A Workplace Design Improvement for Visual Inspection in a Philippine-based Aircraft Parts Company: A Cognitive Ergonomic Approach

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Abstract

Poor ergonomics leads to frustrated and fatigued workers that may not perform their job like they were trained which could create a product quality issue. In workstations for visual inspections, operators can have visual fatigue due to excessive usage of devices with light emissions, glare from inspection or poor lighting and too many components to check within a very short period. Similar conditions exist in a leading manufacturer of aircraft parts for the commercial and business jet aircraft markets. Visual quality of parts is what works in an aircraft interior that showcases comfort, safety and even luxury, the sensual benefits conveyed to passengers. Providing standard operating procedures and reference target specifications will not be enough to ensure consistency and reliability of visual inspection results without first identifying the ergonomic risk factors in a visual inspection workstation. Accordingly, with the heavy use of the faculty of eyesight and other faculties of cognition to assess visual quality performance of aircraft parts products, this study aims to assess the importance of incorporating cognitive ergonomics in the design of work conditions and environments that enhance cognitive functioning at work, and as a consequence, improve worker productivity and product quality.

Keywords
Visual Inspection Workstation, Visual Quality, Ergonomic Risks, Cognitive Ergonomics

1. Introduction

The aerospace industry is one of the largest and most influential industries worldwide, which supplies five markets such as military aircraft, missiles, space, commercial airliners, and general aviation. The aerospace industry's product line is, by necessity, broad because its primary products, flight vehicles, require up to millions of individual parts. In addition, many support systems are needed to operate and maintain the vehicles. Many parts are needed before an aircraft is assembled, divided into three categories based on previous research.

The subject company is a manufacturer of aircraft passenger cabin interior products for the commercial and business jet aircraft markets. The company had a leading worldwide market share in all of its primary product lines. It served all of the world's airlines, aircraft manufacturers, and leasing companies virtually through its direct global sales and customer support organizations.

Since it began the production and management system used by the manufacturer of aircraft parts is JIT System and have been established to improve the competitiveness on the market. The company is the parts supplier specifically for aircraft industries.

However, the company of interest has been experiencing a not-so-good trend in customer complaints related to visual defects for the past one-and-a-half years. According to data, 69% in 2015 to almost 86% in January-May 2016 may require serious attention to look into how its workplace design contributes to a paramount concern on visual inspection, which is deemed the last gate before shipping out parts products airline companies worldwide. The earlier mention of the research gap on the topic of interest and the preceding discussion of the situation of a company engaged in the aircraft manufacture industry is imperative drivers to the need to research this critical area of concern that can lead to putting in place a better reference in enhancing workplace design with consideration of elements of cognitive ergonomics in improving the quality of not only the visual inspection activities but also other essential operations in the aerospace industry.

In the light of the above-mentioned discussion, this study seeks to find an answer to the research question: What can be the ergonomic considerations in improvement of workplace design and outgoing product quality at the Visual Inspection in an Aircraft parts manufacturer? This study aims at three things. The first is to assess the workplace of the Visual inspection area of an aircraft parts manufacturer. The second is to determine the significant factors that can affect inspector's productivity and the quality of their inspection. And lastly, to recommend an improved workplace design framework incorporating elements of cognitive ergonomics with the physical workplace design factors.

The study will benefit the aircraft parts company in obtaining an empirical basis to approach the growing problem of customer complaints related to visual defects, which will significantly enhance its quality image in the industry. Workers in the subject company's visual inspection area will gain from the findings of the study in improving their performance and contribution to the company's quality improvement initiatives. The results of the research study may benefit the other segments of the aerospace industry in considering the approach that will be taken by the research study in exploring ways to improve their operations continuously. The research community will be able to use this research's findings in expanding the scope of this study to cover other related and essential areas to further add to the knowledge on hand, which the author intended to do with the use of industrial engineering know-how and techniques.

The study will be conducted in aircraft parts manufacturing in the Philippines, focused only on the workplace design of Visual Inspection. The study will also cover only the customer complaints that are related to visual defects only. The study assumed that the final inspectors are well trained and experience in the visual inspection task.

2. Methodology

Figure 1 represents the conceptual framework. The study's concept is to develop a workplace design incorporating the cognitive ergonomics towards a quality visual inspection of an aircraft manufacturer. Factors that affect the workplace design of visual inspection will be assessed for the gathering of data. The incorporation of cognitive ergonomics has been considered in the study to understand significantly human factors in the visual inspection task. Questionnaires and anthropometric data will be analyzed using multiple regression analysis to develop a recommendation of workplace design that will improve the visual inspection quality. Moreover, the following hypothesis was formulated based on the structured conceptual framework of this study.

$H1_0$: Workplace design has no relationship with the worker’s productivity in the Visual Inspection Area.
$H1_A$: Workplace design has a significant relationship with the worker’s productivity in the Visual Inspection Area.

$H2_0$: Cognitive ergonomics has no relationship to the worker’s productivity in performing the visual inspection.
$H2_A$: Cognitive ergonomics has a significant relationship with the worker’s productivity in performing the visual inspection.

$H3_0$: Workplace design with cognitive ergonomics has no relationship to the worker’s productivity in the Visual Inspection Area.
$H3_A$: Workplace design with cognitive ergonomics has a significant relationship with the worker’s productivity in the Visual Inspection Area.

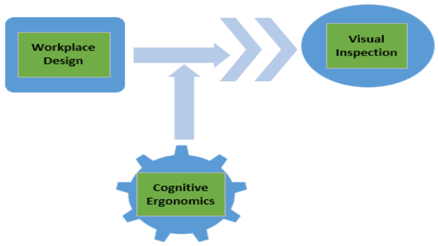

Figure 1. Conceptual Framework

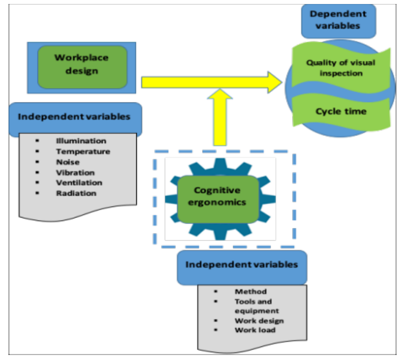

Figure 2. Operational Framework

An operational framework is also developed to permit a more tactical procedure for the workplace improvement of the visual inspection area, as shown in Figure 2 below. To provide convergent support and better understand and improve the workplace in a cognitive approach, independent variables in the workplace were identified, such as illumination, noise, temperature, vibration, ventilation, and radiation. Simultaneously, independent variables for cognitive ergonomics were also identified for assessment, such as work movement, anthropometric data, workload, work posture, tools, and equipment.

The first dependent variable considered in the study is the cycle time of the different models running in Line 2. The researcher conducted tact time for each model and took the average cycle time. The independent variables considered in the study are gender, age, weight, height, years of service, RULA (actual inspection of the unit), RULA (using of a computer), workplace design, and ergonomics in the workplace and presence of pain. The survey questionnaire was based on a Likert scale and had a numerical equivalent: (1) Strongly disagree (2) generally disagree (3) Neutral (4) Generally agree and (5) Strongly agree. Two categories of survey questionnaires are workplace design and ergonomic-incorporated workplace design.

The workplace design category has 11 questions, and it is based on Likert items, which has 5 points. The ergonomic-incorporated workplace design category has six questions based on 5 points Likert items. For each respondent, answers will be converted to numerical equivalent and sum up. The range of the total score for the workplace design category will be from 11 to 55; Score 11 is equivalent to disagree while score 55 is equivalent to strongly agree strongly. In this scoring system, the higher the score, the better is the current workplace design. On the other hand, Ergonomic-incorporated workplace design will have a range of scores 6 to 30. Responses are converted to numerical values to make them scale data. The presence of pain before/during/after work is summed up. The maximum score per respondent is 9.

3. Results and Discussion

The researcher assessed the workplace using survey questionnaires, RULA, and the visual inspectors' anthropometric data. The researcher had designed a survey questionnaire divided into three categories: a) the ergonomic workplace, b) workplace design, and c) the presence of pain experienced by the respondents.

Category A, the survey questionnaire's workplace design, has the criteria given in table 1 to determine the survey results. Category B, which is ergonomics in the workplace of the survey questionnaire, has the criteria given in table 2 to determine the survey results. Responses are converted to numerical values to make them Scale data. And lastly, Category C shown in table 3, which is the presence of the pain before/during/after work of the survey questionnaire, is summed up. The maximum score per respondent is 9. Table 4 represents the summary of scores from the survey questionnaires.

Table 4. Summary of scores from the survey questionnaires

Respondent	Gender	Age	Wt (k)	Ht (cm)	Years Of Service	Workplace Design	Ergo Workplace	Presence Pain
1	1	35	65	168	4.5	37	18	4
2	1	28	79	180	4.5	38	19	3
3	1	27	63	163	4	36	18	4
4	2	36	55	158	4.5	36	19	4
5	2	33	48	152	4.5	36	20	4
6	1	32	69	175	4.5	36	19	2
7	1	32	58	172	3	35	18	2
8	1	26	63	181	4	36	20	2
9	1	33	64	158	4.5	39	20	4
10	1	35	69	180	2.5	37	21	2
11	1	32	55	155	3.5	36	20	3
12	1	34	60	164	3	34	20	3
13	1	43	77	173	4.5	37	20	3

RULA assessment were also performed when using a computer and when performing a visual inspection of the unit. Table 5 represents the summary of the result for respondents' results on RULA assessment.

Table 5. Respondents' result on RULA assessment

Respondent	RULA Visual Inspection of Unit	RULA Computer
1	4	5
2	3	5
3	4	6
4	4	6
5	4	6
6	3	5
7	3	5
8	3	5
9	4	6
10	3	5
11	4	6
12	4	6
13	3	5

The cycle time of each model running in line 2 was also gathered to represent the productivity of inspectors. Table 6 represents the result of the productivity assessment using the cycle time.

Table 6. Respondents' result on productivity assessment using cycle time

Respondent	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	AveCycle_Time
1	18.61	14.12	18.27	13.11	16.44	10.81	15.23
2	17.36	18.89	19.09	18.43	16.05	12.06	16.98
3	19.82	14.83	18.48	14.20	17.10	10.52	15.82
4	20.68	19.29	22.06	17.15	21.14	13.48	18.97
5	25.99	19.29	22.06	17.15	21.14	13.48	19.85
6	16.96	16.79	19.23	15.73	16.69	10.10	15.92
7	19.52	16.26	18.72	15.73	16.60	11.24	16.34
8	19.77	18.25	18.89	16.26	15.81	11.86	13.66
9	17.96	20.52	17.81	15.47	15.41	12.18	16.56
10	15.68	20.99	19.33	19.73	17.79	14.62	18.03
11	17.34	17.10	18.64	16.88	15.05	12.73	16.29
12	15.87	15.18	14.92	18.15	15.23	11.71	15.18
13	13.77	17.19	17.13	16.39	16.54	12.64	15.61

After the gathering of survey questionnaires, a statistical test was performed through ANOVA, bivariate correlation, multi-collinearity and multiple regression. Two set of data analysis was performed using SPSS software to check if productivity and quality was affected with the considered variables. For the first data analysis, age, weight, height, years of service, RULA in performing visual inspection, RULA in using the computer, design of workplace, ergonomics of workplace and presence of pain were all correlated on the cycle time of different models running in Line 2 to check if the productivity of the respondents was affected by the variables. The researcher set the significance level of 95%.

3.1 Productivity Analysis

Data for productivity has been tested and based from the variance inflation factor(VIF), which has a formula of VIF=1/collinearity statistics, there are variables that has a VIF of more than 10. Table 7 shows the result of VIF from collinearity table of the dependent variables.

Table 7. VIF from collinearity table of dependent variables

Independent Variable	VIF					
	Line 2 Model Dependent Variables					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Gender	12.926	12.926	12.926	12.926	12.926	12.926
Age	12.05	12.05	12.05	12.05	12.05	12.05
Weight	50.226	50.226	50.226	50.226	50.226	50.226
Height	52.263	52.263	52.263	52.263	52.263	52.263
Years Of Service	5.728	5.728	5.728	5.728	5.728	5.728
RULA Vision	21.144	21.144	21.144	21.144	21.144	21.144
RULA Computer	18.904	18.904	18.904	18.904	18.904	18.904
Workplace Design	3.973	3.973	3.973	3.973	3.973	3.973
Ergo Workplace	2.661	2.661	2.661	2.661	2.661	2.661
Presence Pain	21.913	21.913	21.913	21.913	21.913	21.913

Based on the initial run in SPSS of each model, there are 7 out of 10 independent variables with a VIF value greater than 10. Data with a VIF of more than 10 means that the variable should not be included in the regression model. See Appendix for the multi-collinearity table of each model. Based on the coefficient table, most of the variables have multi-collinearity issues except for the following variables: Years of Service, Workplace design, and ergonomics in the workplace. This leads to the conclusion that the model must be rerun, excluding the variables with issues. The second set of new statistical test was done for each model. Models considered as dependent variable are Model 1, 2, 3, 4, 5, 6.

Table 8 represents the values obtained at the collinearity statistics and VIF for the coefficient table did not exceed the threshold of 0.1 for the statistic or 10 for the VIF. Since the values are lower than 10 for the VIF, there are no issues, and that these variables can be used in the regression model. Checking outliers based on Mahalanobis distance, the values for a maximum point on the residual statistic, the Mahalanobis distance is 7.285, which is lower than the critical point chi-square value for 0.001 probability, which is 16.266. Influential points were also checked, and based on Cook's distance, the maximum value must not exceed 1.00. This model's value is 0.606, which means no significant points might deviate from the model. The R square in the model summary has 0.184 or 18.4% of the variance in productivity is due to the three factors, and roughly 80% may be due to other factors. Based on the statistical significance (hypothesis testing), p=0.587, which is higher than d, the null hypothesis must not be rejected. Evaluating the predictor variables based on the coefficient table, the standardized coefficient beta explains an excellent contribution to the model's prediction. There is a significant contribution to predicting the outcome if the p-value is less than the alpha.

Table 8. Summary of statistical analysis for Model 1

Independent Variable	VIF	Mahalanobis distance	Cook's distance	R^2	Statistical significance
Years Of Service	1.536	7.285	0.606	0.184	0.587
Workplace Design	1.447				
Ergo Workplace	1.212				

Table 9 represents the result of VIF for the model. Based on this, the values do not exceed the threshold, which means this variable can be used in the regression model. Mahalanobis distance has a value of 7.285, which means there is no outlier. The value of Cook's distance is 1.362, which means it has an influential point. R square for this model is 0.111 or 11.1% and has an ANOVA significance of 0.775. Therefore the null hypothesis cannot be rejected. The statistical significance is relatively low; p values are higher than the alpha.

Table 9. Summary of statistical analysis for Model 2

Independent Variable	VIF	Mahalanobis distance	Cook's distance	R^2	Statistical significance
Years Of Service	1.536	7.285	1.362	0.111	0.775
Workplace Design	1.447				
Ergo Workplace	1.212				

Table 10 represents the Value of VIF. Based on this, the values do not exceed 10, meaning there are no collinearity issues for the model. The Mahalanobis distance has a value of 7.285, which means there is also no outlier for the model's data. Cook's distance of the data has 2.137 that means the data has significant points that might deviate the model. R square is 0.137 or 13.7% that is due to the three factors. ANOVA significance is 0.706. Therefore the null hypothesis cannot be rejected. The value of the standardized coefficient beta from evaluating predictor variables is moderately low; p values are higher than the alpha.

Table 10. Summary of statistic analysis for Model 3

Independent Variable	VIF	Mahalanobis distance	Cook's distance	R^2	Statistical significance
Years Of Service	1.536	7.285	2.137	0.137	0.706
Workplace Design	1.447				
Ergo Workplace	1.212				

Table 11 shows that the VIF value does not exceed 10, which means there are no collinearity issues. The Mahalanobis distance also has a value of 7.285 that makes the value in the data have no outliers. The data also has a cook's distance of 0.502, and there are no significant points in the model's data. R square of the data is 0.615 or 61.5%, which is due to the three factors. The ANOVA significance p-value is 0.029. It is less than the alpha that means the null hypothesis must be rejected. The standardized coefficient beta on the coefficient table is relatively high for workplace design and ergonomics in the workplace; ergonomics in the workplace has a p-value lower than the alpha.

Table 11. Summary of statistic analysis for Model 4

Independent Variable	VIF	Mahalanobis distance	Cook's distance	R^2	Statistical significance
Years Of Service	1.536	7.285	0.502	0.615	0.029
Workplace Design	1.447				
Ergo Workplace	1.212				

Table 12 shows that VIF value for the model does not exceed 10, which means there are no collinearity issues. The Mahalanobis distance value is 7.285 that means it has no outlier in the data. Cook's distance value is 0.483, which means there are no significant points in the data. R square of the model is 0.573, or 57.3% of the variance is due to the three factors. The ANOVA significance is 0.045, lower than the alpha. This means the null hypothesis can be rejected. The value for the standardized coefficient beta is high in the ergonomics in the workplace and shows a significant contribution in the outcome at a p-value of 0.026.

Table 12. Summary of statistical analysis for Model 5

Independent Variable	VIF	Mahalanobis distance	Cook's distance	R^2	Statistical significance
Years Of Service	1.536	7.285	0.483	0.573	0.045
Workplace Design	1.447				
Ergo Workplace	1.212				

Table 13 shows that VIF values for the three factors does not exceed 10. The data of the Model 5 have no collinearity issues. Mahalanobis distance is 7.285, and this value states that there is no outlier on the data. Cook's distance value is 0.624, which means no influential points might deviate from the model. The R square value is 0.54, or 54% of the variance is due to the three factors. The ANOVA significance value is 0.062 for this model. It is higher than the alpha and means the null hypothesis cannot be rejected. In the coefficient table, the value of ergonomics in the workplace for the standardized coefficient is high, with a significance at 0.027

Table 12. Summary of statistical analysis for Model 6

Independent Variable	VIF	Mahalanobis distance	Cook's distance	R^2	Statistical significance
Years Of Service	1.536	7.285	0.624	0.54	0.062
Workplace Design	1.447				
Ergo Workplace	1.212				

3.2 Quality Analysis

The table 14 represents the summary of the statistical analysis for quality analysis of this study. One model was considered in the data generated since total units were considered, regardless of the product model. The VIF values for multicollinearity values are lower than 10, though the variable presence of pain requires attention since the VIF is 7.073. Overall, all variables can be included in the regression analysis.

The Mahalanobis distance from the residual table has a minimum value of 1.859, while the maximum value is 7.922. Based on the critical values using chi-square, for a model using five independent variables, the critical value is 20.515. There is no outlier in the data since the maximum Mahalanobis distance does not exceed the critical value.

Cook's distance value is at minimum 0 while the maximum value is 0.521. Cook's distance must not be more than 1.00, and else there are influential points in the data set. Since the maximum point here is 0.521, the data set does not contain any influential points.

R square value is 0.294 for this data, which means 29.4% of the variance of having failed units is due to the five factors being studied. The statistical significance from the ANOVA table is 0.715. It is greater than the null hypothesis and cannot be rejected. Evaluation of predictor variables from the standardized coefficient beta is highest at workplace design.

Table 14. Summary of statistical analysis for quality analysis

Independent Variable	VIF	Mahalanobis distance	Cook's distance	R^2	Statistical significance
RULA Vision	6.096	7.922	0.521	0.294	0.715
RULA Computer	2.103				
Workplace Design	2.006				
Ergo Workplace	1.377				
Presence Pain	7.073				

4. Conclusion

Upon analyzing the results from the survey, the researcher concluded that the workplace on the visual inspection area has ergonomic medium risk in the visual inspection process and needs intervention to prevent long term effect on the inspector's health.

After a data analysis of the researcher using SPSS for the productivity, it can be said that it is inconclusive since there is no relationship among the variables treated as dependent variables. In contrast, it was determined that the significant factor's that affects the quality of the output using SPSS are: visual inspection of the unit, use of computer, workplace design, ergonomics in the workplace, and the presence of pain.

After the assessment made by the researcher on the visual inspection area, it was proven that improvement of the situation in the workplace design with the incorporation of cognitive ergonomics with the physical workplace design factors should be made. The following are the recommended improvement; provide light/lamp in the visual inspection area to improve the lighting condition, relocate the position of the computer to minimize the risk on the inspector's health, embed the actual pictures of the unit in work instruction to serve as information display that will guide and support the inspector. It is also recommended to provide a shadow board for a tool that will be used in visual inspection to improve the recognition of defects.

5. Recommendation

It is also recommended that the parts aircraft manufacturer recognize the benefits of cognitive ergonomics in the visual inspection area. The support of top management in improving the workplace through cognitive ergonomics will improve visual inspection quality, thus decreasing customer complaints regarding visual defects.

Based on the study's preceding findings, further studies of productivity analysis should use different approaches and tools assessment. As a result of ANOVA, it is inconclusive for the productivity analysis since there is no relationship seen among the variables treated as dependent variables. There are still variables that fit the dependent variable that may lead to a conclusion.

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