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Optimization of Decision Variables (DVs) in Products Mix of Foams Manufacturing Companies in Gombe State

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OPTIMIZATIONOFDECISIONVARIABLESDVSINPRODUCTSMIXOFFOAMSMANUFACTURINGCOMPANIESINGOMBESTATE

Strictly as per the compliance and regulations of:

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Wirnkar, A. D.

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Keywords: decision variables, product mix, optimum solution quantities, existing solution quantities, foam manufacturing companies, linear programming, sensitivity analysis, excel solver, SPSS.

I. Introduction

The alarming and continuous degenerating state of the Nigerian economy warrants that corporations use resources optimally in attaining their objectives. This is because an organization might have more than one decision variable to utilize in order to attain a particular objective. Decision variables are subject to some constraints (limited resources) necessitating their optimal rationing to attain the best result for the organization. When limited resources are optimized, wastages of resources are kept at minimum, the cost of production is minimized and the profit is maximized. Goh, et al (2014) observed that resources typically include machines, labor, money, time, and raw materials. According to Tatay (2013), one wide field of the quantitative tools that can be applied to support practical management decisions is operations research, which is also called management science or decision science that deals with optimization theory. Tatay (2013) also added that production management decisions can be successfully supported by the results and models of operations research and that, linear programming (LP) is such a holistic decision support tool that can be applied to support operational decision making relating to several functional fields of corporate operation. In addition, Agarana, et al (2014) opined that linear programming is a time-lasted-problem solving approach that enhances decision making of managers especially when certain restrictions or constraints exist which could affect the decision making process. Moreover, they stated that linear programming is a procedure for finding the maximum or minimum of a linear function where the augments are subject to linear constraints; and lastly that the Simplex method, which was first proposed by Dantzig in 1947, is one well known algorithm belonging to this class. Still on the importance of linear programming, Khan, et al (2011) noted that linear programming is a powerful tool for the optimal allocation of scarce resources with the objective of maximization of profit. In practical terms, Dahiya & Verma (2007) opined,

The merits of linear programming are nowadays well established and linear programming is widely accepted as a useful tool in Operations Research and Management Science. A large number of companies are using this way of modeling to solve various kinds of practical problems. Applications include transportation problems, production planning, investment decision problems, blending problems, location and allocation problems, among many others. (p.1).

Still elaborating on the practical application of linear programming (LP), Wiley (2002) observed that: many real world problems lend themselves to LP modeling; many real world problems can be approximated by linear models; and that, LP model has been successfully applied in the following areas: Manufacturing, Marketing, Finance (investment), Advertising and Agriculture. The noble laureate Leonid Kantorovich (USSR) and Tjalling Koopmas (USA) as

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cited by Khan, et al (2011), were awarded for their work on the optimal allocation of resources using the technique of linear programming. Basically, there are two methods for attaining an optimal solution in linear programming, the graphical method and the Simplex method. Khan, et al (2011) stated that the Simplex method is regarded as the most important and credible method that was devised in the mid 20th century and at the moment, it is a benchmark optimizing tool saving thousands and millions of dollars in many organizations.

Dahiya & Verma (2007) stated that most of the packages available for solving linear programming do not only solve the LP problem but also provide the option to ask for information on the sensitivity of the solution to certain changes in the data and referred to this technique as sensitivity analysis or post optimality analysis. Considering the practical application of linear programming models, Tatay (2013) observed that sensitivity analysis can be as important as finding the optimal solution itself because based on sensitivity analysis, results effects of the changes of the environmental factors (prices, costs) on the optimal solution and the probable effects of managerial decisions (changes in the capacity, demand management) can be evaluated.

Foam manufacturing companies in Gombe State produce foams of different types and sizes for sale. From the review of related literature, optimization techniques have been used to appraise the state of operations of some industries for optimality both local and international but little if any in the foam producing companies in Gombe State. The essence of producing optimally in the fast becoming global competitive market cannot be over emphasized but clearly imagined. More so, the degenerating economic reality of the country warrants judicious use of scarce resources more than ever before. It is not understood if foam producing companies in Gombe State apply an optimization technique, a trial and error method or intuitive approach in product planning for profitability objective. In brief, are foams manufacturing companies in Gombe State operating optimally in product mix planning? In addition to the above question, this research will also provide answers to the following questions:

- Do foams manufacturing companies in Gombe State use an optimization model for product-mix planning? If so, which optimization model(s) do they use?
- Are foams manufacturing companies in Gombe State operating optimally?
- Which of the factor(s) of production is/are most limiting foams manufacturing companies in Gombe State from operating optimally?
- How do we mitigate these problems if any and situate foams manufacturing companies in Gombe State to operating optimally?

To attain the main objective of the research, the following hypothesis was tested:

HO_1: There is no significant difference between operating at optimum solution quantity X_i and existing practice quantity X_i

This study will be of benefit to a number of stakeholders: the management, employees, and suppliers of raw materials, customers, creditors, investors, banks, the federal government, and the community at large. Operating optimally ensures survival and sustainability for any company as well as for the various linkages (stakeholders) of the corporation. The study covered a time period of three years (2016 to 2018) of foams manufacturing companies in Gombe State. The remaining part of this research include, literature review, methodology, results, conclusion, recommendations and references

II. Literature Review

A number of people have defined Linear Programming in a number of ways and among them are: Soumendra (2005), Sankheerth, et al (2010) and Wiley (2002). Soumendra (2005) defined LP as, "A minimization problem where we are asked to minimize a given linear function subject to one or more linear inequality constraints. The linear function is also called the objective function."(p.1). Sankheerth, et al (2010) defined LP as, " A mathematical modeling technique useful for the allocation of "scarce or limited" resources such as labour, material, time, warehouse space, etc….., to several competing activities such as product, service, job, new equipments, projects, etc…on the basis of a given criteria of optimality."(p.3). Wiley (2002) defined LP as, "A model that seeks to maximize or minimize a linear function, subject to a set of linear constraints; a model consisting of the following components: a set of decision variables, an objective function and a set of constraints."(p. 2).

A linear programming problem with "n" decision variables and "m" constraints can be mathematically modeled as in (Taha, 1975; Zeleny, 1982; Winston, 1995; Higle and Wallence, 2003) in Khan, et al (2011, p.207) as follows:

$$MAXIMIZE\ Z : C_1X_1 + C_2X_2 + - - - - - + C_nX_n$$
$$S.t$$
$$a_{11}X_1 + a_{12}X_2 + - - - - - - - - - - + a_{1n}X_n \le b_1$$
$$a_{21}X_1 + a_{22}X_2 + - - - - - - - - - - + a_{2n}X_n \le b_2$$
$$- \quad - \quad - \quad -$$
$$- \quad - \quad - \quad -$$
$$- \quad - \quad - \quad -$$
$$a_{n1}X_1 + a_{n2}X_2 + - - - - - - - - - - + a_{mn}X_n \le b_m$$
$$X_1, X_2 - - - - - - - - - - - - - - - - X_n \ge 0$$
$$Max\ Z = C^t x$$
$$S.t.,$$

This can be written as,

$$a_x \le b$$
$$X \ge 0$$

Oladokun and Johnson (2012) applied mathematical optimization techniques to the feed formulation problem of the typical Nigerian poultry farm using locally available feed ingredients and found that the weekly cost of producing layers feed is N47974 using the existing practice of the farm compared with the N43798 if feed formulation is based on the proposed mathematical model. And that this is a substantial savings of about 9%. Igwe, et al (2013) applied linear programming approach to combination of crops, Monogastric Farm Animal and Fish Enterprises in Ohafia Agricultural Zone, Abia State, Nigeria and prescribed 0.29 hectares for yam, 0.02 hectares for cassava and 0.13 hectares for cassava/maize/cocoyam for crop enterprises while 0.14 for 500 birds (70 birds) broiler II done August –December, 0.22 of 1000 fish (220 fish) of fish I done January – June and 0.41 of 500 birds (205) of Layer for the livestock enterprises in the study area to maximize gross margin. The results indicate that optimum plans resulted in an increase in gross margin over the existing plan by 72.90%. This implies that farm resources were not optimally allocated in the existing plan.

Khan, et al (2011) used linear programming and sensitivity analysis to determine the optimal production planning for Ici Pakistan and found the followings; that the company can generate a profit of R.s 3273786300, an amount R.s 30,300 greater than the presently operating profit. That the cost of goods sold, quantity sold of polyester, paints and chemicals are binding constraints and they are consumed fully whereas all the other constraints are non-binding and are available for the future production runs. That among the four different products manufactured at the company taken into consideration, the analysis predicted that the production of Soda Ash is contributing more than other products to the objective function. Also determined were the lower and upper limits of the variables in which the solution is optimal.

According to Agarana, et al (2014), an effective way of evaluating bank's credit policies for bad debt is through the linear programming approach. Moreover, Agarana, et al (2014) applied linear programming technique to find an optimal way of managing the loan portfolio of banks in order to maximize profit and found that in order to reduce the risk of bad debt incidence to the barest minimum, the banks should reduce the percentage of the unsecured loans since that will not significantly affect the achievement of their aims and objectives. Okoli et al (2012) applied linear programming technique in production planning and scheduling of five parts of two particular plastic products on three different machines and found the optimum profit of N4,898,182, the optimum production plan as follows; Ice cream body 203,636 pieces, Paint bucket body 120,000 pieces, Paint bucket handle 120,000 pieces, Paint bucket cover 120,000 pieces, the Ice cream cover 203,636 pieces and that all parts that make up the Paint bucket should be produced only during the night shifts while those of Ice cream container should be produced only during the day.

III. Research Methodology

The survey research and exploratory research design was found more appropriate and the primary source of data was used. The primary source of data collection was by interview and administration of questionnaire to management staff of the sampled companies. The population of the study is all the four local foam manufacturing companies in Gombe State and a sample size of two based on size and data availability was chosen. The collected data was analyzed using both descriptive and inferential parametric statistics. The descriptive statistics employed include: frequency, mean and standard deviation (See appendix D) while linear programming and sensitivity analysis were used to ascertain the optimal solution quantities, the optimal profits, minimum, maximum and range of optimality, minimum, maximum and range of feasibility, binding constraints, non-binding constraints, shadow price(s) and slack (excess capacities in the constraints) and definition and naming of variables for further analysis (See appendix B1 and B2). Sequentially, the optimal solution quantities were juxtaposed vis-à-vis results from the existing practice of the cases under study (See appendix C). This was followed by the test of hypotheses using the parametric inferential statistics of the independent T-test equation for testing the difference between means as in, Chambers and Crawshaw (1990) (See appendix, D). All the above statistical procedure was done via Excel Solver and SPSS (version 22).

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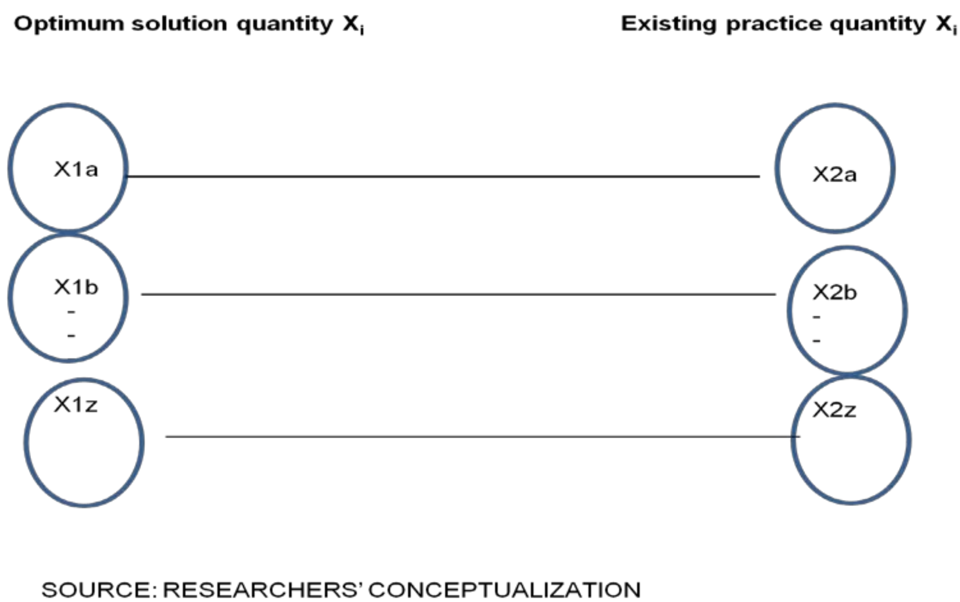

Fig. 1: Variables description

The Independent T-Test Equation for Testing the Difference between Means

The independent t-test for testing the difference between means (See Chambers and Crawshaw (1990:481), is stated here.

$$/Z/ = \frac{(x_1 - x_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{\delta_1^2}{n_1} + \frac{\delta_2^2}{n_2}}}$$

$Where\ /\ \mathrm{Z}\ /\ = \text{magnitude of mean difference between}:$

$(1)\ \text{Optimum solution quantity}\ X_i\ and\ existing\ practice\ quantity\ X_i$

$X_1 = mean\ or\ average\ of\ :$

$(2)\ Optimum\ solution\ quantity\ X_i$

$X_2 = mean\ or\ average\ of\ :$

$(3)\ Existing\ practice\ quantity\ X_i$

$\mu_1 = \mu_2 = mean\ of\ population\ (number\ of\ foams\ producing\ companies)$

$\partial_1^{\ 2} = Variance\ of\ :$

$(1)\ Optimum\ solution\ quantity\ X_i$

$\partial_2^{\ 2} = Variance\ of\ :$

$(2)\ Existing\ practice\ quantity\ X_i$

$n_1 = numerical\ number\ of\ ;$

$(1)\ Optimum\ solution\ quantity\ X_i$

$n_2 = numerical\ practice\ quantity$

$(2)\ Existing\ practice\ quantity\ X_i$

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Decision rule:

The null hypothesis is accepted if the magnitude / Z / or t-value falls within / **Z** / or t > 1.96 that is -1.96 < Z or t < +1.96 at 5% level of significance otherwise the alternate hypothesis is accepted. Alternatively, the null hypothesis is rejected if p-value is less than 5%. The two tail test was used.

IV. Results

The results from the analysis show among other findings that: foams manufacturing companies in Gombe State do not use an optimization model in product mix planning; foams manufacturing companies in Gombe State are not operating optimally although the optimum solution quantities and the existing solution quantities showed a correlation of 0.741 and a t-value of -0.751 signifying the acceptance of the null hypothesis that there is no significant difference in the mean values of operating at optimum solution level and operating at the existing solution level. Making further analysis vis-à-vis percentage change in revenue per week for both companies under peak and low periods is contained in table 1.

Table 1: Analysis of Revenue per Week

	Revenue per week during peak and low periods for both the optimal solution and the existing solution quantities					
	Company A			Company B		
	Optimum solution revenue(N)	Existing solution revenue(N)	% increase/ (decrease)	Optimum solution revenue(N)	Existing solution revenue(N)	% increase/ (decrease)
Peak period	3106153	338461	817%	8127643	794871	922%
Low peak	1553076	169230	817%	4063821	397435	922%

Source: Researcher's computation (2019)

If company A were to shift to adopt an optimization technique in product mix planning, this will results to a 817% increase in the weekly revenue while for company B, it will be 922% increase in weekly revenue.

Another finding of this work is that all the demand constraints are binding on production. The demand constraint could be mitigated by resorting to surveys to find out what is appealing and not appealing in the optimal product mix of the company.

V. Conclusion

The findings of the study are limited by the appropriateness of the statistical techniques, models and software packages employed for the analysis of data. Moreover, the findings of the study are limited by the validity of information as collected via interview, and by questionnaire. Finally, the researcher emphasize that those who filled the questionnaire were reluctant to disclose some vital information more importantly, sales values and profits. Research of this nature with an increased sample size and or covering more years should be conducted on foams manufacturing companies in Gombe state. Moreover, there are other Small and Medium Scale enterprises that are still virgin domains for a research of this nature to be conducted in Gombe state and other parts of the country.

VI. Recommendations of the Study

- Foams manufacturing companies in Gombe State should integrate optimization model in product mix planning in order to operate optimally
- Foams manufacturing companies in Gombe State should always be willing to and should disclose valid information to students and researchers
- Efforts via advertisement should be made by foams manufacturing companies in Gombe State in order to accelerate demand

References Références Referencias

1. Agarana, et al (2014). Application of Linear Programming Model to unsecured loans and bad debt risk control in banks. BEST: International Journal of Management, Information Technology and Engineering (BEST: IJMITE) ISSN 2348-0513 Vol. 2, Issue 7, Jul 2014, 93-102
2. Dahiya, K. & Verma, V. (2007). Positive Sensitivity Analysis in Linear Programming With Bounded Variables, ASOR Bulletin Volume 26, Number 4@ http://www.asor.org.au/publication/files/dec2007/Paper-Dec07.pdf
3. Crawshaw, J. & Chambers, J. (1984): A Concise Course in A-Level Statistics(Second Edition).Avon, Britain: Bath Press
4. Goh, et al (2014). A Constraint Programming-based Genetic Algorithm (CPGA) for Capacity Output Optimization. Journal of Industrial Engineering and Management, JIEM, 2014 – 7(5): 1222-1249 – Online ISSN: 2013-0953 – Print ISSN: 2013-8423 http://dx.doi.org/10.3926/jiem.1070
5. Igwe, K.C. et al (2013). Linear Programming Approach to Combination of Crop, Monogastric Farm Animal and Fish Enterprises in Ohafia Agricultural Zone, Abia State, Nigeria, Global

Journal of Science Frontier Research Agriculture and Veterinary Sciences Volume 13 Issue 3 Version 1.0 @ https://globaljournals.org/GJSFR_Volume13 /3-A-Linear-Programming-Approach-to.pdf
6. Khan, et al (2011). Optimal Production Planning for ici Pakistan using linear programming and sensitivity analysis, International Journal of Business and Social Science, Vol. 2, No. 23(Special Issue – December 2011) @ http://ijbssnet.com/journals/ Vol_2_No_23_Special_Issue_December_2011/24. pdf
7. Okoli et al (2012). Modeling of Production Plan and Scheduling of Manufacturing@ www.iiste.org
8. Oladokun, V.O. and Johnson, A. (2012). Feed formulation problem in Nigerian poultry farms: a mathematical programming approach. American Journal of Scientific and Industrial Research© 2012, Science huβ, http://www.scihub.org/ajsir or Process for a Plastic Industry in Nigeria. Industrial Engineering Letters, Vol 2, No.8, ISSN 2224-6096 (Paper) ISSN 2225-0581 (online)@ www.iiste.org
9. Sandkheerth, P. et al (2010). Linear Programming @http://www.slideshare.net/tiwarimanutiwari/linear-programing
10. Soumendra, N. (2005). "Solving Set Cover using Linear Programming" @https://www.google.com.ng/?gfe_rd=cr&ei=dnh8VaDXFcrH8geZj4CoDg&gws_rd=ssl#q=1.%09Soumendra,+N.+%282015%29.+Solving+Set+Cover+using+Linear+Programming
11. Wiley, J. (2002). Linear and Integer Programming Models. USA: John Wiley & Sons, Inc

Appendix A: A copy of the questionnaire is available on demand from: wadphonse26@yahoo.co.uk or +2348036047101

Appendix B1: Optimum Solution Quantity Results Ans Sensitivity Report for Company A

Microsoft Excel 12.0 Answer Report

Worksheet: [Working now on sensitivity analysis.xlsx]Sheet1

Report Created: 2/6/2019 12:52:53 PM

Target Cell (Max)

Cell	Name	Original Value	Final Value
$G$10	Revenue	0	121140000

Adjustable Cells

Cell	Name	Original Value	Final Value
$B$10	S	0	749
$C$10	D	0	0
$D$10	V	0	140
$E$10	A	0	0
$F$10	SH	0	650

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$13	Labour	31165.7	$B$13<=$D$13	Not Binding	34.3
$B$14	Machine	1392.51	$B$14<=$D$14	Not Binding	11.49
$B$15	Diesel	5940.5	$B$15<=$D$15	Not Binding	143.5
$B$16	Calcium	48047.5	$B$16<=$D$16	Not Binding	52.5
$B$17	Polyol	147407	$B$17<=$D$17	Not Binding	13
$B$18	Silicon	2314	$B$18<=$D$18	Not Binding	26
$B$19	Stanous	2867.8	$B$19<=$D$19	Not Binding	51.2
$B$20	Fabrics	155945.4	$B$20<=$D$20	Not Binding	54.6
$B$21	TDI	146210.5	$B$21<=$D$21	Not Binding	39.5
$B$22	MC	30960.8	$B$22<=$D$22	Not Binding	44.2

$B$23	Amine	22.548	$B$23<=$D$23	Not Binding	7.452
$B$24	Water	11700	$B$24<=$D$24	Binding	0
$B$10	S	749	$B$10<=749	Binding	0
$C$10	D	0	$C$10<=527	Not Binding	527
$D$10	V	140	$D$10<=140	Binding	0
$E$10	A	0	$E$10<=222	Not Binding	222
$F$10	SH	650	$F$10>=0	Not Binding	650
$B$10	S	749	$B$10>=0	Not Binding	749
$C$10	D	0	$C$10>=0	Binding	0
$D$10	V	140	$D$10>=0	Not Binding	140
$E$10	A	0	$E$10>=0	Binding	0

Microsoft Excel 12.0 Sensitivity Report

Worksheet: [Working now on sensitivity analysis.xlsx]Sheet1

Report Created: 2/6/2019 12:52:53 PM

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$10	S	749	17264.95726	60000	1E+30	17264.95726
$C$10	D	0	-14829.05983	45000	14829.05983	1E+30
$D$10	V	140	58632.47863	80000	1E+30	58632.47863
$E$10	A	0	-24102.5641	40000	24102.5641	1E+30
$F$10	SH	650	0	100000	40400	24785.71429

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$B$13	Labour	31165.7	0	31200	1E+30	34.3
$B$14	Machine	1392.51	0	1404	1E+30	11.49
$B$15	Diesel	5940.5	0	6084	1E+30	143.5
$B$16	Calcium	48047.5	0	48100	1E+30	52.5
$B$17	Polyol	147407	0	147420	1E+30	13
$B$18	Silicon	2314	0	2340	1E+30	26
$B$19	Stanous	2867.8	0	2919	1E+30	51.2
$B$20	Fabrics	155945.4	0	156000	1E+30	54.6
$B$21	TDI	146210.5	0	146250	1E+30	39.5
$B$22	MC	30960.8	0	31005	1E+30	44.2
$B$23	Amine	22.548	0	30	1E+30	7.452
$B$24	Water	11700	8547.008547	11700	1.031886024	7605

Appendix B2: Optimum Solution Quantity Results Ans Sensitivity Report for Company B

Microsoft Excel 12.0 Answer Report

Worksheet: [Working now on sensitivity analysis.xlsx]Sheet2

Report Created: 2/6/2019 12:51:15 PM

Target Cell (Max)

Cell	Name	Original Value	Final Value
$G$10	Revenue	0	316978090.9

Adjustable Cells

Cell	Name	Original Value	Final Value
$B$10	U	0	624
$C$10	W	0	1378
$D$10	H	0	364
$E$10	N	0	575
$F$10	SH	0	719.1636364

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$13	Labour	60302.22182	$B$13<=$D$13	Not Binding	21129.77818
$B$14	Machine	643.8509091	$B$14<=$D$14	Not Binding	32.14909091
$B$15	Diesel	780.0290909	$B$15<=$D$15	Not Binding	25.97090909
$B$16	Calcium	24314.55455	$B$16<=$D$16	Not Binding	385.4454545
$B$17	Polyol	79554.67273	$B$17<=$D$17	Not Binding	1045.327273
$B$18	Silicon	1300	$B$18<=$D$18	Binding	0
$B$19	Stanous	469.7669273	$B$19<=$D$19	Not Binding	24.23307273
$B$20	Fabrics	48686.60909	$B$20<=$D$20	Not Binding	713.3909091
$B$21	TDI	38415.55455	$B$21<=$D$21	Not Binding	584.4454545
$B$22	MC	10169.65455	$B$22<=$D$22	Not Binding	360.3454545
$B$23	Water	3841.555455	$B$23<=$D$23	Not Binding	58.44454545
$B$10	U	624	$B$10<=624	Binding	0
$C$10	W	1378	$C$10<=1378	Binding	0
$D$10	H	364	$D$10<=364	Binding	0
$E$10	N	575	$E$10<=575	Binding	0
$F$10	SH	719.1636364	$F$10>=0	Not Binding	719.1636364
$B$10	U	624	$B$10>=0	Not Binding	624
$C$10	W	1378	$C$10>=0	Not Binding	1378
$D$10	H	364	$D$10>=0	Not Binding	364
$E$10	N	575	$E$10>=0	Not Binding	575

Microsoft Excel 12.0 Sensitivity Report

Worksheet: [Working now on sensitivity analysis.xlsx]Sheet2

Report Created: 2/6/2019 12:51:15 PM

Adjustable Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$B$10	U	624	50363.63636	110000	1E+30	50363.63636
$C$10	W	1378	53636.36364	90000	1E+30	53636.36364
$D$10	H	364	17000	65000	1E+30	17000
$E$10	N	575	28454.54545	75000	1E+30	28454.54545
$F$10	SH	719.1636364	0	80000	28333.33333	80000

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$B$13	Labour	60302.22182	0	81432	1E+30	21129.77818
$B$14	Machine	643.8509091	0	676	1E+30	32.14909091
$B$15	Diesel	780.0290909	0	806	1E+30	25.97090909
$B$16	Calcium	24314.55455	0	24700	1E+30	385.4454545
$B$17	Polyol	79554.67273	0	80600	1E+30	1045.327273
$B$18	Silicon	1300	145454.5455	1300	18.54612903	395.54
$B$19	Stanous	469.7669273	0	494	1E+30	24.23307273
$B$20	Fabrics	48686.60909	0	49400	1E+30	713.3909091
$B$21	TDI	38415.55455	0	39000	1E+30	584.4454545
$B$22	MC	10169.65455	0	10530	1E+30	360.3454545
$B$23	Water	3841.555455	0	3900	1E+30	58.44454545

Appendix C: Optimum and Existing Solution Quantities

		Optimum Solution Quantity	Existing Solution Quantity
1	S	749	936
2	D	0	585
3	V	140	234
4	A	0	234
5	SH	650	78
6	U	624	780
7	W	1378	1760
8	H	364	390
9	N	575	598
10	SH	719.1	390

Appendix D: Independdent T-Test for Testing the Difference between Means

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Optimum Solution Quantity	519.9100	10	417.46892	132.01527
	Existing Solution Quantity	598.5000	10	485.30615	153.46728

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Optimum Solution Quantity & Existing Solution Quantity	10	.741	.014

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Optimum Solution Quantity - Existing Solution Quantity	-78.59000	330.98807	104.66762	-315.36460	158.18460	-.751	9	.472