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Response Surface Optimization of Production Mix of selected Raw Materials for Plastic Production

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Authors' contributions

This work was carried out in collaboration between all authors. Authors OPC and CJL designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors OBS and NEC managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Practically, it is not viable to obtain the optimization of production mixture of the raw material for high recital and quality which is subject to numerous performance controls by trial and error through the normal process can be a extremely tricky task and time intense. This leads to the development of statistical experiment design and analysis particularly for the purpose of optimizing mixes, like the plastic products, in which the final product properties does not depend on their absolute quantities but on the virtual proportions of the mechanism. Mixture methods have been of little application in the plastic industry even though they have been used to inflate products like gasoline, metal alloys, foods and detergents in industries. An examination in which a statistical mixture design tool called response surface design optimization tool was explained in this work where it is used to optimize the six mixture components of 32 mm plastic pressure pipe, in order to achieve

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the best mixture ratio and their corresponding product yield. The results also showed an optimal mixture ratio of stabilizer (0.0001), PVC (14010.43), Carbonate (377.520), Titanium (1.4337), Steric acid (2265.110), and pigment (1.4337) for 32 mm pressure pipe. The optimal yield and composite desirability for the 32 mm pressure pipe are 79960 kg and 0.99951 respectively. The result showed an increase in profitability of the final products by reducing the wastage of raw materials. The proposed model is recommended to the case company for effective utilization of their various raw material mixtures so as to realize their various production yields and optimal solution of their raw material mixture.

Keywords: Louis carter; optimization; response surface; plastic production; production mixture; raw materials.

1. INTRODUCTION

There has been a significant increase in the world population these last few decades thereby causing a considerable increase in demand for low cost living condition and these has lead to a tremendous increase in plastic usage. The international annual production of plastics is over hundred million ton per year according to the past statistics [1]. There has been a high competition among plastic manufacturers in Nigeria in such that the product mixture ratio must be competent for any of the individual industry to live to tell the tale and make profit. Thus, plastic industries have rapidly grown in Nigeria over the years but like any other industry in excess of the globe, they are faced by means of shortage of production input/manpower leading to low capacity consumption and as a result of low outputs. In the meantime, an economy can only develop if managing decisions [2] at the firm stage outcome is boosted production through output maximization climaxing in increased production in the actual sector by well-organized information of the raw material mixture [3]. Hence, firm managers are looking for the right resolutions always in command to meet their objectives function [2]; which is how best to amplify profit and this can only result as soon as the right mixture ratio of the raw material provides a maximum quantity of the product [4]. This needs waste reduction either at the raw material level or at the completed product level but can only be attained when complete information of the precise quantity of the product to be achieved from an agreed quantity of the raw material mixture is identified.

There is pressure on management by the industrial growth to find the best scheduling, systematized, and effective levels of production in the range of productive industries of the economy [5]. Base on this pressure, administrative assumption of the firm are set up to analyze business environment and to resolve practical business problems such as operational problems arising from inside the industry [6], and environmental problems within the industry operates from. To analyze these decision problems, theoretical and quantitative techniques are developed, which includes the response surface design and its optimization tool, which employed mathematical method [7] if an accurate knowledge of the exact quantity of products towards a given period of time from a specified quantity of raw material mixture input over a set period of time.

One of the upcoming plastics industries in Nigeria is Louis Carter plastic industry limited (LCPI). The toil inside the market of diverse plastic product like extrusion product for both domestic and industrial utilize, sales of their product carry a burly seasonality outcome. Throughout the dry period be the peak, and rainy period be the period of building stock (inventory). There is no production to stock that occurs without an explicit manufacturing influence from customers (the products are customer linked). Thus, it is expected to be achieved from a given quantity of raw material mixture in order to be able to act in response to customers' requirements when needed and also raw material mix optimization is achieved.

This research work aimed towards investigate production quantity of LCPI limited, to establish the possibility of adopting response surface design and its optimization tool in formative the quantity of products to contain produced over a known period of time from a given quantity of raw material mixture that they have put in. Nnewi in Anambra state, Nigeria is one of the most industrialized communities in Anambra state because of its strategic location with a cluster of industries and, therefore houses most of the industries and LCPI limited is one of them. The choice of response surface design and its optimization tool is informed by the capacity of the techniques to solve problems relating to quantity of products to be achieved by a given quantity of raw material mix over a given period of time, it is in a better position to determine waste over that period of time. This work is aimed at optimizing the production quantity of products from a given quantity of raw material mixture, determining the accurate mixture ratio of the respective components of the raw material to be mixed in order to give optimum production.

2. RESEARCH METHODOLOGY

2.1 Data Collection and Regression Model

The production mixture data of Louis carter Plastic Industry Limited were collected. Regression analysis was used to statistically investigate the relationships between variables. Regression analysis is widely used for prediction and forecasting, where its use has substantial overlap with the field of machine learning. Regression analysis was used to correlate among the independent variables and dependent variable, and to explore the forms of these relationships. In restricted circumstances, regression analysis can be used to infer causal relationships between the independent and dependent variables. Though this can guide to illusions or false relationships, so caution is advisable; [8] for instance, correlation does not imply causation.

Many techniques for carrying out regression analysis have been developed. Familiar methods such as linear regression and ordinary least squares regression are parametric, in that the regression function is defined in terms of a finite number of unknown parameters that are estimated from the data.

Nonparametric regression refers to techniques that allow the regression function to lie in a specified set of functions, which may be infinite-dimensional. The performance of regression analysis methods in practice depends on the form of the data generating process, and how it relates to the regression approach being used. Since the true form of the data-generating process is generally not known, regression analysis often depends to some extent on making assumptions about this process. These assumptions are sometimes testable if a sufficient quantity of data is available. Regression models for prediction [9] are often useful even when the assumptions are moderately violated, although they may not perform optimally. However, in many applications, especially with small effects or questions of causality based on observational data, regression methods can give misleading results [5,10].

Regression models involve the following variables: The unknown parameters, denoted as β , which may represent a scalar or a vector.

The independent variables, X.

The dependent variable, Y.

In various fields of application, different terminologies are used in place of dependent and independent variables. A regression model relates Y to a function of X and β.

$$Y \approx f(X,\beta) \tag{1}$$

The approximation is usually formalized as E.

(Y | X) = f(X, β). To carry out regression analysis, the form of the function f must be specified. Sometimes the form of this function is based on knowledge about the relationship between Y and X that does not rely on the data. If no such knowledge is available, a flexible or convenient form for f is chosen.

Assume now that the vector of unknown parameters β is of length k .In order to perform a regression analysis the user must provide information about the dependent variable Y: If N data points of the form (Y, X) are observed, where $N < k$, most classical approaches to regression analysis cannot be performed: since the system of equations defining the regression model is underdetermined, there are not enough data to recover β. If exactly $N = k$ data points are observed, and the function f is linear, the equations $Y = f(X, \beta)$ can be solved exactly rather than approximately. This reduces to solving a set of N equations with N unknowns (the elements of β), which has a unique solution as long as the X are linearly independent. If f is nonlinear, a solution may not exist, or many solutions may exist. The most common situation is where $N > k$ data points are observed. In this case, there is enough information in the data to estimate a unique value for β that best fits the data in some sense, and the regression model when applied to the data can be viewed as an over determined system in β. In the last case, the regression analysis provides the tools for: (i) Finding a solution for unknown parameters β that will, for example, minimize the distance between the measured and predicted values of the dependent variable Y (also known as method of least squares), and (ii) Under certain statistical assumptions, the regression analysis uses the surplus of information to provide statistical information about the unknown parameters β and predictors predicted values of the dependent variable Y.

2.2 Response Surface Methodology

Response surface methodology is an empirical statistical approach for modeling problems in which several variables influence a response of interest. In RSM, an approximate relation between a single response and multiple variables is modeled as a polynomial equation obtained through regression analysis. The equation is called a response surface and is generally represented graphically on a contour plot for analyzing an optimal solution. Usually, a low-order polynomial in some regions of variables is used [11]. Assume that *y* denotes the response and *xg* denotes the variables, $g = 1,\ldots, N$. When a linear function of variables can effectively model a response, then the response surface is a first-order model, as follows.

$$\hat{Y} = \hat{\beta}_o + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \cdots + \hat{\beta}_N X_N \quad (2)$$

where g is the regression coefficients, $g = 1, \ldots, N$.

When specifying curvature of a response surface, a polynomial of a high order is appropriate for the response surface. For instance, a second-order model of the response surface is

$$\hat{Y} = \hat{\beta}_o + \sum_{g=1}^{N} \hat{\beta}_{gg} X_g^2 + \sum_{g<f} \sum \hat{\beta}_{gf}\, X_g X_f \quad (3)$$

The fitted response surface is an adequate approximation of the true response function when an appropriate model is selected. Furthermore, model parameters are estimated effectively when proper experimental designs are used to obtain experimental data. Details of experimental designs for fitting response surfaces are found in [11,12].

3. DATA PRESENTATION

3.1 Method of Data Analysis

Response Surface Methodology was used to model and design, while optimization methods was used to optimize the production mixture of Louis Carter manufacturing industry to observe the optimum production output of the raw materials.

Table 1. Presentation of 2009-2010 monthly data on production output

Year	Month	M. units	32 mm pressure pipe (units)
2008	Jan	1	0
	Feb	2	46,461.00
	Mar	3	31,088.00
	April	4	7,158.00
	May	5	37,333.00
	June	6	48,429.00
	July	7	38,224.00
	Aug	8	73,043.00
	Sept	9	61,579.00
	Oct	10	70,311.00
	Nov	11	55192.00
	Dec	12	65016
2009	Jan	13	89,331.00
	Feb	14	92,197.00
	Mar	15	44,739.00
	April	16	30,697.00
	May	17	40,537.00
	June	18	58,965.00
	July	19	82,225.00
	Aug	20	98,665.00
	Sept	21	60,565.00
	Oct	22	50,987.00
	Nov	23	66,334.00
	Dec	24	0

Source: Louis Carter grouped data: X_1= 32 mm Pressure pipe, and X_2= 25 mm Waste pipe

4. DATA ANALYSIS AND DISCUSSION

4.1 Response Surface Regression Model: 32 mm Pressure Pipe Versus PVC, Stabilizer, ...

Table 2 presents the Response Surface Regression Model for 2008-2009 monthly data on production output of 32 mm pressure pipe versus PVC, Stabilizer, etc.

Table 2. Presentation of 2008-2009 monthly data on production output of 32 mm pressure pipe

32 mm pressure pipe (units)	32 mm pressure pipe (1.2 kg each)	PVC	Stabilizer	Calcium carbonate	Steric acid	Titanium dioxide	Pigment
0	0	0	0	0	0	0	0
5498	6597.462	5333.15	177.7717	1066.63	17.77717	1.422173	0.711087
3679	4414.496	3568.519	118.9506	713.7038	11.89506	0.951605	0.475803
847	1016.436	821.6501	27.38834	164.33	2.738834	0.219107	0.109553
4418	5301.286	4285.368	142.8456	857.0736	14.28456	1.142765	0.571382
5731	6876.918	5559.052	185.3017	1111.81	18.53017	1.482414	0.741207
4523	5427.808	4387.644	146.2548	877.5288	14.62548	1.170038	0.585019
8643	10372.11	8384.436	279.4812	1676.887	27.94812	2.23585	1.117925
7287	8744.218	7068.51	235.617	1413.702	23.5617	1.884936	0.942468
8320	9984.162	8070.836	269.0279	1614.167	26.90279	2.152223	1.076111
6531	7837.264	6335.361	211.1787	1267.072	21.11787	1.68943	0.844715
7694	9232.272	7463.035	248.7678	1492.607	24.87678	1.990143	0.995071
10571	12685	10254.1	341.8032	2050.819	34.18032	2.734426	1.367213
10910	13091.97	10583.08	352.7693	2116.616	35.27693	2.822154	1.411077
5294	6352.938	5135.486	171.1829	1027.097	17.11829	1.369463	0.684731
3632	4358.974	3523.637	117.4546	704.7274	11.74546	0.939637	0.469818
4797	5756.254	4653.148	155.1049	930.6296	15.51049	1.240839	0.62042
6978	8373.03	6768.455	225.6152	1353.691	22.56152	1.804921	0.902461
97210	11675.95	9438.416	314.6139	1887.683	31.46139	2.516911	1.258455
11675	14010.43	11325.53	377.5175	2265.105	37.75175	3.02014	1.51007
7167	8600.23	6952.115	231.7372	1390.423	23.17372	1.853897	0.926949
6033	7240.154	5852.679	195.0893	1170.536	19.50893	1.560714	0.780357
78410	9419.428	7614.325	253.8108	1522.865	25.38108	2.030487	1.015243
0	0	0	0	0	0	0	0

Source: Louis Carter grouped data

Table 3. Estimated regression coefficients for 32 mm pressure pipe (kg)

Term	Coef	SE Coef	T	P
Constant	49333	0	1657624.684	0.000
PVC	30425	7354	4.137	0.009
Stabilizer	19981	9020	2.215	0.078
Calcium carbonate	1144	793	1.443	0.209
Steric acid	-2103	2917	-0.721	0.503
Titanium dioxide	-129	252	-0.510	0.632
Pigment	14	33	0.428	0.686
PVC*PVC	-1914196	1836880	-1.042	0.345
Stabilizer*Stabilizer	-1115313	1458640	-0.765	0.479
Calcium Carbonate*Calcium Carbonate	1678741	1595078	1.052	0.341
Steric acid*Steric acid	1415124	1439362	0.983	0.371
Titanium dioxide*Titanium dioxide	149614	576460	0.260	0.806
Pigment*Pigment	3830	5127	0.747	0.489
PVC*Titanium dioxide	3846849	3669188	1.048	0.342
Stabilizer*Pigment	2219326	2915195	0.761	0.481
Calcium Carbonate*Titanium dioxide	-4056978	3363770	-1.206	0.282
Calcium Carbonate*Pigment	702331	397640	1.766	0.138
Steric acid*Pigment	-2840356	2872132	-0.989	0.368
Titanium dioxide*Pigment	-88972	153810	-0.578	0.588

S = 0.0113596
PRESS = 0.0140103
R-Sq = 100.00%
R-Sq(pred) = 100.00%
R-Sq(adj) = 100.00%

$$32 \text{ mm Pressure pipe (kg)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 {X_1}^2 + \beta_8 {X_2}^2 + \beta_9 {X_3}^2 + \beta_{10} {X_4}^2 + \beta_{11} {X_5}^2 + \beta_{12} {X_6}^2 + \beta_{13} X_1 X_5 + \beta_{14} X_2 X_6 + \beta_{15} X_3 X_5 + \beta_{16} X_3 X_6 + \beta_{17} X_4 X_6 + \beta_{18} X_5 X_6 \quad (4)$$

PVC = X_1
Stabilizer = X_2
Calcium Carbonate = X_3
Steric acid = X_4
Titanium dioxide = X_5
Pigment = X_6
Constant = β_0
Coefficient = β

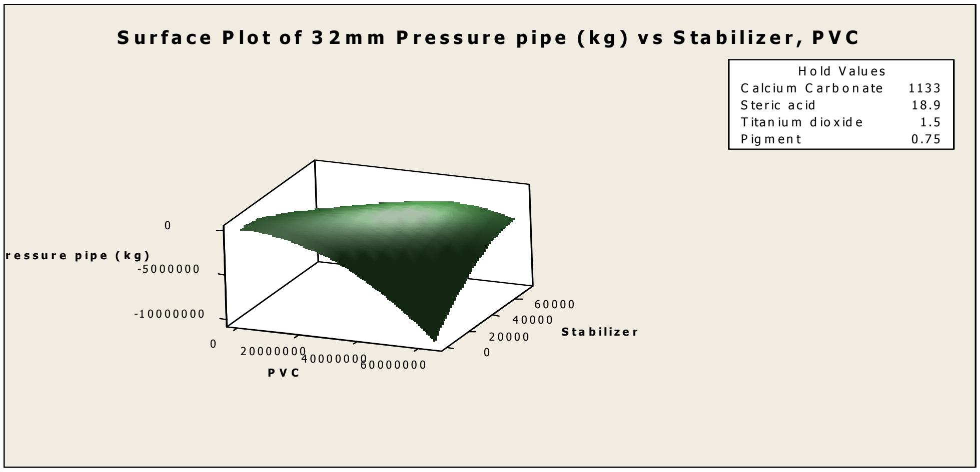

Figure 1. Surface plot of 32 mm pressure pipe (kg) vs stabilizer, PVC

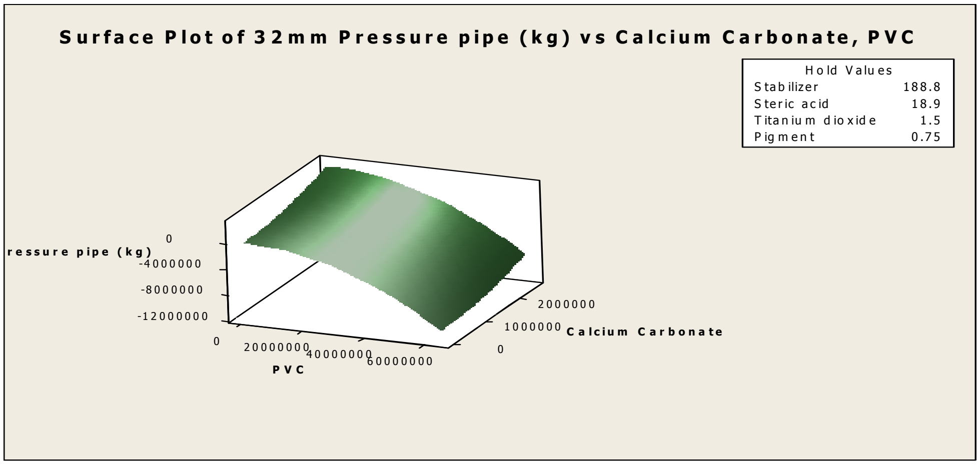

Figure 2. Surface plot of 32 mm pressure pipe (kg) vs calcium carbonate, PVC

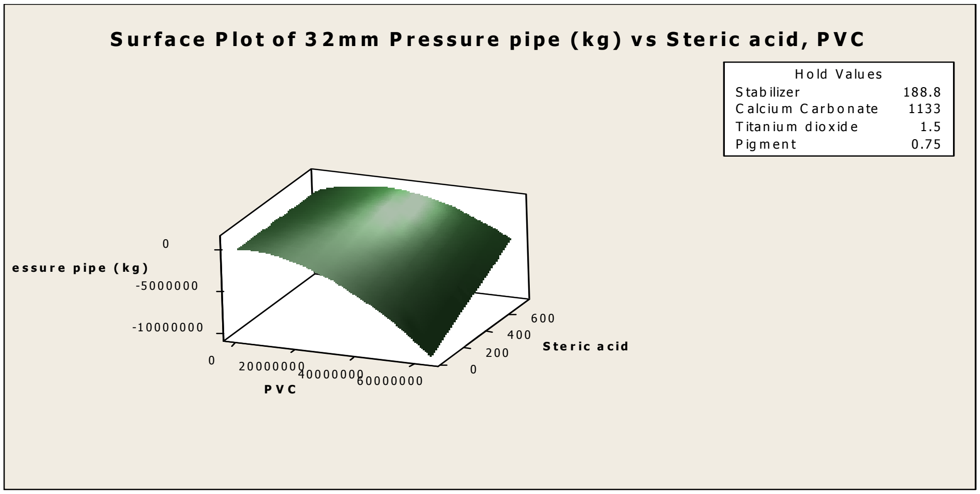

Figure 3. Surface plot of 32 mm pressure pipe (kg) vs Steric acid, PVC

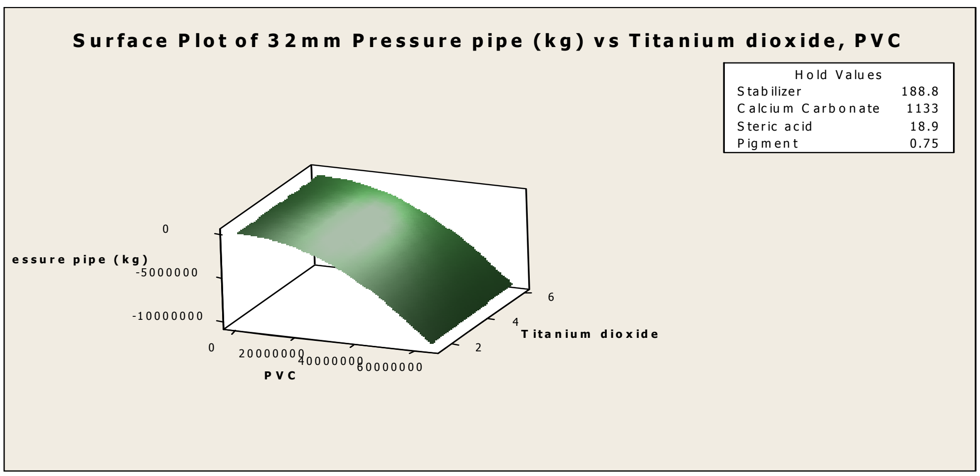

Figure 4. Surface plot of 32 mm pressure pipe (kg) vs Titanium dioxide, PVC

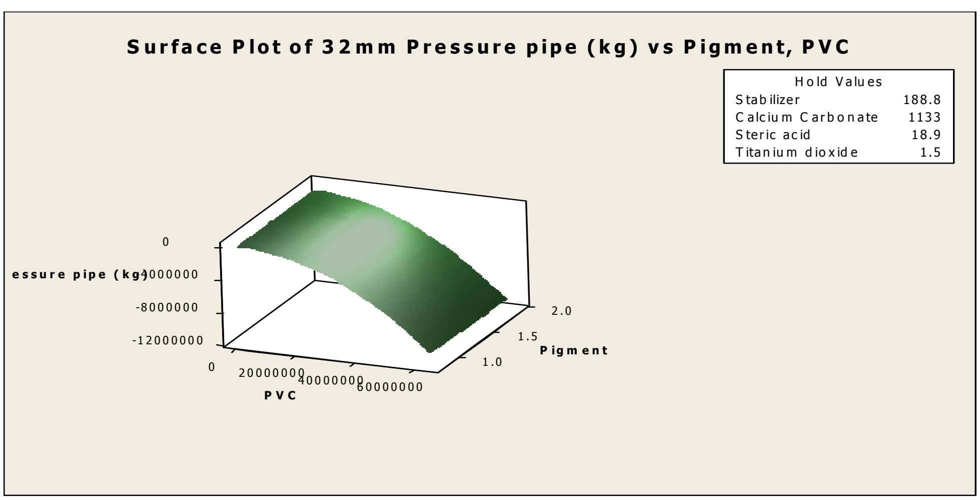

Figure 5. Surface plot of 32 mm pressure pipe (kg) vs pigment, PVC

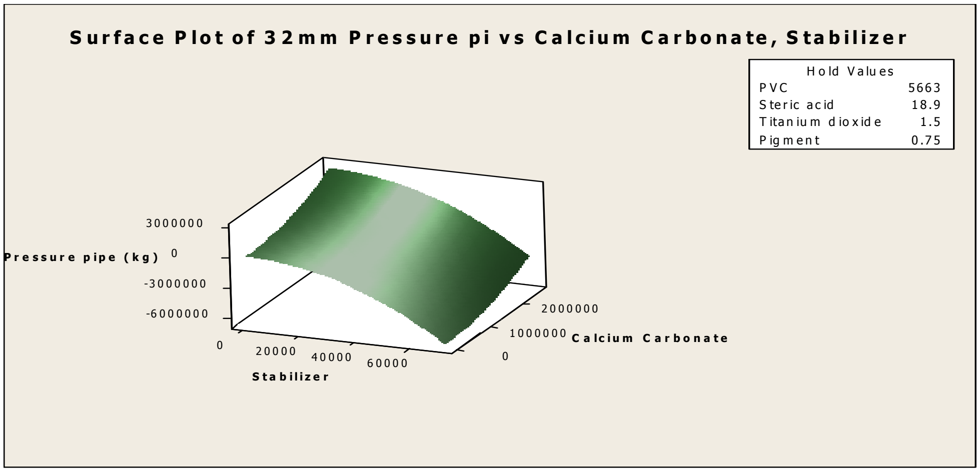

Figure 6. Surface plot of 32 mm pressure pipe (kg) vs calcium carbonate, stabilizer

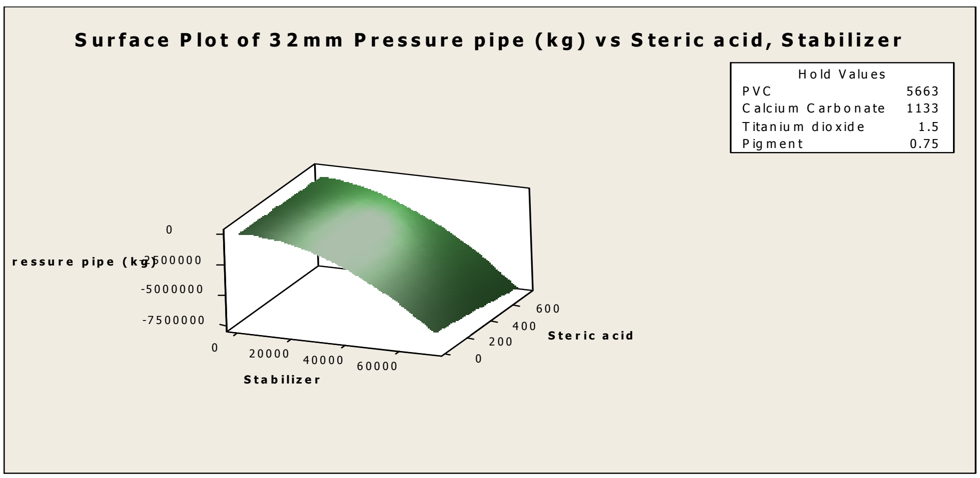

Figure 7. Surface plot of 32 mm pressure pipe (kg) vs Steric acid, stabilizer

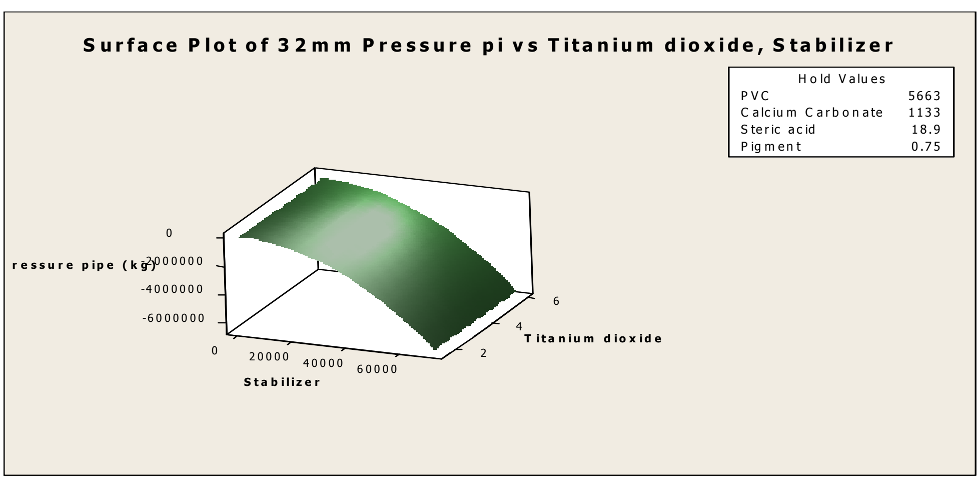

Figure 8. Surface plot of 32 mm pressure pipe (kg) vs Titanium dioxide, stabilizer

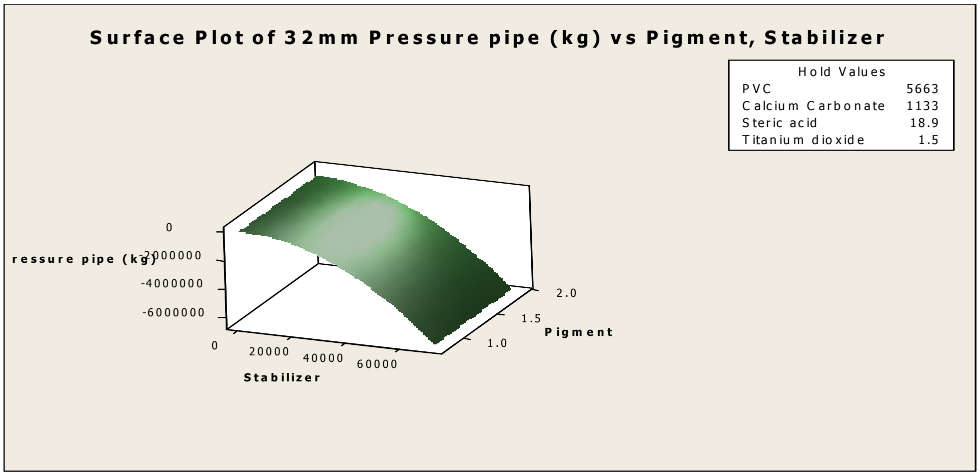

Figure 9. Surface plot of 32 mm pressure pipe (kg) vs pigment, Stabilizer

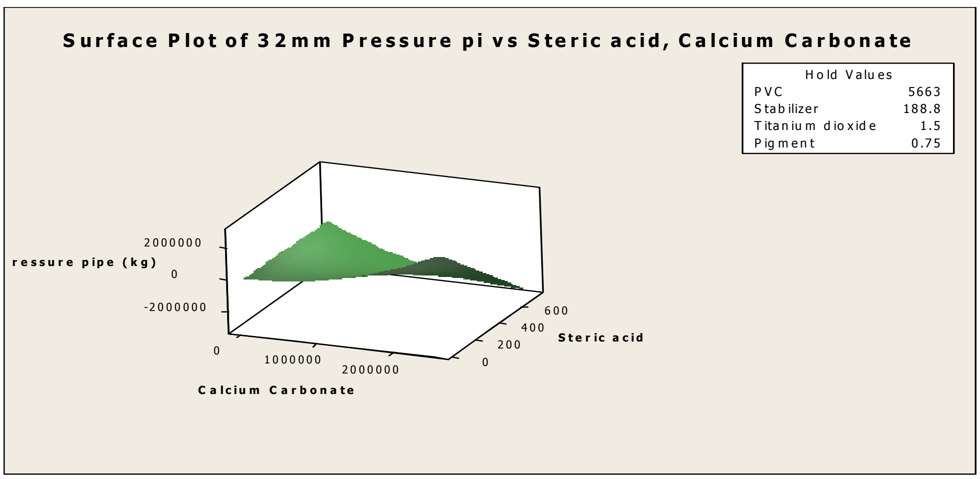

Figure 10. Surface plot of 32 mm pressure pipe (kg) vs Steric acid, calcium carbonate

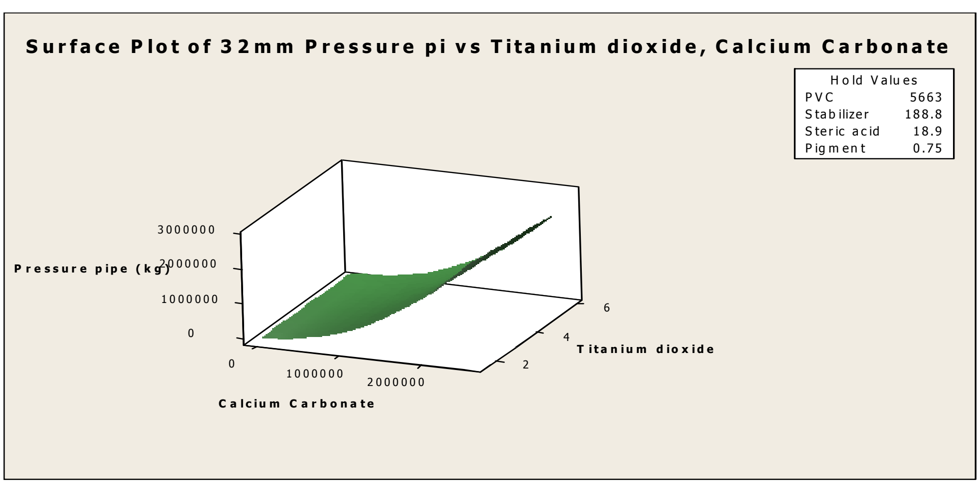

Figure 11. Surface plot of 32 mm pressure pipe (kg) vs Titanium dioxide, calcium carbonate

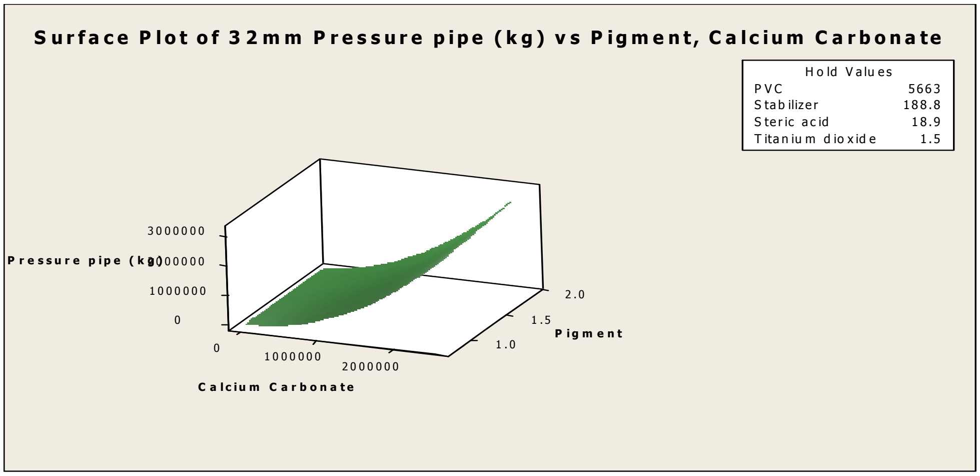

Figure 12. Surface plot of 32 mm pressure pipe (kg) vs pigment, calcium carbonate

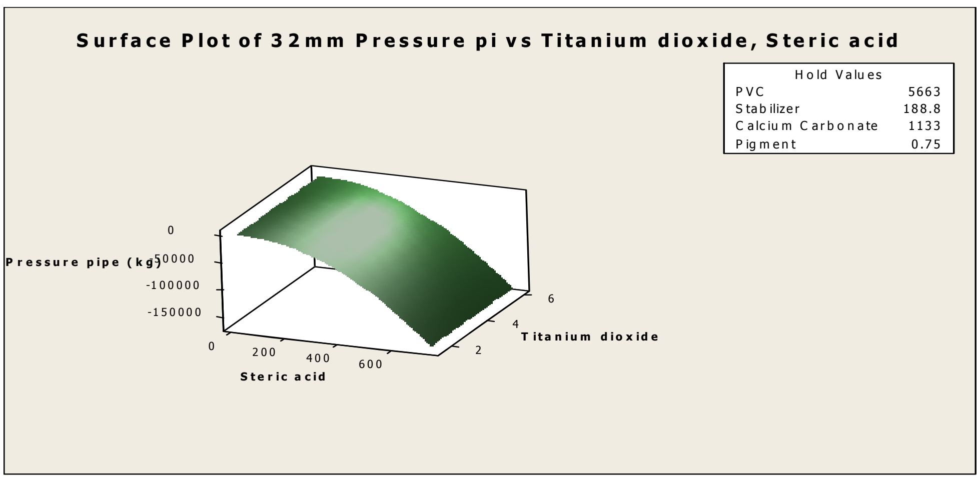

Figure 13. Surface plot of 32 mm pressure pipe(kg) vs Titanium dioxide, Steric acid

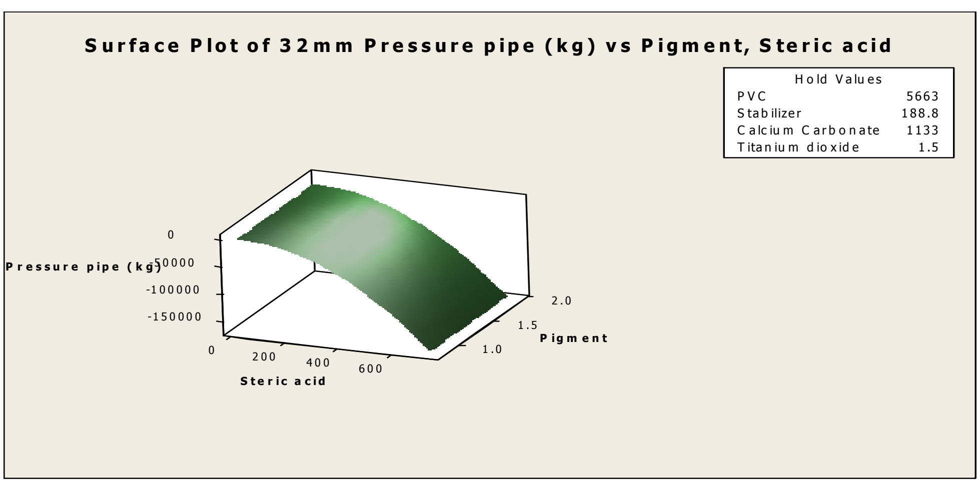

Figure 14. Surface plot of 32 mm pressure pipe (kg) vs pigment, Steric acid

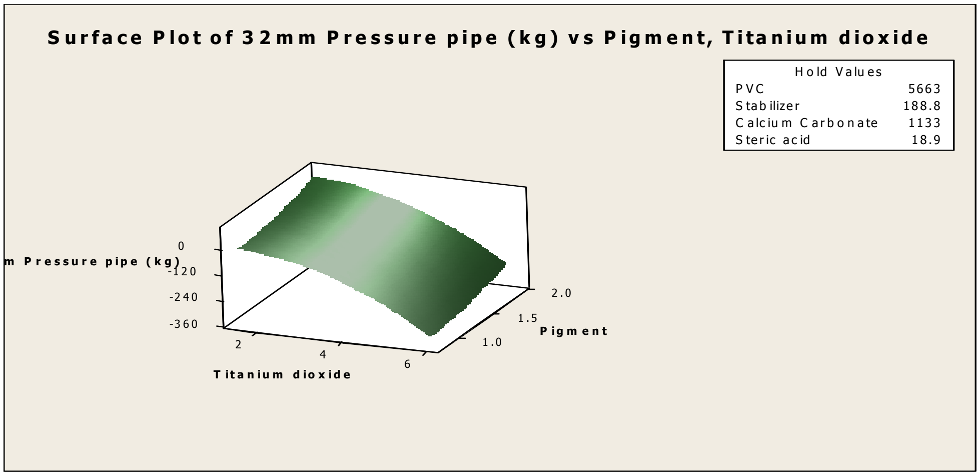

Figure 15. Surface plot of 32 mm pressure pipe (kg) vs pigment, titanium dioxide

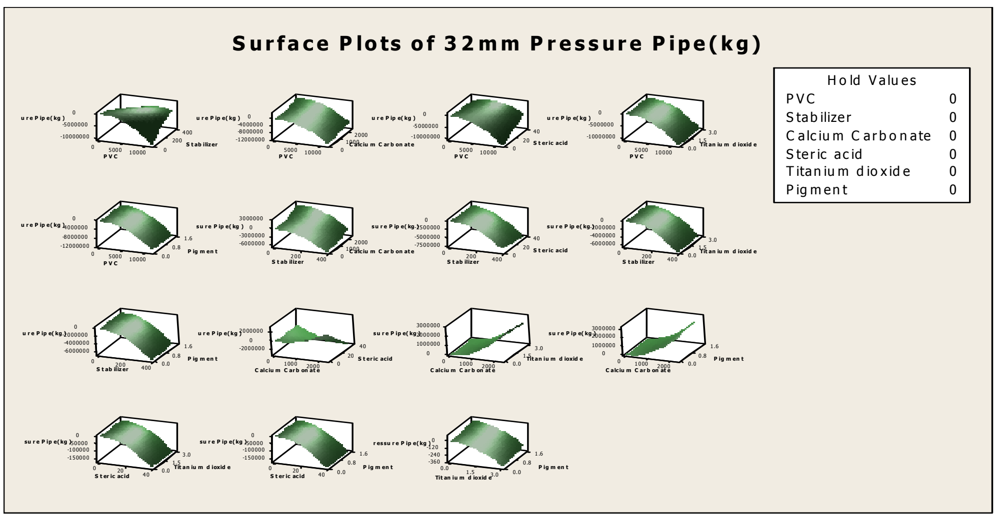

Figure 16. Surface plots of 32 mm pressure pipe (kg)

Table 3. Local solutions

S/n	PVC	Stablizer	Calcium carbonate	Steric acid	Titanium dioxide	Pigment
1	14010.4	0.0000626	377.52	2265.11	37.75	1.43374
2	14010.4	0	377.52	2265.10	37.6204	0.0954751
3	14010.4	11325.5	377.520	2265.11	37.7498	3.01939
4	14010.4	11325.5	377.52	2265.10	37.5856	0.121127
5	7005.22	5662.77	188.76	1132.56	18.875	1.51001
6	0.0000352	11325.5	0.172450	0	0	3.02
7	0.0000327	11325.5	0.0007029	0.0006424	0.0000605	0.0021735
8	0.0000902	0.0003169	0.441434	0	0	3.02
9	0.156263	0.548765	0	1.65996	0	3.02
10	0	0.0000415	0.0000365	2265.11	0.0000347	1.22298
11	0.0000726	11325.5	0.0000266	2265.11	0.0000357	1.25839
12	14010.4	0	377.520	0.0017509	37.75	1.68494
13	14010.4	11325.5	377.520	0.0017973	37.75	1.64954
14	14010.4	0.0000626	377.52	2265.11	37.75	1.43374

4.2 Response Optimization

Parameters						
32mm Pressure Pipe	Goal Target	Lower 1000	Target 80000	Upper 200000	Weight 1	Import 1

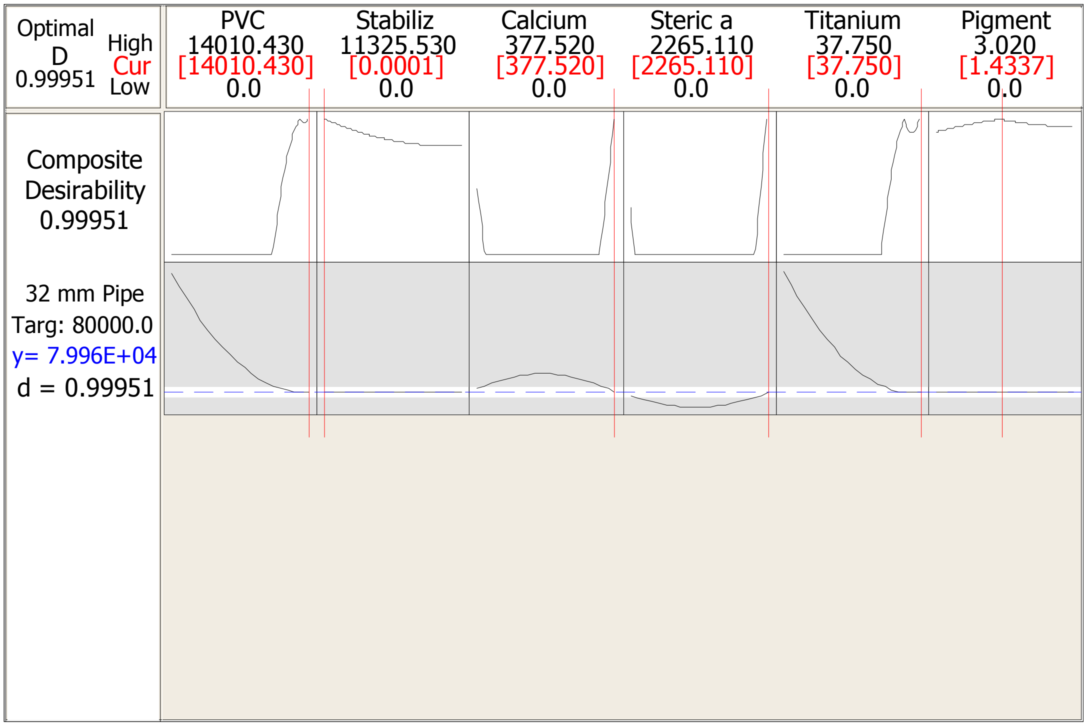

Figure 17. Optimization plot

Table 4. Predicted responses

S/N	32 mm waste pipe	Desirability	Composite desirability
1	79961.6	0.999514	0.999514
2	88587.1	0.928441	0.928441
3	98665.0	0.844458	0.844458
4	110911	0.742412	0.742412
5	49332.5	0.611804	0.611804
6	39899.9	0.492404	0.492404
7	23019.0	0.278721	0.278721
8	18631.9	0.223189	0.223189
9	14345.8	0.168934	0.168934
10	190572	0.078568	0.078568
11	190723	0.077309	0.077309
12	191065	0.074457	0.074457
13	191230	0.073085	0.073085
14	79961.6	0.999514	0.999514

The results show the optimal production mix of the raw materials in the selected products. Response surface model was used to show the optimal production of the products over the months. From this model, there is a good connection among the dependent variables and the independent variables and the coefficient of the relationship of the models (R-sq) is 100%. Also it shows from the surface plot, the relationship between the selected products and two different raw materials. The 32 mm pressure pipe Vs stabilizer, PVC increases the stabilizer and also shows increase in the production, again in the 32 mm pressure pipe Vs steric acid, calcium carbonate shows that increase in the product slightly increases the calcium carbonate, and decreases the steric acid. The optimal solution analysis of the 32 mm pressure pipe shows an optimal production of 79960 kg for the production of the products monthly. If the case study will be watchful of their wasted raw materials during the production, the company can achieve the results. Therefore in order to achieve the optimal of their production mixture for the raw materials, the model is recommended to the case study company for its applicability for the production of their products.

5. CONCLUSION

This study has determined the production mixture of the raw material of LCPI limited for 32 mm pressure pipe successfully. This was achieved using response surface design and its optimization tool. Optimal quantities of the various PVC raw materials are to be mixed within the study period in order to maximize profit were recognized in the process. It's a benefit of going further than mere knowledge of existing decision making tools of using wishful mental analysis to actual practical utilization of good engineering powerful tools in decision making of industries. From the researchers comments in the course of the study, the case study company has a well trained factory manager, skilled in the operation research techniques and also poses a broad understanding of business environment and knowledge of the managerial roles and functions and base on these facts, the firm should rely on him and any contribution made by external researchers to bring this and other techniques to bear on management decision problems. This will solve the issue of how the managerial cadre of the company could employ these techniques in arriving at the objective function of the study, and also in assisting the management, at least, in the short run. Though, in the long run, the case study company would probably gain more from having more permanent employees who can suggest opportunities to make use of these new techniques. There should be people not just one person who can effectively and efficiently understand the results of mathematical analysis in the company's particular context, as well as possess the necessary competence in the utilization of computers for easy handling of the complex mathematical techniques involved.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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