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Full Length Research Paper

Effect of work related variables on human errors in measurement

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What one cannot measure one cannot control. Measurement plays a key role in science, technology and industry. Where there are measurements there is associated errors. Study of measurement errors has a long history. Attempts have been made to classify and understand the factors that contribute to errors in measurement. The understanding of this is useful for error reduction and also providing the margin for errors and reducing damage caused due to errors. For the purpose of classification and study, measurement errors have been divided into instrument error, method error and human error. The former two are easier to study and correct, but the later is less understood. In this study an attempt has been made to study the effect of selected work related variables on human errors in observing and noting measurements which contribute to measurement errors. In a measuring system, though some of the effects of variables on measurement errors can be guessed, only an experimental study will be able to isolate, quantify and present the effect of each variable separately. Hence an experimental study was designed and conducted to quantify and present the effect of selected work related variables of two sets of human subjects used in the experiments. Analysis of the results revealed that the variables identified and studied have significant effect on measurement errors, and their effects were also separately quantified. This will be of use to professionals trying to reduce measurement errors, especially in industrial environments, where knowing the variables and the extent of error they induce, appropriate work related settings can be adopted to keep human errors within the tolerable limits.

Key words: Measurement error, test type differences, instrument differences, time of work, time pressure, environment.

INTRODUCTION

Measurement is essential for technological investigations. It is so fundamental and important to science and engineering that the whole science can be said to be dependent on it (Blanchard, 1973). Instruments are developed for measuring and displaying physical variables. Every act of measurement has to deal with errors (Carmen, 2005). Errors can result in negative consequences [example: loss of time, faulty products] as well as positive ones [example: learning, innovation]. The large negative consequences for example, accidents such as the chernobyl or challenger disasters tend to be widely observed (Meijman and Mulder, 1998) and have been of high interest to scholars and laypeople alike (Reason, 1990). The scientific understanding of the negative effects of errors is much better developed than that of the potential positive effects of errors (Carter, (1986). One way to contain the negative and to promote the positive consequences of errors is to use error management (Cannon and Edmondson (2001). This approach assumes that

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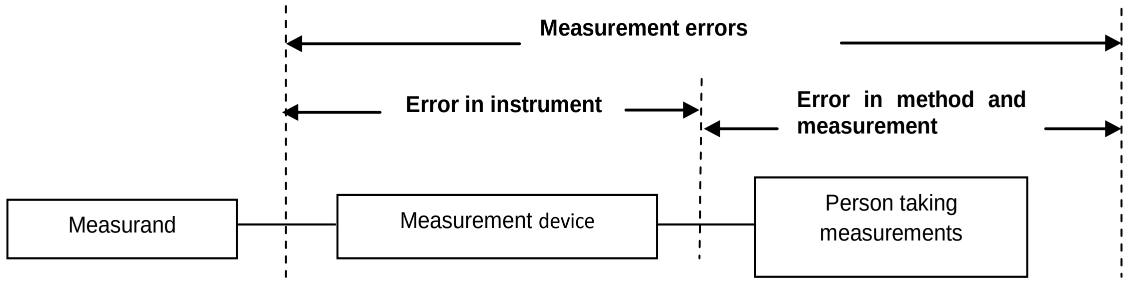


Figure 1. Measurement system.

human errors per se can never be completely prevented, and, therefore, it is necessary to ask the question of what can be done after an error has occurred (Frese, 1991; Frese, 1995). Errors are not easily defined (Cathy et al., 2005). Errors may be unintended deviation from goals, standards, and a code of behavior, the truth, or from some true value (Carmen, 2005). A measurement system comprises generally three parts as shown in Figure1.

Measurand is the physical parameter being measured. The measuring device can be of different types such as analog, digital, electronic, mechanical etc. Measurement errors may be due to the measuring device and/or the method and the person involved in measurements Chesher, (1991). Measurement error is defined as the difference between the output of the measurement system and the reference [known, actual, true, master, and standard] value (Parasuraman et al., 2000). Now, the measurement system could be defined as only the measuring instrument or as comprising of the measuring instrument and the person taking or doing the measurement and reporting the measured output Douglas and Esa, (2002). The later definition of a measuring system is more in tune with the practice of measurement. There is no general consensus in the literature about the terminology used to categorize and classify errors (Cathy et al., 2005). Several different taxonomies of human error exist with varying degrees of overlap Gawron et al., (1989). For example, studies on “decision errors” may classify errors in terms of knowledge based mistakes (Zapt et al., 1992). The other errors are diagnostic errors and planning errors Wiegmann and Shappell, (1997).

Production and quality control engineers who deploy human resource to take readings from instruments need to understand the effect of various factors on the errors induced by the human resource Helmreich and Merritt, (2000). Errors induced by humans during measurement can be further split to arise from two sources (a) from the work related factors (b) from the human related factors Mark and Brian, (2000); Nordstrom et al., (1998). In this study the focus is on the work related variables and their influence on human induced errors in measurement. To study the effect of only work related variables using experiments, it was necessary to remove the effect of measurement error due to human factors and the method of measurement (David, 1996). For doing this and isolating the effect of work related variables only on measurement errors, the same persons were asked, to use the same set of instruments and standardized methods, for making measurements with only one work related variable changed at a time over two different experimental setups. Thus reducing the error involved to almost only the human error induced due to change in work related variables.

In order to identify the variables to be taken in the study, a review of literature was done to identify some work related variables influencing human induced errors in measurement. A survey was also carried out among experts supervising production and quality control in different production environments to generate a list of possible variables usually found in industry, the effect of which would be useful to explore. These two sources were used to make the list of variables for the study. These variables were then classified into stable and transient (Senders and Moray (1991). Stable variables were those work related variables that Drury et al., (1989) would remain the same over time for the experimental setup (voltage, resistance, analog, digital, A/c, non A/c, forenoon, afternoon etc). Transient variables would change over time for a given experimental setup (instrument temperature, input values, aging etc). The study concentrated on the effect of stable work related variables on human errors in measurement. Now when human errors due to observing and noting become the area of study, the major work related factors influencing these are test type variables, time of day, time pressure and environment. The test type variables studied are

Abbreviations: VAP; Voltage analog parameter, **VDP;** voltage digital parameter, **RAP;** resistance analog parameter, **RDP;** resistance digital parameter, **ET;** experienced technicians, **IE;** inexperienced subjects, **IQ1;** above average intelligent quotient, **IQ2;** average intelligent quotient, **IQ3;** below average intelligent quotient, **B. Tech.;** Bachelor of Technology (four year engineering degree program in India).

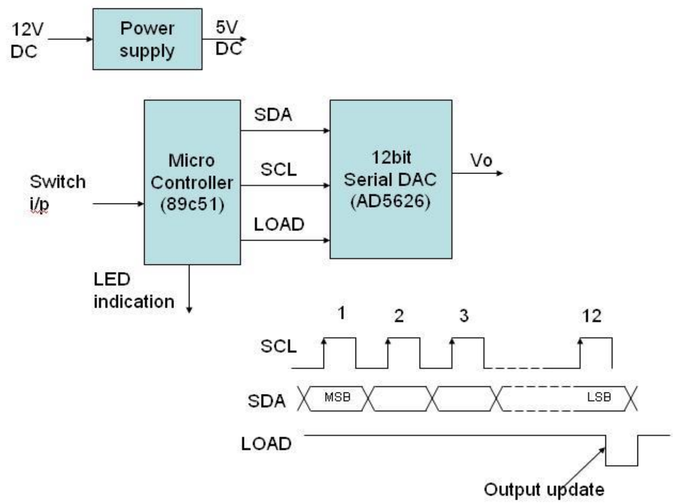


Figure 2 . Test pattern generator.

task type (voltage and resistance measurement) and technological difference in the measuring instrument (analog and digital). The effect of time of day was studied by doing the measurement during forenoon and afternoon. To study effect of time pressure, work was carried out in a set of experiments without any upper time limit and in the second set of experiments the time allowed was limited to the normal time required (as per work study). Experiments were carried out under normal laboratory environment and in an air-conditioned laboratory. All the subjects were given training Dormann and Frese (1994), before doing the experiments. Two sets of human resource, one Diploma holders with work experience and the second, B. Tech. (Bachelor of Technology) and Diploma Holders without work experience were used in the study.

METHODOLOGY

Procedure for testing work related variables

Voltage

There was need to isolate the effect of work related variable, therefore in the experiments one variable was changed at a time. In this case, the work related variable, type of work was set to Voltage measurement. A setup was made to generate predetermined set of 50 voltages, one after the other to be provided as an input for the subject doing the experiment to measure voltage using two types of voltmeters one analog and the other digital. The test voltage generator was to ensure that all subjects were given the same set of values. For doing this a microcontroller based test pattern generator which gives 50 different voltage outputs has been designed and used for the study. This setup kept errors due to system being measured out of the experiment and the focus could be maintained on error due to observation and noting. Different experiments were carried out using the microcontroller based test pattern generator where analog and digital meters were used for measurement and the other variables such as time of day, time pressure, environment and experience of human resource were varied one at a time.

A block schematic of digitally controlled analog test pattern generator is shown in Figure 2. This generator gave different prefixed voltages for each hit of a switch. Display devices such as analog multi-meter (Make: SUNWA, Model: YX-3600TREB) and digital multi-meter (Make: CLASSIC, Model: 333) were used for testing VAP and VDP. In an experiment a subject had to push the switch for the next reading and make note of fifty such consecutive readings.

Resistance

A set of fifty different valued [covered] resistances were used for these set of experiments to study the effect of work type: measurement of resistance, on human errors in measurement. These covered resistances numbered from 1 to 50 were given to subjects in experiments where they used digital and analog multimeters to make the measurements and note the same. In different experiments the other variables such as time of day, Time pressure, environment and experience of human resource were varied one at a time. Though the method involved in this case is very simple all subjects were also trained in it.

Subjects for the experiments

Experiments were conducted using different subjects, the key differentiating factors of the subject groups are given as follows:

1) Experienced technicians (ET) in the age group of 31 to 40 years and 41 to 50 years. Their IQ test showed that all were in the below average (IQ3) category.
2) Inexperienced (IE) B. Tech. and Diploma holders in the age group of 21 to 30 years and with different IQ levels Above Average (IQ1), Average (IQ2) and Below Average (IQ3).
3) 20 subjects from each of the different categories participated in the experiment. This was found to be statistically sufficient for the mean error measurement which has been taken for analysis in this study (There is no significant change in the measure of mean and standard deviation of the error when sample was increased from 15 to 20).

Note: It was very difficult to get sufficient number of experienced technicians in IQ1 and IQ2 category. A summary of the subjects and the experiments is given in the Table 1.

Experiments

The impact of instrument differences were studied by comparing the errors occurred when using analog and digital readouts. To check the effect of task differences, subjects were asked to measure resistances and voltages using analog and digital measuring devices. The subjects were made to do the measurements during both forenoon and afternoon sessions. The following procedure was adopted for the experiment:

1) Twenty subjects of each category were selected.
2) On a given day, one category subjects were made to take one set of measurement (say only resistance measurement using analog device) both in the forenoon and afternoon. This was repeated

on different days till all subjects had done all types of measurement experiments.
3) No feedback on their performance was given to them.
4) The measurements were conducted within a time frame as given as follows:

a) 30 min to make fifty measurements when using analog device for measuring both resistance and voltage. (This being the standard allowed time for such work in India as based on work study).
b) 20 min to make fifty measurements when using digital device for measuring both resistance and voltage (This being the Standard allowed time for such work in India as based on work study).
c) Inexperienced subjects were also allowed to do the measurement in a relaxed environment without time limit to complete the fifty measurements.
d) The experiments were done in a normal laboratory environment and air conditioned environment.
e) Training was given to all subjects for taking the measurements before start of the experiments.

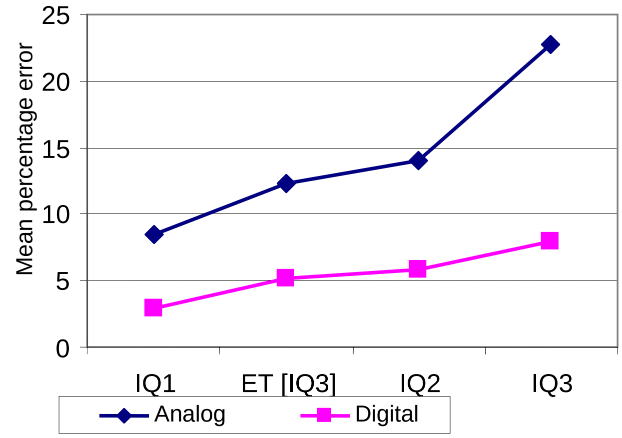


Figure 3. Instrument differences.

RESULTS AND DISCUSSION

The results from the experiments were analyzed and descriptive statistics such as mean, standard deviation and coefficient of variance of error were calculated. The mean percentage error for each category was used for further analysis to remove the effect of individual characteristics. Parametric analysis such as one sample T-test, paired sample T-test and ANOVA were carried out to understand the effect of different factors on the measurement errors observed Holland, (1986). The results of the analysis are discussed variable-wise in the next section.

Test type differences

Instrument differences

The effect of technology on work reduction and simplification is well known Wickens et al. (1998). In this study the effect of two technologies in measuring instruments that is analog and digital on human error in measurement has been examined. For this, subjects with experience and without experience and having different IQ levels were asked to do measurements of voltages and resistances using analog and digital devices and to note their readings using pen and paper. A graph showing changes in the mean percentage error with change in category of the subjects for both analog and digital measurement of voltages are shown in Figure 3.

The errors are more when using analog technology. The error was seen to change with IQ level of the subjects and a significant jump in error occurs when the below average (IQ3) category was given analog instruments for measurement. It can be observed from Tables 2 and 3 that the errors were always more in the afternoon when compared with forenoon. The magnitude of increase of error between forenoon and afternoon was more when using analog devices.

The measurement error occurring in the afternoon session for the IQ1 category when using digital instruments for measurement was even less than the error they make in the forenoon when using analog instruments as is instruments as is evident from Tables 3 and 6.

The experienced technicians were seen to make 7.3% more error when measuring with analog devices than with digital devices. Figure 3 also shows that when using analog devices 9.5% more error occurs than when using digital devices on an average for inexperienced subjects. It can be therefore said that digital devices when used for measurement will result in only one by ninth Human error in measurement when compared to analog.

ANOVA test was carried out to check the effect of different variables on human error. It can be inferred that all variables studied have significant (at 0.05 level) impact on human errors in measurement. The sum of squares also shows that Digital measurement is superior to Analog Measurement.

Task differences

The other work related variable is the difference in parameters to be measured. In this study the parameters measured were voltage and resistance using both analog and digital devices thus there were two tasks.

It can be noticed that irrespective of the subject’s experience or IQ, the errors when measuring voltage were more than when measuring resistances. The IQ1 category makes least error for both resistances and voltage measurements followed by experienced technicians with IQ level IQ3 (Figure 4). The results of ANOVA test shown in Table 3 and paired sample test shown in Table 4, shows that there was significant change in error

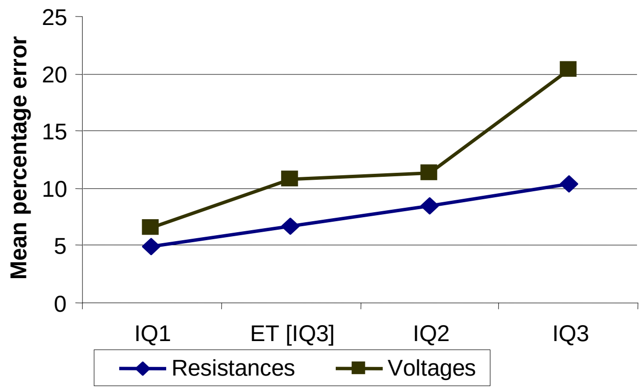
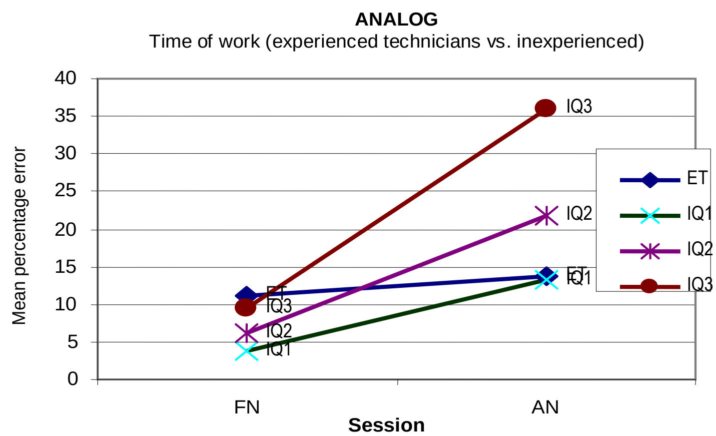
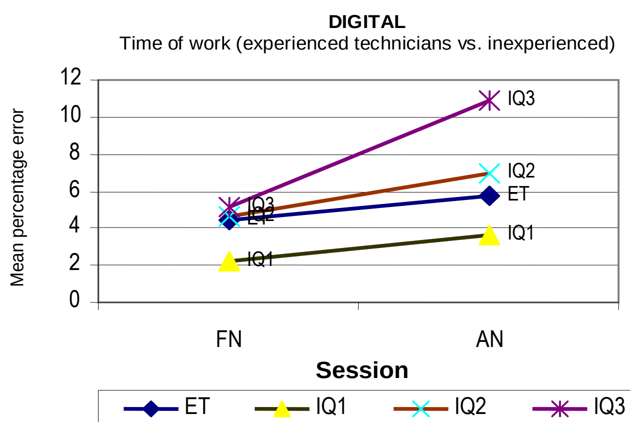


Figure 4. Test type differences.





when doing both resistance and voltage measurement using digital and analog devices except for the pair RDP-VDP (Resistance measurement using digital device voltage measurement using digital device. An interesting observation in this experimental work is that though the voltage measurement work is simpler compared to resistance measurement, more errors were seen in voltage measurement. A possible explanation could be that when a simple task is given subjects may pay less attention to the work and thus human errors could become higher.

Time of work

The subjects were seen to make more errors in the

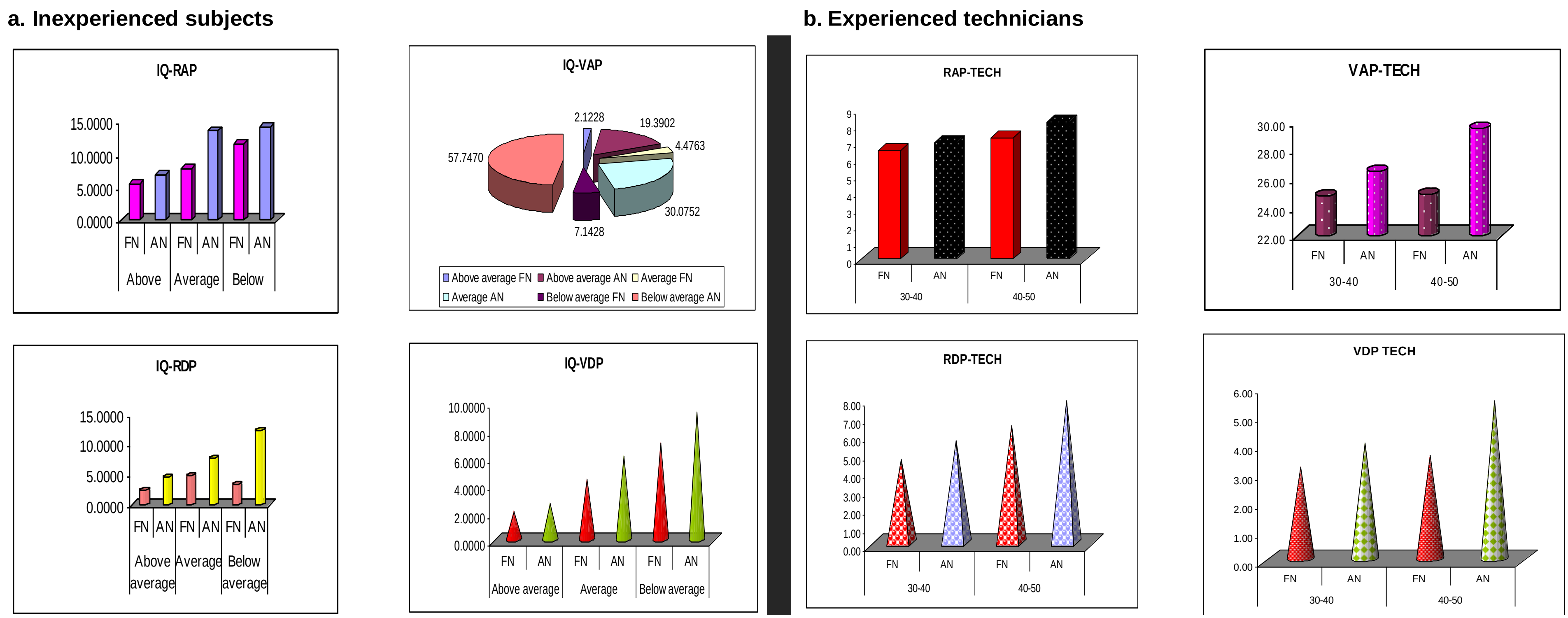


Figure 6. Inexperienced vs. experienced subjects.

afternoon irrespective of their experience, intelligent quotients (IQ), instrument differences and type of measurement they were carrying out.

It can be observed from Figure 5 that in the case of experienced technicians, the error increase for analog devices in the afternoon compared to the forenoon is about 2.6% and for digital devices it is 1.3%. But for the inexperienced subjects with IQ levels IQ1, IQ2 and IQ3, the error increase is in the order of 9.4, 15.7 and 26.6% respectively with analog devices. For digital devices it is 1.4, 2.3 and 5.7% respectively. It can also be noticed that even though inexperienced B. Tech. and Diploma Holders with IQ above average [IQ1] were making less error compared to the experienced subjects, but the error growth in the afternoon was very high with inexperienced subjects. This may be because of, the experienced technicians are more tuned to long and tiring working hours and the increased room temperature in tropical climate afternoons and therefore make fewer errors in adverse working conditions when compared to inexperienced subjects.

Figure 6 shows that the error is less with digital measurements compared to analog measurements. The error is more with voltage measurements than resistance measurements. It can also be observed that the error is more in the afternoon than forenoon. The t-test given in Table 7 shows the significance in error difference between forenoon and afternoon.

Time pressure

Inexperienced subjects in the IQ1, IQ2 and IQ3

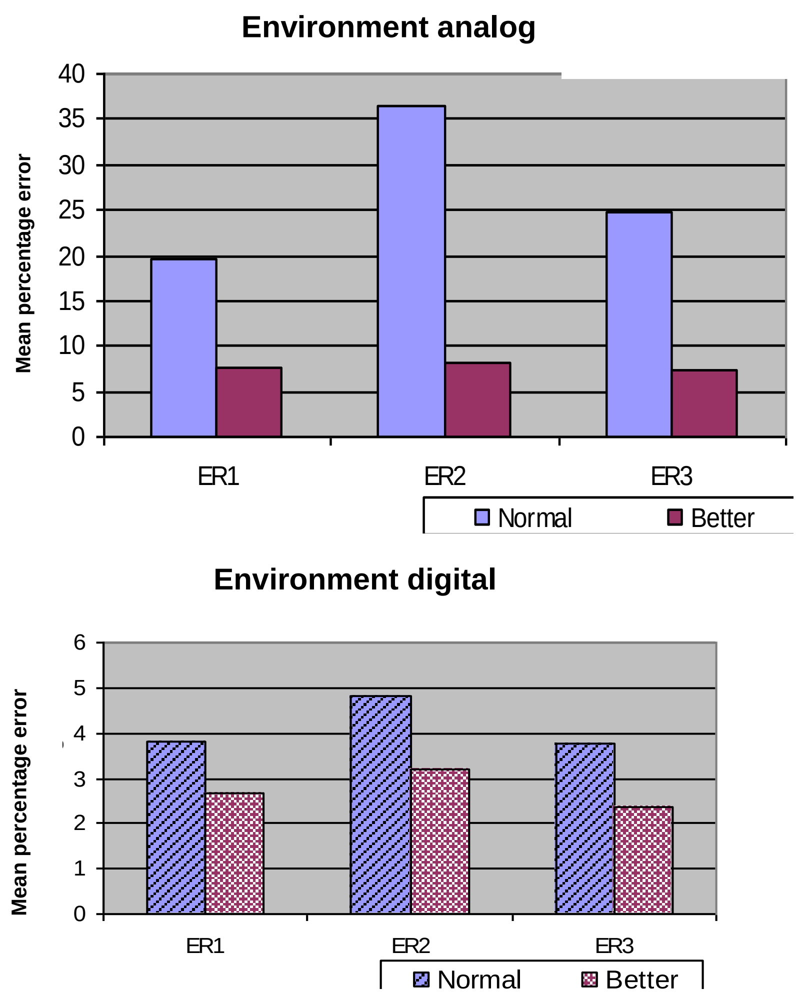


Figure 7. Environment.

categories were also asked to do the resistance measurement using analog and digital multimeter without any upper limit of time for completing the work. Table 8 shows that with relaxed time the analog measurement errors reduced by 13.4%, 18.6% and 21.3% respectively for IQ1, IQ2 and IQ3 categories. The corresponding reduction in errors when digital multimeter was used was 1.4%, 0.6% and 0.8%.

The t-test helps us to conclude that there is significant reduction in error when the time limits for doing the work are relaxed, in the case of analog measurement of resistance. But in the case of digital measurement, there is a significant error reduction only in the IQ1 category. Similar results were observed in the case of forenoon and afternoon sessions. This gives that relaxed time gives better result especially when a keen observation is involved in measurements (as in analog meter) rather than just read out (as in digital meter).

Environment

The IQ1, IQ2 and IQ3 categories were done the measurements of resistance both in normal and better conditions.

Figure 7 gives that air conditioned environment provides error reduction of 12, 28.2 and 17.3% respectively for IQ1, IQ2 and IQ3 categories in analog measurements. In the case of digital measurements it is 1.1, 1.6 and 1.4% respectively.

Conclusion

The outcome of a manual measuring system includes the results produced by the measuring instrument and what was observed and noted by the human subject involved in the manual measurement exercise. This paper focused

Table 1. Subjects for the experiments.

Measurand subject	Voltage		Resistance	
	Analog	Digital	Analog	Digital
ET - IQ3 (Age=31 to 40 yrs) [ET = Experienced technicians]	20	20	20	20
ET - IQ3 (Age=41 to 50 yrs)	20	20	20	20
IE - IQ1 (Age=21 to 30 yrs) [IE = Inexperienced subjects]	20	20	20	20
IE - IQ2 (Age=21 to 30 yrs)	20	20	20	20
IE – IQ3 (Age=21 to 30 yrs)	20	20	20	20

Table 2. Experienced technicians total data.

Subject		RAP	RDP	VAP	VDP
FN	Mean	6.92	5.51	15.22	3.39
	Standard deviation	0.73	1.62	4.71	0.36
	CV	10.58	29.33	18.93	10.67
AN	Mean	7.63	6.71	19.68	4.76
	Standard deviation	1.92	2.11	4.98	1.30
	CV	25.15	31.46	17.75	27.28
Total	Mean	7.28	6.11	26.45	4.08
	Standard deviation	1.46	1.93	4.99	1.16

Table 3. Inexperienced subjects total data.

Subject		N	FN - Mean	AN – Mean
RAP	Above average [IQ1]	20	5.48	6.92
	Average [IQ2]	20	7.87	13.61
	Below average [IQ3]	20	11.60	14.25
	Total	60	8.32	11.60
RDP	Above average [IQ1]	20	2.34	4.68
	Average [IQ2]	20	4.78	7.70
	Below average [IQ3]	20	3.27	12.40
	Total	60	3.47	8.26
VAP	Above average [IQ1]	20	2.12	19.39
	Average [IQ2]	20	4.48	30.08
	Below average [IQ3]	20	7.14	57.75
	Total	60	4.58	35.74
VDP	Above average [IQ1]	20	2.10	2.63
	Average [IQ2]	20	4.44	6.12
	Below average [IQ3]	20	7.01	9.33
	Total	60	4.52	6.03

Table 4. Inexperienced subjects ANOVA.

Subject		Sum of squares	Df	Mean square	F	Sig.
RAP	Between groups	470.441	2	235.221	8.499	0.001
	Within groups	1577.613	57	27.677		
	Total	2048.054	59			
RDP	Between groups	191.349	2	95.675	4.397	0.017
	Within groups	1240.304	57	21.760		
	Total	1431.654	59			
VAP	Between groups	4953.264	2	2476.632	7.165	0.002
	Within groups	19702.204	57	345.653		
	Total	24655.468	59			
VDP	Between groups	336.983	2	168.491	96.087	<0.001
	Within groups	99.951	57	1.754		
	Total	436.934	59			

Table 5. Paired sample test type differences.

Paired subject		t	df	Sig. (2-tailed)
Pair 1	RAP - RDP	5.087	59	<0.001
Pair 2	RAP - VAP	-4.224	59	<0.001
Pair 3	RAP - VDP	6.863	59	<0.001
Pair 8	RDP - VAP	-6.268	59	<0.001
Pair 9	RDP - VDP	1.048	59	0.299
Pair 14	VAP - VDP	6.155	59	<0.001

Table 6. Time of work experienced vs. inexperienced.

Experienced				Inexperienced				
Analog FN	Analog AN	Digital FN	Digital AN		Analog FN	Analog AN	Digital FN	Digital AN
11.07	13.66	4.45	5.74	IQ1	3.8	13.16	2.22	3.66
				IQ2	6.18	21.85	4.61	6.91
				IQ3	9.37	36	5.14	10.87

Table 7. Time of work t-test.

Subject	Session	Mean	Standard deviation	CV	t	df	Significance (2-tailed)
RAP	FN	21.51	10.24	47.62	-2.977	58	0.004
	AN	30.62	13.27	43.33			
RDP	FN	2.04	0.71	34.55	-5.887	58	0.001
	AN	3.79	1.46	38.64			
VAP	FN	41.10	21.02	51.15	-2.132	58	0.037
	AN	52.32	19.72	37.69			
VDP	FN	5.77	2.49	43.11	-3.760	58	0.001
	AN	9.01	4.00	44.44			

The t-test results between errors in forenoon and afternoon of all categories show that there is a significant increase in error in the afternoon.

Table 8. Time pressure t-test.

Category	Subject	Time	Mean	t	Sig. (2-tailed)
IQ1	RAP	Normal	20.4850	5.802	<0.001
		Relaxed time	7.1237		
	RDP	Normal	3.7471	-2.775	0.012
		Relaxed time	2.3405		
IQ2	RAP	Normal	25.8860	11.012	<0.001
		Relaxed time	7.3075		
	RDP	Normal	3.6338	-0.922	0.369
		Relaxed time	3.0521		
IQ3	RAP	Normal	29.3066	4.113	0.001
		Relaxed time	8.0431		
	RDP	Normal	4.6823	-1.191	0.249
		Relaxed time	3.8865		

on the effect of a few variables such as task assigned, type of instruments used, time of day, time pressure and environmental difference when experiment was done on measurement error. Using a standardized setup for the experiments, and only changing one parameter at a time, the measurement error in this study has been reduced to human errors in observation and noting. It was seen from the experiments conducted that, humans produce significant errors in measurement. The human errors due to observation and noting ranged from a minimum of 0.6 % to a maximum of 28.2%. It was necessary to study and bring out these values, since knowing the values would help in dealing with the errors when they are significant in the system. This study brings out values of human errors under different work related variable combinations; these may be taken as expected error values under those conditions for work system design.

The study has also been able to examine and quantify the effects of different work related variables on human errors induced in different types of subjects working under normal and air-conditioned environment. It was seen that, experienced technicians with below average IQ, were able to reduce the measurement error by 7.3% when using digital display devices instead of analog. A large segment of the workforce used in Industry for production and quality control measurements belong to this group. Digital measuring devices should only be used by them especially in areas where errors would be disastrous. Reduction in error with change over from analog to digital for the inexperienced category of subjects is also significant and stands at 9.5% on an average. Moving from use of analog to digital will therefore reduce human errors at least by 7.3%. The simpler task of voltage measurement, in all categories of subjects, unexpectedly, produced maximum error. A possible explanation being that, voltage measurement being a relatively simple task, having this in mind and not paying enough attention to the simple work at hand could have induced more human errors. It can also be noted that, persons with high IQ make less error. This is substantiated by the observation that inexperienced B. Technicians and Diploma holders with IQ above average [IQ1] were making less error when compared to the experienced subjects with lesser IQ. The increase of errors between forenoon and afternoon was least for experienced technicians. This could be because of their being used to working in the forenoon and afternoon regularly. The effect of doing the measurement without time limits for completion, on inexperienced subjects, is a reduction of errors on an average by 18% and 1% in analog and digital measurements respectively. The inexperienced subjects reduce error by 19 and 1.5% on an average in analog and digital measurements respectively, when they have performed the measurement under air-conditioned conditions.

The study has identified some variables that contribute to human errors in measurement. In the decreasing order of influence on human errors the parameters are: Instrument differences (digital-analog), working environment, time pressure, time of day and type of work. Identification of these parameters and an assessment of the extent of errors they produce will be of use to practitioners who rely on measurement for research, control and production, and quality control. This work has also demonstrated a simple methodology that can be used for such work. This work was started small with only a few parameters, since taking too many parameters all at a time would make the experiment very difficult to conduct and control. It is hoped that this work will help users of measurement in practice to better understand

and manage the phenomena of Human errors in measurement. In Future, studies need to be done to examine the effect of other type of variables on human errors in measurement. There is also need to look at the individual and interaction effects among different variable types.

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