus the causes of failures.

Common Error Precursors

A comprehensive statement regarding various common error precursors causing operation and maintenance failures due to human mistakes/errors is provided in (DOE-HDBK-1028-2009). The common precursors are provided in Table 2.

When we compare these mentioned list of factors with the other factors reported by earlier researchers, the list is quite exhaustive in nature. However, there is no sufficient quantifiable data available on errors leading to events caused by operation and maintenance failures.

Table 2: Common Precursors of Human Error.Reproduced from DOE-HDBK-1028-2009.

Task Demands	Individual Capabilities
1. Time Pressure (in a hurry)	1. Unfamiliarity with task / First time
2. High workload (large memory)	2. Lack of knowledge (faulty mental model)
3. Simultaneous, multiple actions	3. New techniques not used before
4. Repetitive actions / Monotony	4. Imprecise communication habits
5. Irreversible actions[α]	5. Lack of proficiency / Inexperience
6. Interpretation requirements	6. Indistinct problem-solving skills
7. Unclear goals, roles, or responsibilities	7. Unsafe attitudes
8. Lack of or unclear standards	8. Illness or fatigue; general poor health or injury

Work Environment	Human Nature
1. Distractions / Interruptions	1. Stress
2. Changes / Departure from routine	2. Habit patterns
3. Confusing displays or controls	3. Assumptions
4. Work-arounds / OOS[β] instrumentation	4. Complacency / Overconfidence
5. Hidden system / equipment response	5. Mind-set (intentions)
6. Unexpected equipment conditions	6. Inaccurate risk perception
7. Lack of alternative indication	7. Mental shortcuts or biases
8. Personality conflict	8. Limited short-term memory

When we compare the above mentioned list of factors with the other factors reported by earlier researchers, the list is quite exhaustive in nature. However, there is no sufficient quantifiable data available on errors leading to events caused by operation and maintenance failures.

Error Causes Leading to Significant Industry Accidents

In recent times, apart from Fukushima accident in 2011, other nuclear and process industry accidents does involve human error causes. Reason (1990) comprehensively reported and discusses these errors. Table 3 mentions some catastrophic accidents.

Table 3: Mega accidents along with causes. Reproduced from Reason (1990).

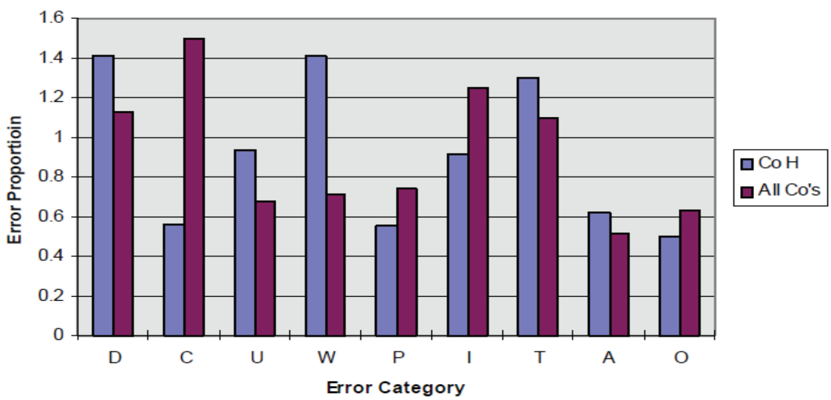
	TMI	Bhopal	Chernobyl	Total
Design	2	6	3	11
Maintenance	1	5		6
Management	5	25	5	35
Operator	2	2	2	6
Procedure		1		1
Regulatory	2	3		5
Training	1			1

We may observe that maintenance and operation related errors are present in most of the cases at considerable extent.

Treatment to Error Causes

Bilke (1998) report provides a comprehensive treatment of causes observed which are prone to error. For example, the report enlists the causes as illustrated in Fig. 3 here.

Figure 1: Error Causes Reported by Operators. Reproduced from Bilke (1998).



The abbreviated causes are also defined in Table 4.

Table 4: Abbreviations used for error causes by Bilke (1998).

D	Distraction	P	Mistake in a procedure
C	Communication	I	I operated the wrong device
U	Unscheduled job	T	Trying to do much at a time
W	Job written incorrectly	A	Automatic device malfunctioned

O: for others

Now the important point to make here is that the author utilized few representation to describe through cause-effect diagram to represent the causes leading to error. In addition, the author also reports using Error Analysis Diagram (EAD).

Human Error Prevention Tools/Techniques

More recently, the nuclear industry has introduced practicing tools and techniques to prevent individual as well as organizational weaknesses leading to failures. These tools/techniques are listed in Table 5.

Table 5: Tools/Techniques used for prevention of human error at workplace (Source: IAEA No.

NG-T-2.7, 2013, DOE-HDBK-1028-2009).

Pre-Job/Post-Job Briefings	Place Keeping	First Check
Two-Minute Rule	Flagging/Operational Barriers	STOP When Unsure
Three-Way Communication	Self-Checking	Peer Checking
Phonetic Alphabet	Independent Verification	Post-Job Review
Procedure Use & Adherence	Concurrent Verification	Event Investigations
Self-assessment	Benchmarking	Trending
Operating experience feedback	Independent oversight	Field observations and coaching

The use of these tools and techniques in the industry is highly recommended in the available literature (IAEA No. NG-T-2.7, 2013 and DOE-HDBK-1028-2009), however, there is no particular study available (or reported), to the best of authors' knowledge, that probes a qualitative or quantitative analysis of usage of these tools in the power generation sector (GENCO) industry in Pakistan.

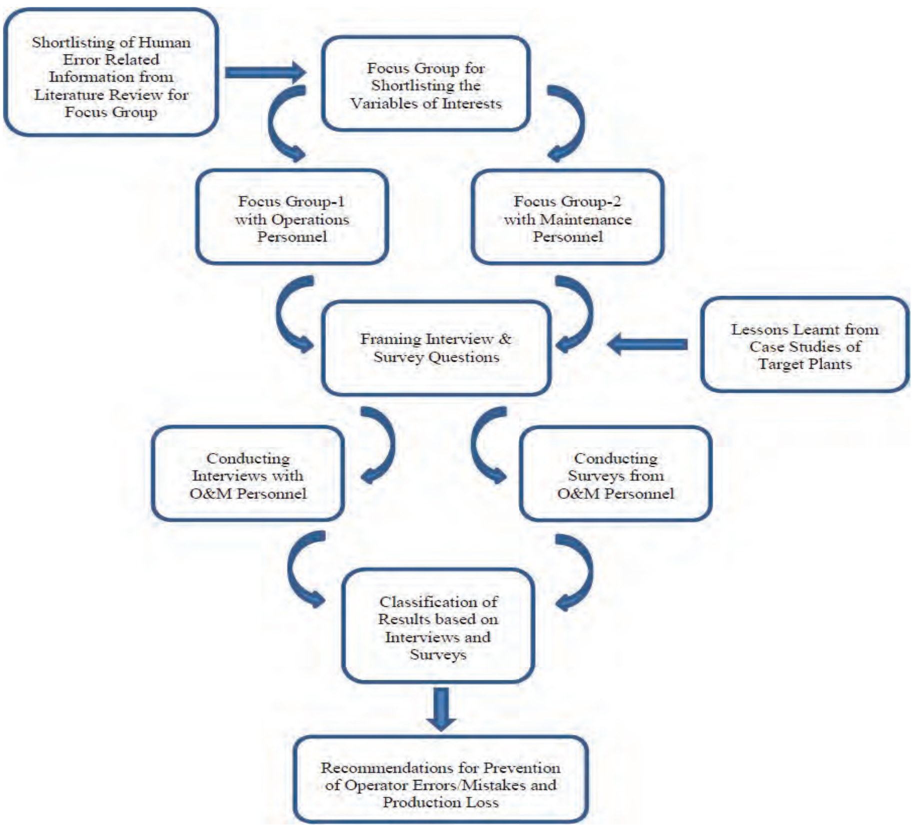
After going through the literature on human error causing revenue losses in industry, it is evident that very few studies actually have targeted identification of a particular human error leading to revenue losses to the industry, rather major industry players have focused on safety aspect which is obviously justified.

Most of the studies and reports reviewed during this work have identified terminologies describing error causes and interestingly these causes do converge to a point where one can start observing the play of these causes by recording and quantifying the error data. We draw the most observed causes of human error leading to revenue or more appropriately production losses from the available literature and design our research methodology to obtain an agreement from industry practitioners based on our selected causes and subjective reports from the industry practitioners. Secondly, regarding the treatment given to the obtained data, we did not find any formal usage of error prevention tools from the available literature, however, such tools are getting familiarity in nuclear industry which is one large segment of this research work. Hence, we do consider obtaining reports regarding usage of tools or management controls to limit the probabilities of human error in the target industry.

RESEARCH METHODOLOGY

When generalization does not bring out the unique insights into the research focus, interpretivism can be a useful approach (Saunders et al. 2009). It means that in the absence of sufficient and authentic set of quantitative studies or results on relationship between production (revenue) loss and operator error(s)/mistake(s), we need to proceed with a selected (or available) sample of population and explore the underlying relationship between variables of interest. In the proposed work, research design is built upon such that the desired research objectives are achieved using appropriate research techniques. Figure 4 illustrates the research design methodology:

Figure 4: Methodology of the Proposed Research Approach.



Primarily, there are two main type of research approaches, i.e., deductive approach and inductive approach. A deductive approach is essentially development of a theory or hypotheses to be tested. Here, our choice is to reach from specific cases of observations such as sampled subjective interviews and surveys towards generalization of variables of interest. In this scenario, we adopt an inductive approach.

Furthermore, the inductive approach will enable qualitative analysis of the data using the frequency assigned to our variable of interests, by the interviewers and survey replies. This qualitative analysis will lead to generalization of results.

Data Collection

Data through interviews was collected by having a scheduled telephonic, online, or face-to-face conversation with selected personnel of O&M departments. Further data was collected through survey questionnaire using emailing and/or posting of links to various platforms.

Sample Size & Sampling Technique

The intended sample size was 100 personnel for survey questionnaires. The sampling size for interviews is 5 personnel. Snowball or volunteer sampling is a type of sampling where participants volunteered to participate in the research, instead of being chosen by the researcher. For survey questionnaires, we use snowball sampling method where potential participants are invited through various mediums of communications. For interview sessions, we go for convenience sampling where potential participants are chosen as per availability.

Primary Research Sources

For focus group discussion, two target groups were selected as per availability. First group termed as FG1 comprises of 5 personnel from operations department of five different power generation units located across Pakistan.

The personnel of FG1 have experience of working in operations department of the relevant industry ranging from 8 to 15 years of overall experience. All these personnel have a minimum qualification of bachelor’s in engineering in concerned field and some of these have professional licensing certification as well.

The second group named as FG2 comprises of 4 personnel from maintenance department from different power generation units located across Pakistan.

The personnel of FG2 possess work experience of relevant area from 10 years to over 20 years. All these personnel have a minimum qualification of bachelors in engineering in the respective field with some having certification and a few having exposure of training abroad.

Interview questionnaires were framed primarily based on the input from FG1, FG2 and secondary research data. We propose to use a semi-structured type of interview since our research is of exploratory nature and as interpretivists, we may take advantage from a semi-structured type of interview that may allow us responses with explanation from interviewees.

Like interview questionnaire, survey questions are framed considering the input from FG1, FG2 and secondary research data. Transcript of survey questionnaire is attached at Annexure-A.

RESULTS

Responses from Focus Group-1 (FG1)

The participants reported different situation that they experienced during their work experience. They however, could not remember any event that alerted the management regarding loss of revenue calculations quantitatively. Few were of the view that if production takes the priority, then safety might be compromised with less ownership of job. Updated knowledge on issues, retention of good working staff and health related issues with workers were seen as challenges to their job.

Major causes of error were identified as time pressure, multitasking, communication issues, complacency, and lack of identification of risk. Remedies for these were identified as updated training, use of operating experience, coaching and effective supervision by the supervisors. The panel suggested to incentivize the operations using reward and penalty schemes with few emphasized on individualized trainings. Finally, the panel suggested that without management commitment, things would not improve. Use of procedures that are technically valid and practicable were focused. Effectiveness of job planning and using lesson learnt from industry were also recommended.

Responses from Focus Group-2 (FG2)

Maintenance personnel group reported few situations where failures or loss of production occurred due to lack of procedure usage, lack of sufficient manpower. They also pointed out lack of proper mechanism for data gathering and keeping. Some indicated these in including as performance indicators for personnel promotion. Maintenance personnel considered skills, grooming, complexity of jobs, unavailability of spares, and ageing equipment as major challenges. Complacency, non-professional behavior, lack of maintenance procedures, time pressure of completing the job were the few causes discussed during the session.

The panel also mentioned that trainings are sometimes deferred due to workload and considered secondary. Mockups and hands-on training setups are expensive to build and utilize. They too recognized job ownership, use of modern tools, provision of better working environment and investing in mockup development as solutions to prevent human errors in maintenance jobs. Other solutions were suggested as uplifting of skill level, risk assessment of job, enhanced coordination between operation and maintenance departments.

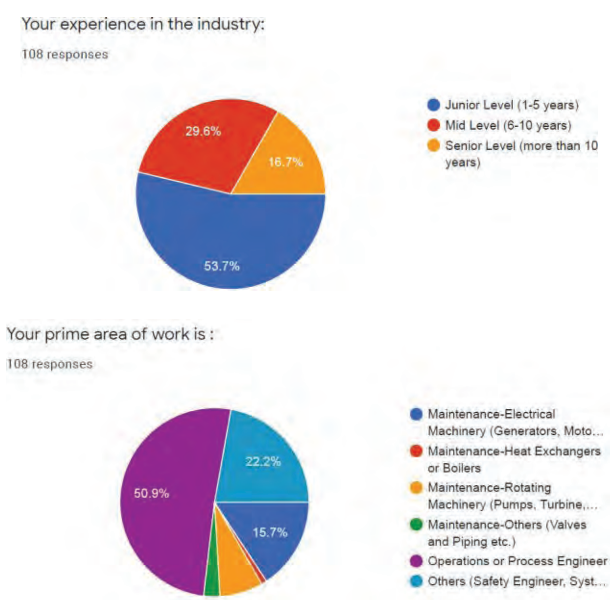
Responses from Interviews

Participants had strong agreement on role of human error in production success or losses. Old plants are more vulnerable to human error thus leading to more revenue losses, where most of plant operations are manual. Plant automation (AI and Robotics based) may prevent error occurrence as new technology has less involvement of human. Few plants keep an eye on performance parameters and reward/penalize the human behavioral based actions. To find out the relationship of variables, multiple correlation test was applied.

Responses from Survey Questionnaires

108 responses were collected from October 01 to October 31, 2020. Participants' profile was also recorded and is shown in Figure 5:

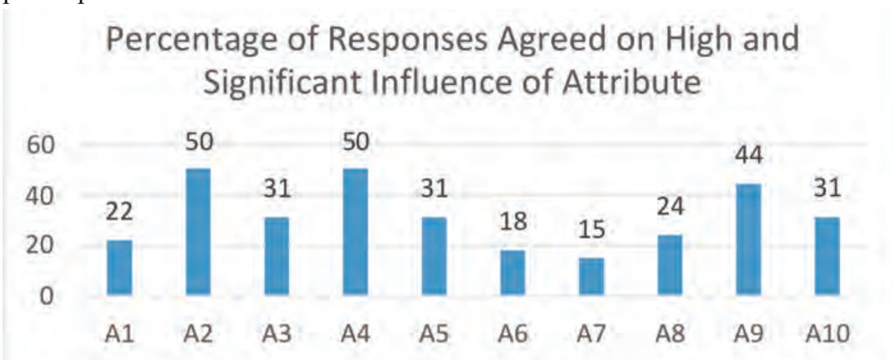
Figure 5: Survey participants' demographics.



Results from Part-A of Survey Questionnaire

This part mainly explores the perception and experience of respondents about issues with operators/maintainers such as complacency, use of incomplete or invalid work practices (procedures), fatigue, insufficient knowledge, lack of experience, time pressure, poor housekeeping, improper tools, lack of team work and inadequate supervision /coaching. The results are illustrated in Figure 6.

Figure 6: Set of responses (A1~A10) rated with high significance by 108 participants.



Codes A_n is described in Table 6.

Table 6:

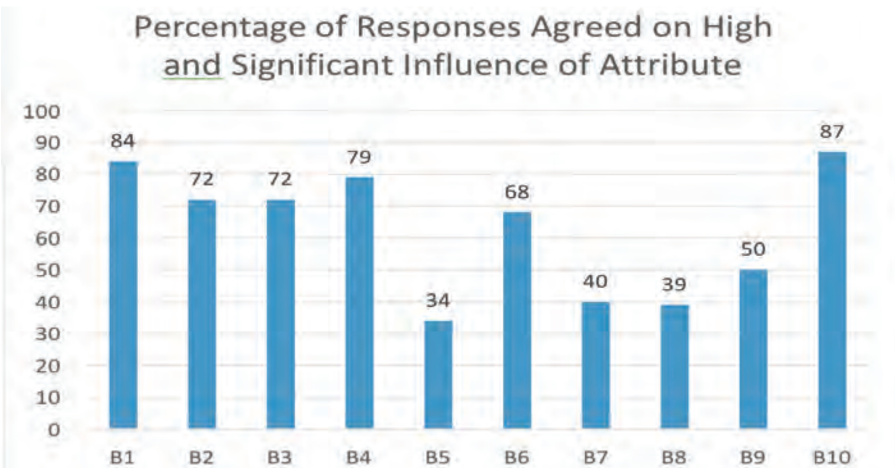
S. No.	Selected Parameter	Attribute
1.	Complacency in using operation/maintenance procedures. Complacency: due diligence/care not practiced	A1
2.	Use of bad procedures. (e.g., incomplete or invalid procedures)	A2
3.	Fatigue during the job/task.	A3
4.	Insufficient knowledge	A4
5.	Inadequate experience	A5
6.	Time pressure/rush to complete the job	A6
7.	Poor housekeeping in the plant/area	A7
8.	Improper/inadequate tools	A8
9.	Poor teamwork (coordination/communication)	A9
10.	Inadequate supervision/coaching	A10

From the results, it is evident that invalid work practices (or procedures) and insufficient knowledge are considered has high influencers in harming production and in a very significant manner. Similarly, poor teamwork and lack of coordination and communication among team members are key influencers.

Results from Part-B of Survey Questionnaire

This part mainly explores the perception and experience of respondents about issues with operators/maintainers such as skill level, motivation, experience, work attitude, physical capabilities, and self-discipline. There were evaluations made on other environmental factors as well such as temperature, humidity, noise level and lighting. The results are illustrated in Figure 7.

Figure 7: Set of responses (B1~B10) rated with high significance by 108 participants.



Codes B_n are described in Table 7.

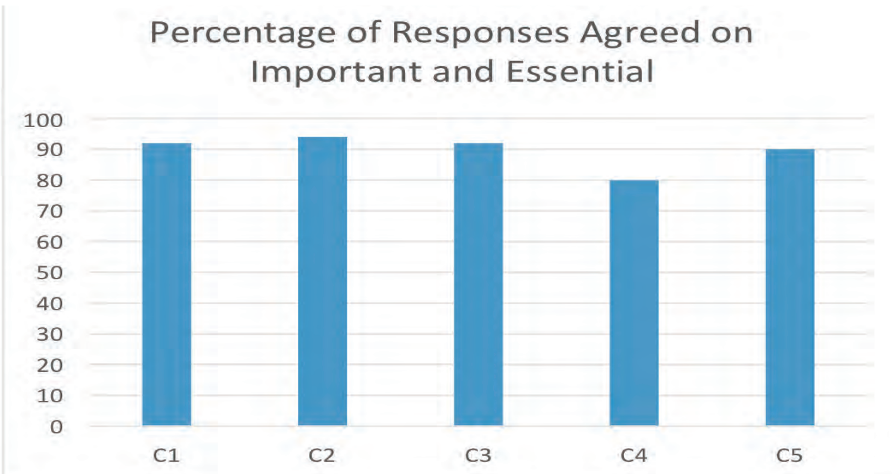
Table 7:

S. No.	Selected Parameter	Attribute Code
1.	**Skill level (tactfulness)**	**B1**
2.	**Motivation**	**B2**
3.	**Experience (seniority)**	**B3**
4.	**Attitude towards work**	**B4**
5.	Physical capability	B5
6.	**Self-discipline**	**B6**
7.	Temperature	B7
8.	Humidity	B8
9.	Noise	B9
10.	**Lighting**	**B10**

Results from Part-C of Survey Questionnaire

This part mainly explores the perception and experience of respondents about solutions to human error, i.e., training, job planning and scheduling, in-house incident reporting, use of industry experience, and commitment of top management. The results are illustrated in Figure 8.

Figure 8: Set of responses (C1~C5) rated with high significance by 108 participants.



Codes C_n are described in Table 8.

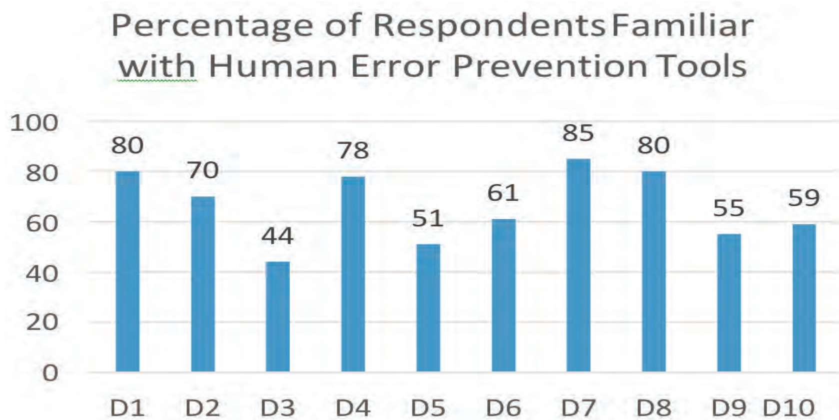
Table 8:

S. No.	Selected Parameter	Attribute Code
1.	**Training**	**C1**
2.	**Job planning & scheduling**	**C2**
3.	**In-house incident reporting and learning system**	**C3**
4.	Use of industry experience/information	C4
5.	**Commitment by the top management**	**C5**

Results from Part-D of Survey Questionnaire

This part mainly explores familiarity of industry participants of this research about human error prevention tools and approaches. The results are based on exploring ten such tools, i.e., Pre-Job/Post-Job Briefing/Review, Self-Checking/STAR approach, Two-Minute Rule, Three-way Communication, Phonetics, Concurrent Verification, Coaching and Observation, Procedure Use and Adherence, Flagging/Operational Barriers, and finally the Independent Verification tool. Results are shown in Figure 9.

Figure 9: Set of responses (D1~D10) rated with high significance by 108 participants.



Codes D_n are described in Table 9.

Table 9:

S.No.	Tools/Techniques	Attribute Code
1.	**Pre-Job Briefing/Post-Job Review**	**D1**
2.	**Self-Checking/ Use of STAR approach**	**D2**
3.	Two-Minute Rule	D3
4.	**Three-Way Communication**	**D4**
5.	Use of Phonetics	D5
6.	Concurrent Verification	D6
7.	**Coaching & Observation**	**D7**
8.	**Procedure Use & Adherence**	**D8**
9.	Flagging/Operational Barriers	D9
10	Independent Verification	D10

CONCLUSION AND RECOMMENDATIONS

From the results and conclusions from interview analysis suggest that all interviewees had a strong agreement regarding the role of human error in production success or losses. The results analyzed are summarized here:

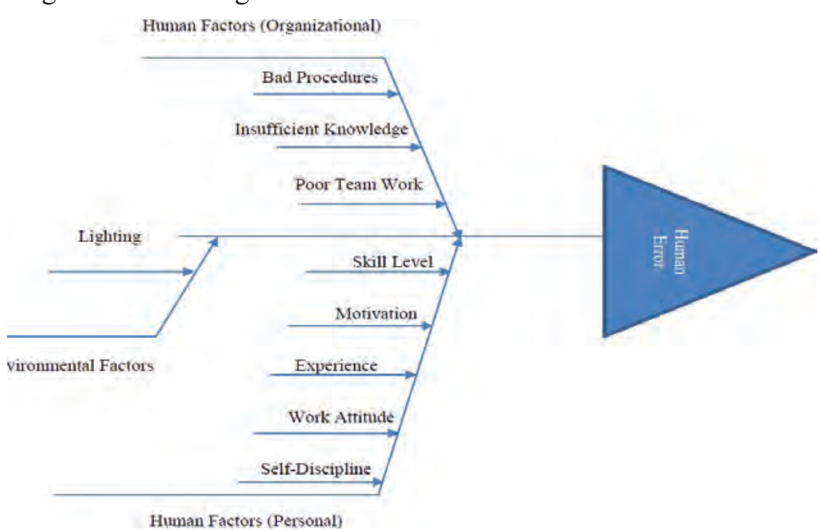
(a) Since old plants are more vulnerable to human error (probably due to excessive maintenance calls and manual operations) thus may lead to more revenue losses. This invites special attention of plant management to observe enhanced levels of caution while operating and maintaining old plants.

(b) Plant automation (AI and Robotics based) may prevent error occurrence as new technology has less involvement of human.

(c) Few plants keep an eye on human performance parameters and reward/penalize the human behavioral based actions. This need to be incentivize so that human actions may respond to the incentives posed in the form of behavioral re-enforcements (both positive and negative ones, whichever applicable).

What we may conclude from our results and earlier discussions is that the causes of human error may be sub-divided in to three prominent areas that include organizational, personal, and environmental factors affecting human performance. These are illustrated in Figure 10 through Fish-Bone diagram.

Figure 10: Factors found most significant through the study, represented through fish-bone diagram.



First, the organizational related causes affecting human performance are summarized here, i.e., bad procedures can be avoided by including the input from the user, and environmental (field-related) considerations. In addition, preliminary validation of procedures may be done to check the usability and applicability.

Regarding the insufficiency of knowledge of operator is concerned, it can be ensured through ensuring appropriate training and qualification processes. Job authorization/assignment shall be linked to job competency that includes knowledge, skills, and attitude (KSA) as fundamental to carry out the job independently.

One possible cause of poor teamwork might be due to lack of communication among working personnel, especially under a dynamic workplace environment. Special focus must be made to introduce team building and intra-team communication must be strengthened.

Secondly, the personal factors affecting the human performance and leading to human error are very much subjective in nature that include skill level, motivation, experience, work attitude and self-discipline. Each of these may be interpreted subjectively, however, the only way to bring these at par is to develop a work culture that may value and reward these factors. Training requirements shall be strictly based on the fulfillment of the desired parameters/factors with a mechanism of continuous monitoring and evaluation and above all improvement.

Finally, the environmental factor which appeared to be most significant from our sampled data is lighting. Nevertheless, earlier studies also recommended this factor as a key factor that might affect productivity but here in our case, this has been identified as one of the significant or potential causes that has a probability of leading to production losses.

Understandably the participants considered training being an essential solution to prevent occurrence of errors. Similarly, job planning and scheduling being a solution as well. This is because when planning is there, less chances of error are there. To prevent the re-occurrence of events, in-house incident reporting and learning system was considered as a good practice. Above all, the management commitment is the icing on the cake to enable rest of the parameters.

From our results and earlier discussion, it is evident that the gap between the problem awareness and practicing the solutions is there. Many of human error prevention tools used in contemporary segments of industry are not being used by other segments of the industry or the participants are not familiar even with the terminology. It is needed to establish a common platform to homogenize the work practices and especially the improvement tools.

Based on the results, discussion and finally the conclusion, we recommend the following:

(a) Generating stations shall provide a comprehensive training plan especially focusing on human performance related objectives. A policy may be formulated with a title of ***Human (Operator) Performance***

Policy. The objectives of the policy shall be clearly target oriented and based on SMART principle, i.e., Specific, Measureable, Achievable, Relevant and Time Bound.

(b) The regulator (i.e., NEPRA) shall provide guidelines and support to the generating stations for implementing the Human (Operator) Performance improvement plan. Initially, this may be introduced as a graded approach with penalizing areas with critical consequences and severity and incentivizing other areas.

(c) Specific focus must be made to old/aging plants where errors are more likely to occur due to technological issues. NEPRA may also take steps to upgrade the safety measures for such stations and gradually phasing out vulnerable stations and encouraging automation.

(d) Timely and effective training of personnel must be ensured incorporating updated practices and knowledge areas. A knowledge repository shall be made available to all generating stations who can access and retrieve the best practices. This can be implemented either through NTDC platform or through regulator (NEPRA) platform.

(e) Human (Operator) Performance Indicators (HPI) program shall be introduced at all working levels.

SUGGESTIONS FOR FUTURE RESEARCH

In future, the present work may be extended to quantitatively categorize the losses causes due to human (operator) error and developing a Human Performance Index based on the HPI statistics

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