Response Surface Methodology and its Application in Evaluating Scientific Activities of Federal University

Abstract

This paper explores the analysis of a second-order response surface methodology (RSM) to modeled the relationship between some selected university ranking indicators and citation variables. The objectives were to investigate which of the selected indicator(s) are relevant to the number of citations received on publication and obtain the best link function that relate the factors variables to response variable, also check if there exist an interaction effect between the selected ranking indicators. The University ranking indicators used in this paper were sourced from google scholar, research gate, the University repository and through questionnaire. The observations were treated as quasi-experimental designs. The results show that the analysis of full factorial experiment on factor affecting number of citations received on publication showed a significant contribution of interaction of articles and collaboration, and also showed that the undergraduate and post graduate project is not negligible in contributing to the number of citations. While, the analysis of variance for the second first order model on publication showed that the first order model, the two-way interaction model and the pure quadratic effects on publication were all significant. Based on these results, the paper recommends that research collaboration among the university researchers should be highly encourage, money should be injected more into research and there should be a provision for more facility in the department in other to maximize research output of the departments.

Keywords: Ranking, Response Surface Methodology, Citation, Full factorial Experiment, Publication

1.0 Introduction

The drives for globalization in all facets of research, universities development and ranking as an essential aspect of checkmating the standard of an institution among its peers at national and international level cannot be over emphasized. Most ranking methods make use of institutions' scientific activities, which can be model for the purposed of ranking. When modeling universities scientific activities, the model required that the system under study should have defined borders and identify the set of factors called input that affects the system (say, numbers of researchers, funding, and facilities, as they affect a university ranking.). This model in turn generates or responds to products resulting from their scientific activity called output, such as

publications and citation. This relationship which links inputs together with outputs is complex and difficult to describe with just simple mathematical models. Hence, there is need for tools that are capable of more complex modeling and that can achieve maximum modification of roles of each variable in the system. This will also check if there is synergetic or opposing interrelationships between the same variables.

The response surface methodology (RSM) is based on the experimental design with the final goal of evaluating optimal functioning of industrial facilities, using minimum experimental effort, here the inputs are called factors and the outputs represent the response that generates the system under the causal action of the factors (Hoffmann and Doucette, 2012).

Dhawan and Gupta (2005) evaluates citations performance of 1101 Indian physics research papers published in 29 high impact physics journals in 1997. The evaluation is based on citations won by these papers within six years of publication. The purpose is to verify to what extent research evaluation based on journal impact factor can be considered objective and fair. The study finds that journal impact factor is not a surrogate to citations. Nearly 12% of papers in high impact journals did win even a single citation within six years of their publication. Secondary papers winning high range of citations per paper were published in a wide range of impact factor journals. In conclusion it is said that although impact factor is not a guarantee to citations but publication in high impact journals does improve the probability of winning citations.

A related study conducted by Iroaganachi and Itsekor, (2014). On a Citation Analysis of social science. It was revealed that the author cited more from text books than journal and internet/electronic resources. Citation from books was 69.4% followed by journals 16% and Internet/ E-Resources 8% among others.

Some researchers have reviewed the response surface methodology and have come to some basic conclusions. According to research conducted Myers, Khuri, and Carter (2009), the orthogonal design was motivated by Box and Wilson (1951) in the case of the first-order model. For the second-order models, many subject matter scientists and engineers have a working knowledge of the central composite designs (CCDs) and three-level designs by Box and Behnken (1960). Also, the same research states that another important contribution came from Hartley (1959), who made an effort to create a more economical or small composite design.

Myers, Khuri, and Carter (2009), the important development of optimal design theory in the field of experimental design emerged following Word World II., and Kiefer and Wolfowitz were some of the various authors who published their work on optimality. One of the important facts is whether the system contains a maximum or a minimum or a saddle point, which has a wide interest in industry. Therefore, RSM is being increasingly used in the industry.

Nonetheless, response surface methodology has an effective track-record of helping researchers improve products and services: For example, Box's original response-surface modeling enabled chemical engineers to improve a process that had been stuck at a saddle-point for years. The engineers had not been able to afford to fit a cubic three-level design to estimate a quadratic model, and their biased linear-models estimated the gradient to be zero. Box's design reduced the costs of experimentation so that a quadratic model could be fit, which led to a (long-sought) ascent direction. [Box, G.E.P. and Wilson, K.B. (2011)].

This study explores the use of response surface methodology to model a relationship between some selected university ranking indicators and citation variables. The study investigates which of the selected indicator(s) are relevant to the number of citation received on publication and also

obtain the best link function that relate the factors variables to our response variable, also check if there exist a synergy (interaction effect) between the selected ranking indicators.

2.0 Materials and Methods

2.1 Materials

The data used in this study was extracted from the scientific production of thirty-eight (38) departments of the Federal University of Technology (FUT) Minna, using the university yearly report book. The production data and citations were taken from the research gate and google scholar. The information on economic and human resources were sourced from the university repository. The indicators used in the evaluation of the FUT, Minna are: number of publications; number of citations; number of researchers (human resources); economics resources (funds); facilities (equipment); numbers of patent' number of post graduate projects; number of undergraduate projects and numbers of partnership (Collaboration). The study used the following indicators in the analysis: Department = DPT, Articles = ATC, Citation = CTN, Human resources = HR, Funds = FD; Undergraduate = UG, Postgraduate = PG, Collaboration = COL, and Percentage of facility = FAC.

2.2 Methods

2.2.1 Response Surface Methodology

The Response Surface Methodology equation can be expressed as:

$$\boldsymbol{y = f(x_i, x_2) + \epsilon} \qquad \textbf{(1)}$$

where $\boldsymbol{y}$ is the response (output) variable, $\boldsymbol{x_i}$ and $\boldsymbol{x_2}$ are independent (input) variables and $\boldsymbol{\epsilon}$ is the experimental error term represents any measurement error on the response, as well as other type of variations not counted in $\boldsymbol{f}$.

But if the response can be defined by a linear function of independent variables, then the approximating function is a first-order model. A first-order model with 2 independent variables can be expressed as

$$y = b_0 + b_1x_1 + b_2x_2 + \epsilon \qquad (2)$$

If there is a curvature in the response surface, then a higher degree polynomial should be used. A second-order model with two independent variables can be expressed as:

$$y = b_0 + b_1x_1 + b_2x_2 + b_{11}x_{11}^2 + b_{22}x_{22}^2 + b_{12}x_1x_2 + \epsilon \qquad (3)$$

2.2.2 Assumptions of Response Surface Methodology (RSM)

The assumptions are:

(i) Error term is assumed to distribute normally with zero mean and variance $\boldsymbol{\sigma^2}$.

(ii) The true response function $\boldsymbol{f}$ is unknown.

(iii) The experiment starts with a low order polynomial in some small region

2.2.3 The analysis of variance (ANOVA)

Hypothesis

The proposed equation to define the responses variable (Numbers of Article) are the effects of the selected input variables (Human resources, Collaboration, Fund and Facility). To define the response equation, H.R, COL, FD, and FAC are assigned to ATC and we have:

Also,

The proposed equation to define the responses variable (Numbers of Citation) are the effects of the selected Input variables (Numbers of Article, Collaboration, Undergraduate project and Postgraduate project). To define the response equation, ATC, COL, U.G, and P.G are assigned to CTN and we have:

The null hypothesis states that there is no quantifiable/significant effect of Input variables in the overall responses (output) variable. If this hypothesis is true then:

$: b_1 = b_{11} = 0, b_2 = b_{22} = 0, b_3 = b_{33} = 0, b_{12} = b_{13} = b_{23} = 0$

$: \beta_1 = \beta_{11} = 0, \beta_2 = \beta_{22} = 0, b_3 = \beta_{33} = 0, \beta_{12} = \beta_{13} = \beta_{23} = 0$

The alternative hypothesis postulated that at least one of the coefficients is different to zero. Then:

: At least one $b \neq 0$

: At least one $\beta \neq 0$

2.2.4 Experimental design versus quasi-experimental design

The experimental designs, as explained above, represent the empirical support of the response surfaces. In the case of a controllable system in a laboratory, the planning and execution of an experimental design implies no more problem than that inherent in the experimentation itself. On the other hand, certain novelties have to be introduced into the methodology if RSM will be used for the evaluation of scientific activity. In the evaluation of scientific activity, there are no true experiments but rather only observations, and therefore the experimental design, in principle, would make no sense.

Although the scientific activity cannot be manipulated in the sense in which variables of physicochemical phenomena are manipulated in a laboratory, they can be selected. That is, we will construct what we will call from here on quasi-experimental designs, which are governed by the same rules as experimental designs, but with specially chosen observations from among the total set of them, in such a way that we find the closest possible values that an experimental design would require. Admitting this, we find that the RSM is feasible. Statistics. Thus confirmed the validity of the quasi-experimental design proposed. The following terms represent the indicator in the analysis; Department = Dept, Articles= Atcl, CTN = Citation, H.R = Human

resources, U.G = Undergraduate, P.G = Postgraduate, COL = Collaboration, FAC = Percentage of Facility

3.0 Results

Fitting of second order linear model with interaction provides the results of analyses of factors affecting numbers of Publication and factors affecting numbers of Citation received in F.U.T Minna (2012-2016) respectively. The results were as follows.

Table 1: Analysis of Full Factorial Experiments on Publication

Term	Estimate	Std. Error	t-value	Pr(>|t|)	Reject H_0	Sig
(Intercept)	-157.05	0.0047701	-0.3292	0.74495	No	No
HR	-7.1800	0.0173970	-0.4129	0.68348	No	No
COL	74.280	0.9506900	0.7813	0.44258	No	No
FD	0.1122	0.0087825	-1.2778	0.21405	No	No
FAC	2.8330	0.0693020	0.4088	0.68645	No	No
HR: COL	1.2320	0.0153160	-0.8043	0.01949*	Yes	Yes
HR: FD	0.0040	0.0017940	2.2475	0.03450*	Yes	Yes
COL: FD	0.0126	0.0064469	1.9569	0.0244*	Yes	Yes
COL: FAC	0.0820	0.7327400	0.1119	0.91187	No	No
FD: FAC	-0.0005	0.0005163	-0.8776	0.38926	No	No
(H: R)^2	0.2503	0.0239980	1.0430	0.30778	No	No
(COL)^2	-4.979	0.0719280	-0.6923	0.49570	No	No
(FD)^2	0.00001	0.0000569	-0.8386	0.41032	No	No
(FAC)^2	-0.0577	0.0042880	1.3457	0.19150	No	No

Multiple R-squared = 0.7055; Adjusted R-squared = 0.5262; F-statistic = 3.935 on (14, 23) DF, *P-value* = 0.001818

The second-order linear model of factors affecting numbers of publication in F.U.T Minna from 2012 to 2016, it was obtained from the result in Table 1 that, the first order effects (HR, COL, FD, and FAC) and their quadratic effect are negligible. That is, not significant while there is a response with respect to the interaction of (HR: COL), (HR: FD), (HR: FAC), (COL: FD), (COL: FAC) and (FD: FAC) which signifies that there is a synergistic effect between the two factors interaction in contributing to numbers of publication.

Also, the overall F-test for all the regression is significant, F-statistic = 3.935 greater than F-table (14, 23, 0.05) = 2.13, and *p-value* = 0.001818 less than significant level (0.05). Multiple R-squared (R^2 = 0:7055), implies that 70:55% of variation in numbers of publication is well explained by the fitted model (ATC) and that the regression equations fit the sample data. Adjusted R-squared (Q^2 = 0:5262), implies 53% of goodness of fit of the model.

Table 2: Analysis of Variance for the second first order model on Publication

Source of Variation	Df	Sum of Square	Mean of Square	F-cal	Pr(>F)	Reject
FO (HR, COL, FD, FAC)	**4**	143917	35979	8.0402	0.0003295	Yes
TWI (HR, COL, FD, FAC)	**6**	87689	14615	3.2660	0.0179736	Yes
PQ (HR, COL, FD, FAC)	**4**	14924	3731	0.8338	0.5176208	No
Residuals	**23**	102923	4475			

The first order model has the *p-value* (0.0003295 < 0.05), which implies that the predictor variables have an additive effect on the response variable. This also means that there is no significant lack of fit with the first model. The two-way interaction model has *p-value* (0.0179736 < 0.05), shows that the interaction of (HR, COL, FD, FAC), is not negligible. That is, there is no significant lack of fit in the interaction model. The pure quadratic effects have *p-value* (0.5176208)> 0.05), shows that, there is no indication of a pure quadratic effect in the model.

Table 3: Analysis of Full Factorial Experiments on number of citations from 2012 to 2016)

Term	Estimate	Std. Error	t-value	Pr(>|t|)	Reject H_0	Sig
(Intercept)	578.521	133.580	4.3309	0.0002468 *	Yes	Yes
HR	-7.1838	17.397	-0.4129	0.68348	No	No
ATC	1263.254	284.764	4.4361	0.0001898 *	Yes	Yes
COL	94.789	112.281	-0.8442	0.0407243 *	Yes	Yes
UG	453.676	212.701	2.1329	0.0438248 *	Yes	Yes
PG	251.005	205.965	1.2187	0.02353200*	Yes	Yes
ATC: COL	757.803	401.178	1.8889	0.00715739*	Yes	Yes
ATC:UG	3766.788	943.827	3.9910	0.0005753*	Yes	Yes

ATC:PG	-1008.354	433.474	-2.3262	0.0291777*	Yes	Yes
COL:UG	-908.384	395.660	-2.2959	0.311326	No	No
COL:PG	284.281	331.767	0.8569	0.4003562	No	No
UG:PG	971.075	576.369	1.6848	0.1055473	No	No
$(ATC)^2$	-1991.989	677.730	-2.9392	0.0073675*	Yes	Yes
$(UG)^2$	-559.370	303.660	-1.8421	0.0783921	No	No
$(PG)^2$	-390.213	295.562	-1.3202	0.1997432	No	No

Multiple R-squared: 0.7854; Adjusted R-squared: 0.6548; F-statistic: 6.013 on 14 and 23 DF, *p-value:* 0.00008414

The second-order linear model of factors affecting numbers of citation, it was opined from the result in Table 3 that, the first order effects (ATC, COL, UG, PG), interaction between ATC: COL and quadratic effect of $(ATC)^2$ were the only significant predictor variable while the rest variables are negligible in contributing to citations. Also, the overall F-test for all the regression is significant. That is, F-statistic: 6.013 greater than F-table (14, 23, 0.05) = 2.13, and *p-value*: 0.000084 less than significant level (0.05). Multiple R-squared (R^2) = 0:7854, implies that 78:54% of variation in numbers of citation is well explained by the fitted model (CTN) and that the regression equations fits the sample data. Adjusted R-squared ($adjR^2$ = 0:6548), implies 65:48% of goodness of fits of the model.

Table 4: Analysis of Variance for the second first order model on Publication

Source of Variation	Df	Sum of Square	Mean of Square	F-cal	Pr(>F)	Reject
FO (ATC, COL, UG, PG)	**4**	5963183	1490796	14.0367	0.0000061	Yes
TWI (ATC, COL, UG, PG)	**6**	1617383	269564	2.5381	0.04926	Yes
PQ (ATC, COL, UG, PG)	**4**	1360519	340130	3.2025	0.03145	Yes
Residuals	**23**	2442758	106207			

The first order model has the *p-value* (0.0000061) < 0.05), which implies that the predictor variables have an additive effect on the response variable. That is, there is no significant lack of fit with the first model. The two-way interaction model has *p-value* (0.04926) < 0.05), shows that

the interaction of (ATC, COL, UG, PG), is not negligible. That is, there is no significant lack of fit in the interaction model. The pure quadratic effect has *p-value* (0.03145) < 0.05), shows that, there is indication of a pure quadratic effect in the model.

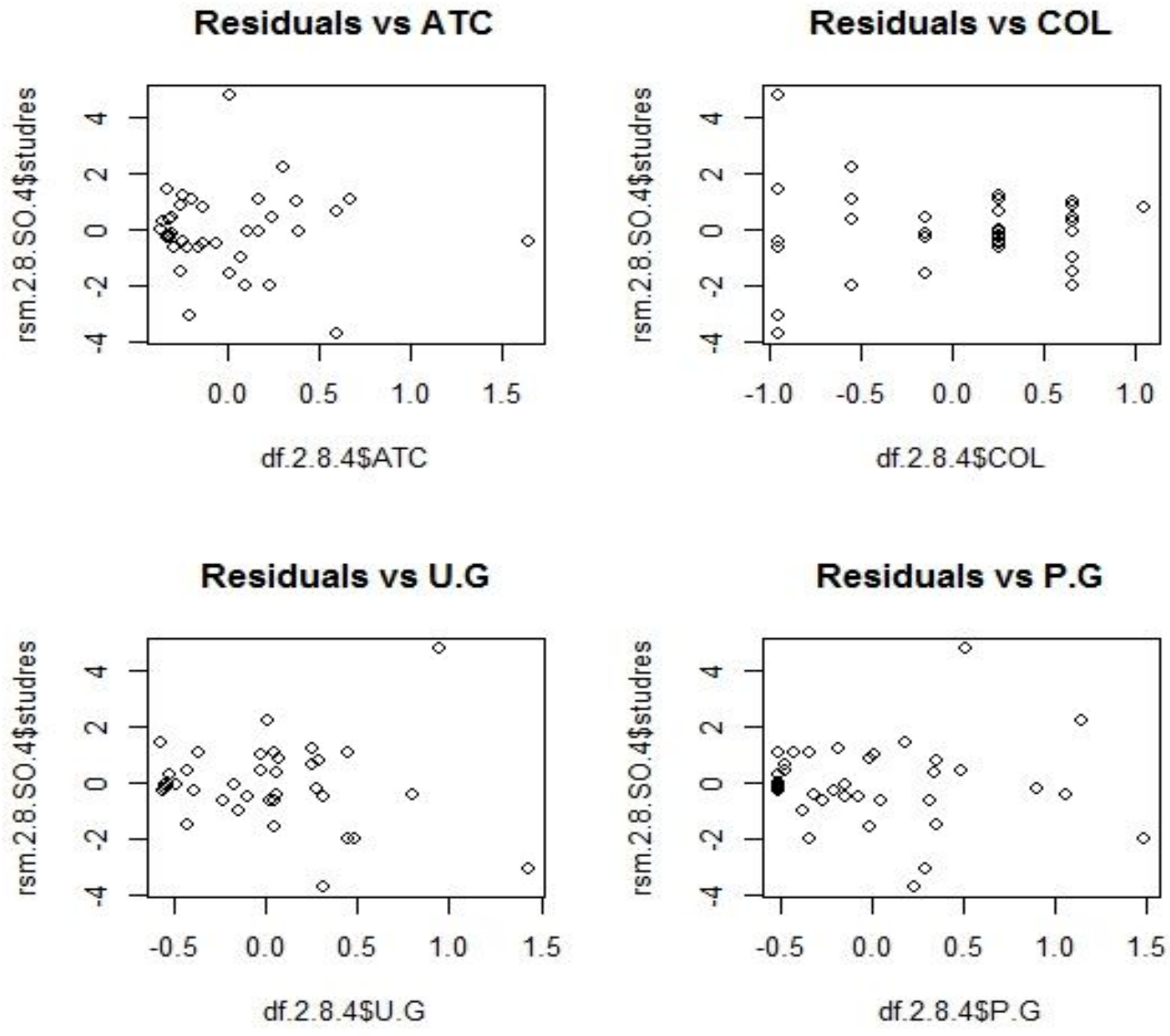

Figure 1: Residuals Plot of ATC, COL, UG, and PG

The diagnostics and plots of estimated response surfaces in Figure 1 displays the random pattern residuals plot of numbers of articles, numbers of undergraduate project and postgraduate, which

it is an indication for a good fit of linear model while collaboration residual plot shows a nonrandom pattern, which it is an indication for a nonlinear model.

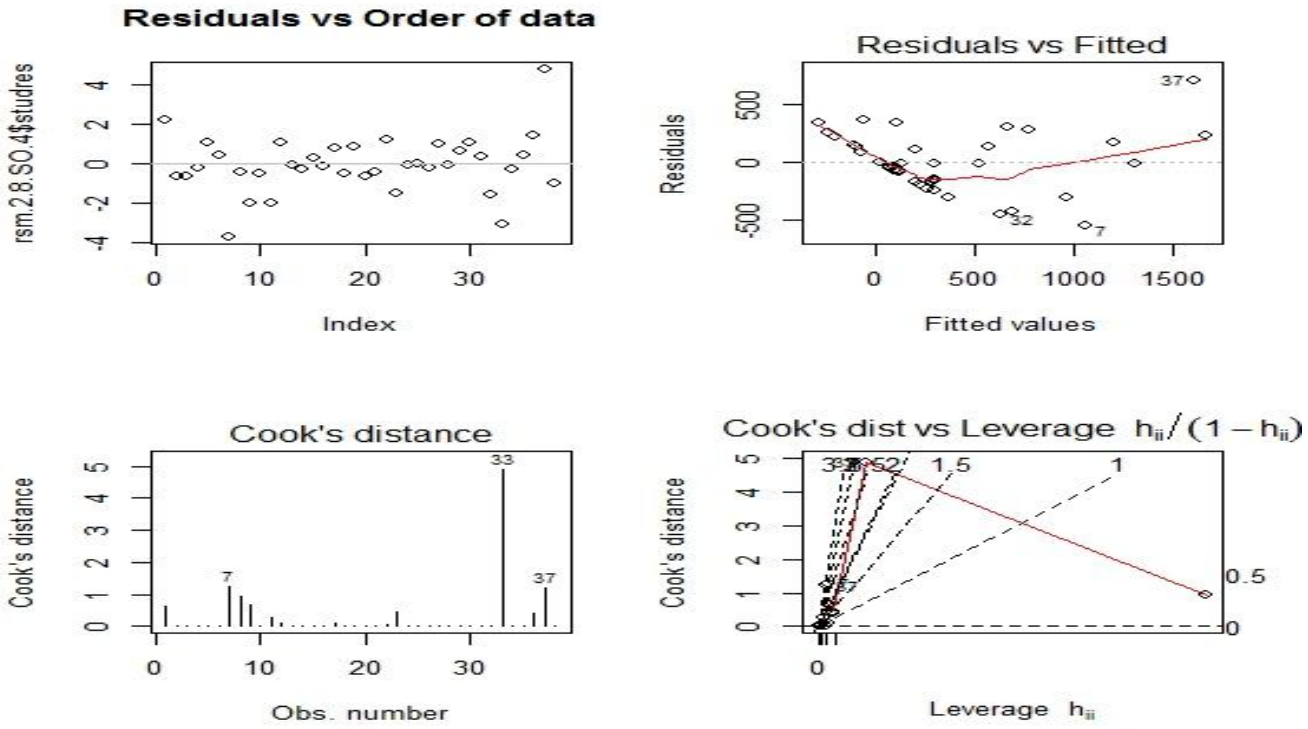

Figure 2: Residuals vs. order of data

The random pattern of residuals against order of data plot and residual against. fitted plot presented in Figure. It also displays cooks' distance of observation which need to be investigated by having higher number of outliers in the fitted model.

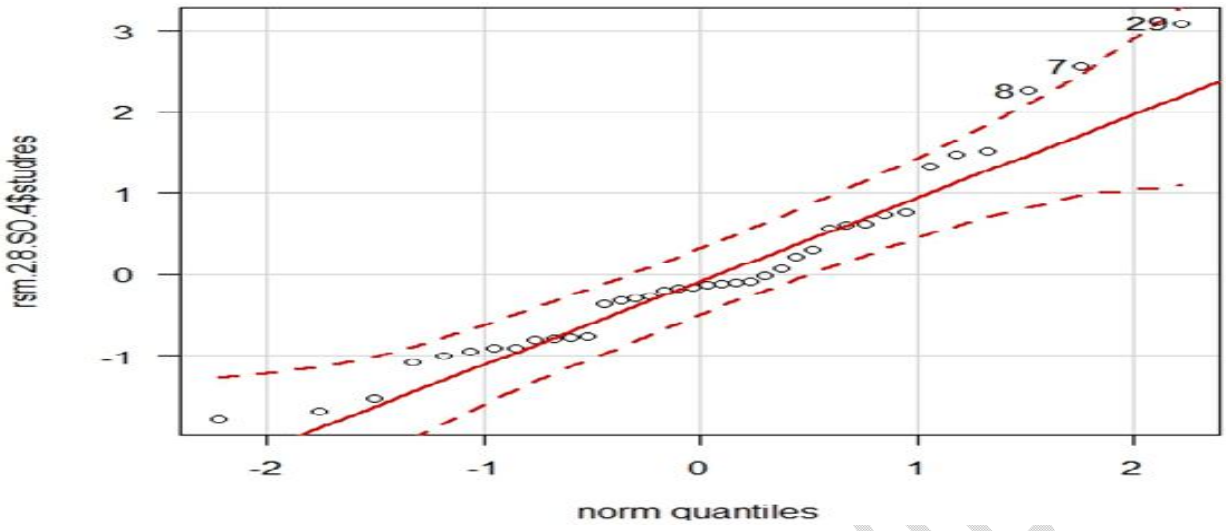

Figure 3: Normality of Residuals

Figure 3 displays quantiles-quantiles plot, this plot shows that residuals are normally distributed.

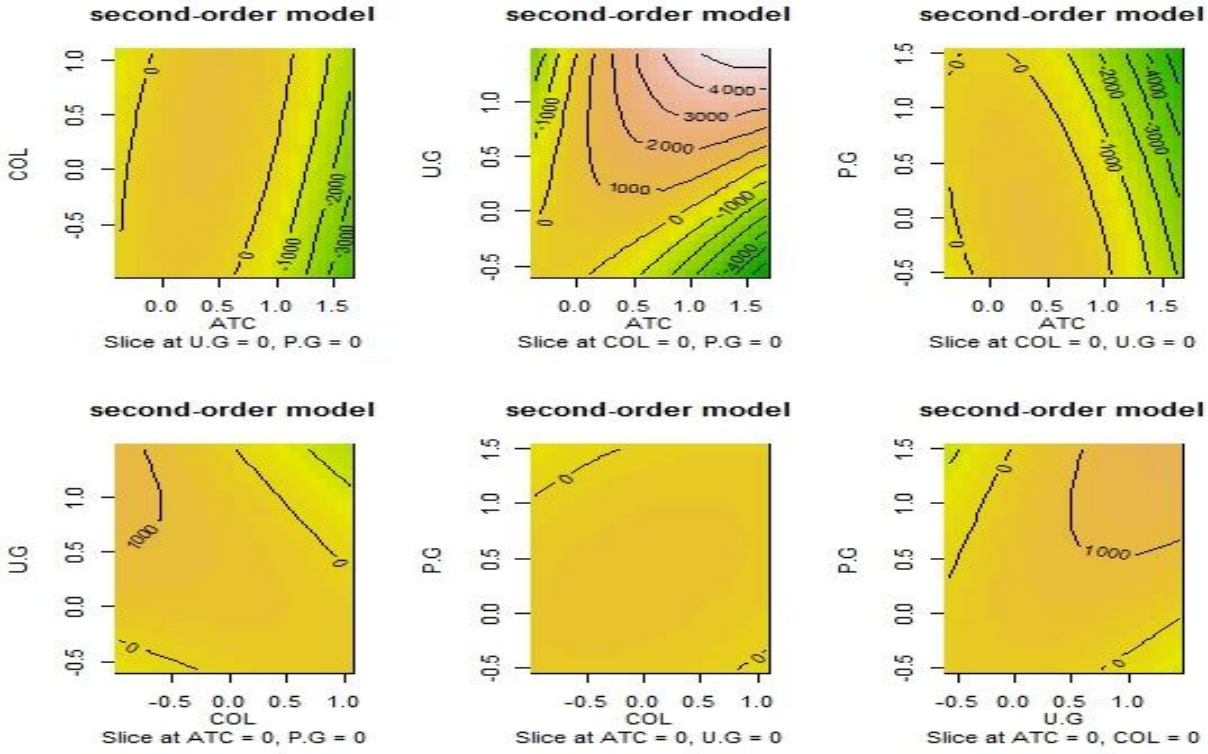

Figure 4: Contour plot illustrating a surface with a maximum among the indicator's interaction

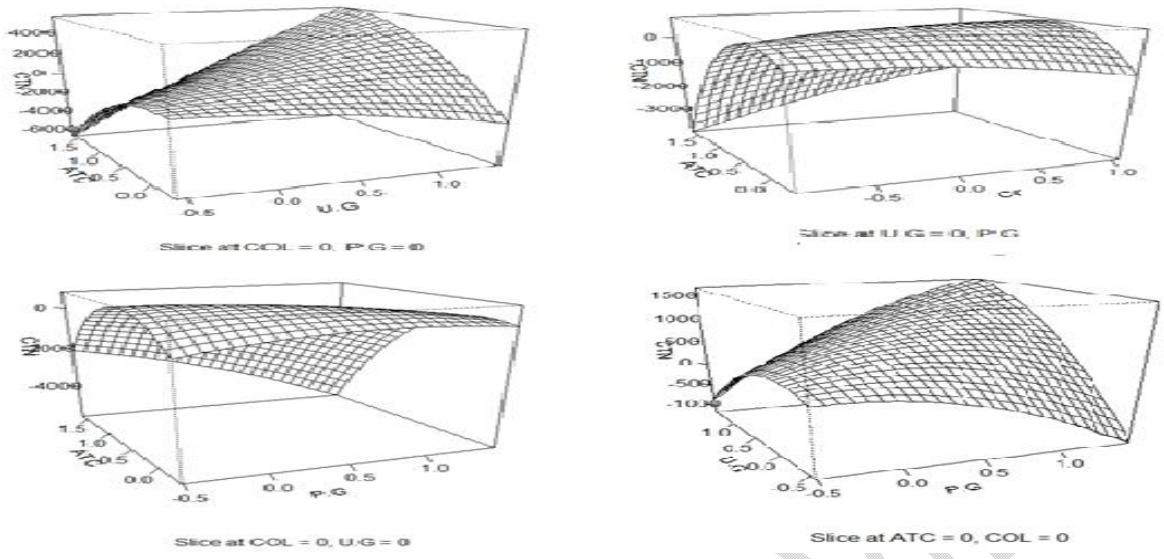

Figure 5: Response surface illustrating a surface with a maximum among the indicator's interaction

4.0 Discussion

This work explores the possibility of the response surface methodology with the scope of analyzing the effect of selected university ranking indicators which constitute the numbers of publication and citations, which bring about quality research output of the institution.

The synergy effect of individual coefficient of human resources and collaboration, human resources and fund, human resources and facility and collaboration and fund were found to be significant in the second other linear model with interaction, on factor contributing to number of publication while first order model and pure quadratic effect are negligible (not significant). Also, the analysis of variance of second first order model on publication shows that first order model predictor variables (H.R, COL, FD, FAC) have an additive effect on the response variable (publication), the interaction effect of the model also contribute to the number of publication while the model shows no indication of pure quadratic effect, that is, not significant in the model.

The synergy effect of articles and collaboration coefficient was found significant along with all first order indicators ATC, COL, UG, P.G and quadratic effect of ATC while all other factor coefficient contribution were negligible and not significant to the number of citations received. Also, analysis of variance of second first order model on citation shows that all the sources of variation that is. first order, two-way interaction and pure quadratic effect were all significant and has effect in contributing to the number of citations.

Conclusion

The analysis of full factorial experiment on factor affecting numbers of publication in FUT Minna shows a significant interaction/synergy effect between the coefficient of H.R*COL and H.R*FD, H.R*FAC and between COL*FD. Also, the contour plot and response surface plot illustrated a surface with a maximum (high number of publication) when the indicators interact together.

The analysis of full factorial experiment on factor affecting number of citations received on publication showed a significant contribution of interaction of articles and collaboration, and also present that the undergraduate and post graduate project is not negligible in contributing to the number of citations.

Also, the analysis of variance of second first order model on citation shows that effect of each first order model, two-way interaction and pure quadratic effect on citation were also significant. The goodness of fit of the response surface model confirmed acceptable with value of coefficient of determination $R^2 = 0.7$ and adjusted R-square $Q^2 = 0.5$. On the other hand, the F-test confirmed also that the fit is satisfactory at the significance level of 5%.

Recommendations

Based on the analysis, it was suggested that the following recommendation should be implemented:

i. There should be an encouragement of research collaboration among the university researchers, because the highest citation is reached only in department of groups with high production and more collaboration.

ii. Money should be injected more into research. If there could be enough funds for research work with maximum numbers human resources, it will maximize research output of the departments.

iii. There should be provision for more facilities in the departments to help researchers in their research work so as to elevate research output to maximum.

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