Journal of the Nigerian Association of Mathematical Physics
Volume 65, (October 2022 – August 2023 Issue), **pp117 – 124**

APPLICATION OF RESPONSE SURFACE METHODOLOGY FOR THE OPTIMIZATION MODELING OF DELIVERY FLEXIBILITY FOR SMEs IN NIGERIA.

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Abstract

The agile manufacturing system is a manufacturing methodology that improves the system's operational efficiency which enhances the response to uncertainties, customers' demand, and the dynamic competitiveness of the market trends. This study model and optimise agile manufacturing flexibility variables using response surface methodology (RSM) based on centre composite design (CCD). Pertinent parameters such as machine flexibility index, probability of operation, volume ordered, and flow index production volume each representing rain and dry season were obtained from Roswell Table Waters located at Oghara in Delta State. The data served as input parameters for the Minitab Software to model and optimize the agile manufacturing flexibility variables, namely; average flow time, volume flexibility, delivery flexibility, and routing flexibility index. The results show that routing flexibility is greatly dependent on production volume (1.0 – 2.0), probability of operation (0.5 – 2.0), and probability of volume (0.5 – 2.0) against constant machine flexibility index and flow index. Volume flexibility increased by 0.02 – 0.15 as production volume increased from 0 – 600. The results showed that delivery flexibility is dependent on the volume ordered and machine index. In addition, the calculated data obtained from the data collected and predicted values for delivery flexibility are in agreement. Hence, the model reproduced the experimental results accurately. The response optimization result showed that varying independent variables such as the production volume, period time, and volume ordered had delivery flexibility peak (2.0) at Delivery flexibility peaked (2.0) when the volume ordered, machine flexibility index, flow index, and the probability of operation was 242, 0.6, 0.7 and 0.8, respectively. Any values outside of this range will reduce the target outputs.

***Keywords*: Agile manufacturing, Delivery flexibility, Mathematical model, Machine, Response surface methodology**

1.0 INTRODUCTION

The market environment of today is becoming more unpredictable and puts increasing pressure on production and cost [1, 2]. Also, the global market is becoming more competitive and customers are becoming more demanding [3]. As a result, product life cycles and delivery time to customers are gradually getting more complex; a more sophisticated agile, and a flexible plan is needed [4,5].

Delivery flexibility remains a critical component of an agile manufacturing system [6], enabling businesses to respond quickly and effectively to changing customer demands and supporting the overall agility of the manufacturing system [7]. Flexibility in supply networks may be taken into account as a possible resource to boost business efficiency and a crucial indicator of supply chain performance. There have been numerous definitions of delivery flexibility by scholars, Chase [8] referred to delivery flexibility as a measure of estimating the supply chain based on supply quantities and lead times. According to [9], delivery flexibility refers to a set of flexibility criteria that directly affect a company's consumers and are shared by two or more operations along the supply chain, whether internal (like manufacturing) or external (like suppliers). Delivery flexibility is the ability of a delivery service to adapt to the changing needs and requirements of its customers [10].

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Also, it can be referred to as the capability of a firm to change the timing of the delivery of its goods and services [11]. Distribution and delivery options are typically within the purview of marketing, which also aims to make products widely accessible. A system can decrease order [12]. Delivery uncertainty (DU) is the degree of uncertainty associated with the exact dates on which the component will be required and/or received [13]. As a result, delivery flexibility influences how long it takes to distribute the target product; this is dependent on transportation and plant schedules [14]. A flexible supply relationship between buyer and seller is required by the modern supply chain. In many instances, the demand for the finished product is extremely ambiguous. In these circumstances, the buyer would decide to use supply flexibility to offset the decline in demand rather than an inventory hoarding strategy.

In Nigeria, there are more than 40 million SMEs, with manufacturing industries accounting for about 30% [15]. The importance of SMEs to Nigeria's economy is enormous; in addition to their contributions to the GDP, they also create jobs, export goods, and introduce new technologies [16]. Therefore, small and medium-sized enterprises (SMEs) remain a key economic driver in Nigeria, which has made it one of the largest economies in Sub-Saharan Africa. Unlike multinational corporations, SMEs are autonomous, non-subsidiary enterprises whose daily operations depend on a small number of workers depending on the type of services rendered. SMEs supply chain and logistics divisions appear to need to focus on optimizing agile-delivery systems along with reaction time in addition to excellent product quality if they are to achieve cost and service leadership [17]. This can include offering multiple delivery options (e.g. standard, express, same-day), allowing customers to track their deliveries in real-time, providing flexible delivery windows, and offering the ability to make changes to an existing delivery (e.g. rescheduling, redirecting) [18].

The delivery system is an important aspect of supply chain management and customer service, as it can have a significant impact on customer satisfaction and a company's bottom line. According to Coyle [19], the provision of high-quality services is now essential to the efficient operation of many transportation, forwarding, and logistics businesses. The modern consumer is becoming more conscious of their rights. The buying mindset has changed significantly. In the past, delivery processes were often rigid and inflexible, with little room for adjustment. However, with the increasing demands of customers for fast and reliable delivery, companies have had to find ways to improve the flexibility of their delivery processes.

With the rise of e-commerce and online shopping, the importance of delivery flexibility has increased sharply, as customers expect to receive their purchases quickly and conveniently. Businesses such as SME’s that can offer flexible delivery options, such as same-day delivery or delivery at specific times are more likely to be successful in this competitive market. In addition to improving customer satisfaction, delivery flexibility can also help companies reduce costs, improve operational efficiency, and increase the overall competitiveness of their business. This can be achieved through several strategies, such as using technology to optimize delivery processes, also companies often utilize technology-based tracking and communication systems, partnerships with multiple carriers, and strategic inventory management [20, 21]. Having a flexible delivery system can lead to improved customer satisfaction, increased operational efficiency, and an overall competitive advantage in the marketplace.

Furthermore, the control of industrial processes in a flexible environment will be aided by giving focus to the development of mathematical models. A variety of models have been used to examine the availability, flexibility, maintainability, speed, and dependability of manufacturing systems, according to Sharma and Vishwakarma [22]. Fault tree analysis, dependability block diagrams, event trees, Petri nets, the Markov theory, and many others are models that produce and analyze the states of the system [1].

Li and Li [23] considered identical parallel batch machines to study the problems of scheduling jobs with sizes, release times, and delivery times, which are all essential factors in a manufacturing environment. Švadlenka [24] considered picture-fuzzy decision-making in sustaining last-mile delivery. In the work of Kamali [25] optimization in logistics was reviewed by considering on-time delivery (OTD), the study defined OTD as the timely dispatch of goods/services to the customer as previously agreed while noting that the term delivery remains an important key element to achieving success. This research used qualitative methods to analyze the current state of the OTD process and evaluated strategies for improving the process, using both primary and secondary source methods through interviews and reviewing the reliable studies conducted on this aspect.

This study, therefore, focuses on the modelling and optimization of delivery flexibility putting into consideration five operating parameters such as production volume, machine flexibility index, probability of operation, flow index, and volume ordered to avoid an error that might occur due to insufficient consideration of pertinent parameters.

The response surface methodology (RSM) based on central composite design (CCD) would be utilized to manipulate these operating parameters. The optimized value of these parameters will be determined to improve the system’s operational efficiency which enhances the response to uncertainties, customers’ demand, and the dynamic competitiveness of the market trends in small and medium enterprises flexibility.

2.0 METHODS

2.1 Case Study

The case study considered in the investigation of the impact and implementation of agile manufacturing on SMEs businesses in Nigeria is Roswells Table water, located at Oghara, Delta-State Nigeria. The case study deals with the production and distribution of various water services with a large market base both within and outside its base community. The raw data obtained from the administrators of the case study was used to evaluate the company's product orders and delivery services on daily bases for three (3) months.

2.2 Research Design

The demand and supply and feedback report on delivery data obtained from the case study was subjected to the mathematical models considered in this study. To assess the delivery flexibility of the data, a modified version of the pickup and delivery with time windows (PDPTW) model described in Equation 1 as given by Beamon [26] was employed. The result is the order by which each order must be picked up and delivered.

$$DF = \frac{\sum_{j=1}^{J} E_j - t^*}{\sum_{j=1}^{J} L_j - t^*} \tag{1}$$

Where: t is the present period, L_j is the due date period (or the latest period during which the delivery can be made for j), E_j is the earliest period during which the delivery can be made for job j

2.3 Mathematical Model and Validation

Data obtained from the case study was utilized in developing a mathematical model to predict future decisions on market strategies. Secondly, the data obtained in this study were subjected to optimization using response surface methodology to ensure the best-fit model is attained for future predictions.

For this study, the experimental design used response surface methodology (RSM) based on central composite design (CCD) because more reliable when the effects of multiple operating parameters on the final output are considered by suggesting the smallest number of experimental runs [27, 28].

The experimental design was first generated using a single response in CCD depicting five operating parameters (production volume, machine flexibility index, probability of operation, flow index, and volume ordered), each of which was considered at five levels -1, +1, 0, -α and + α [29]. The alpha value was calculated using Eqn. (2) and is dependent on several elements in the factorial section of the design.

$$\alpha = [2^n]^{1/4} \tag{2}$$

The number of operating parameters is denoted by n. at -2 and +2, the alpha value is displayed.

After that, a second-order equation was obtained to determine the coefficients (e.g., constant, linear, quadratic, and interactive). The significance of the model regarding the alpha (P-value) constraint and the coefficient of determination (R^2) was used to select the second-order model. Finally, predicting response and determining the model's adequacy by determining its significance and lack-of-fit, which is a measure of the model's inability to represent data in an experimental domain [30, 31].

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k} \sum_{j>1}^{k} \beta_{ij} x_i x_j + \varepsilon_i \tag{3}$$

Where, x_i and x_j are coded independent variables such as production volume, machine flexibility index, probability of operation, flow index and volume ordered, etc. This study employed design expert version 7.0.3 software (Stat-Ease) as a backend algorithm based on hierarchical order of preference to automatically compute the interactions of the x_i and x_j, y represents the delivery flexibility. β_0 represents the constant coefficient while β_i, β_{jj} and β_{ij} are the coefficients for linear, quadratic, and interaction effects respectively and k represents the number of operating parameters, lastly, ε_i represents the random error in the experiment [24].

3.0 RESULT AND DISCUSSION

3.1 Data Analysis

Descriptive statistical analysis was used to represent the variations in output as well as delivery flexibility over one month. Two sets of data were obtained for the agile flexibility analysis. From the analysis, some factors were considered dependent variable while some were considered independent variables as presented in Table 1. The independent variables were the raw data obtained from the case study under review, these variables are; production volume, period time, production

capacity, for the volume flexibility analysis and volume ordered, current time, due date period, and earliest time for delivery flexibility analysis.
The dependent variables are the variables resulting from the combination of two or more dependent variables. These dependent variables include; machine flexibility, flow index, average flow time, and probability of operation for the delivery flexibility analysis.
The first set of data represents the daily entries for the firm for one month during the dry season while the second set of data represents the daily entries for the firm for one month during the rainy season. Using the mathematical models' equations 1 – 3, the delivery flexibility index was calculated.

Table 1: Design of Experiment (DOE)

Std order	Run Order	Pt Type	Blocks	Coded level factors					Delivery Flexibility
				Factor A: Production volume in sub-period time	Factor B: machine flexibility index	factor: The probability of operation	Factor D: flow index	Factor E: volume ordered	
16	1	1	1	514	0.640	0.80	0.9	430	1.5
7	2	1	1	309	0.385	0.65	1.1	243	1
8	3	1	1	514	0.640	0.50	0.5	415	1.5
13	4	1	1	309	0.385	0.65	0.3	250	1
29	5	0	1	309	0.895	0.65	0.7	217	3
15	6	1	1	401	0.385	0.65	0.7	372	1
19	7	-1	1	514	0.130	0.80	0.9	332	1.5
30	8	0	1	404	0.640	0.80	0.5	368	1.5
17	9	-1	1	512	0.640	0.50	0.5	413	1
23	10	-1	1	309	0.385	0.65	0.7	150	1.3
32	11	0	1	368	0.130	0.80	0.9	260	2
21	12	-1	1	413	0.640	0.80	0.9	264	0.5
11	13	1	1	386	0.385	0.65	0.7	300	1.5
25	14	-1	1	326	0.130	0.80	0.5	130	1
12	15	1	1	309	0.385	0.65	0.7	150	1
26	16	-1	1	514	0.130	0.50	0.5	310	1.5
18	17	-1	1	565	0.385	0.65	0.7	390	1
24	18	-1	1	309	0.640	0.80	0.5	460	1.3
3	19	1	1	232	0.640	0.50	0.9	423	1
10	20	1	1	514	0.385	0.95	0.7	217	1.7
22	21	-1	1	346	0.385	0.65	0.7	130	1
20	22	-1	1	309	0.130	0.80	0.5	343	2
4	23	1	1	514	0.130	0.50	0.9	300	1.5
1	24	1	1	346	0.130	0.50	0.9	240	1
2	25	1	1	309	0.385	0.35	0.7	185	1.3
5	26	1	1	514	0.640	0.50	0.9	375	1.2
31	27	0	1	309	0.385	0.65	0.7	255	1.4
14	28	1	1	309	0.385	0.65	0.7	247	0.7
9	29	1	1	432	0.125	0.65	0.7	243	1.1
28	30	0	1	525	0.130	0.50	0.5	463	1.3
6	31	1	1	309	0.385	0.65	0.7	136	1.4
27	32	0	1	435	0.353	0.43	0.6	332	1.2

3.2 Statistical Model and Optimization for Delivery Flexibility

Table 2 presents the ANOVA for the response from the data collected according to the experimentally designed matrix, while Equation 5 shows the mathematical model used to predict delivery flexibility in terms of coded factors.

$$\text{Delivery flexibility} = -0.81 + 4.57B + 0.8C - 3.32D + 0.00263E - 5.1\,BC - 0.0043B \qquad (4)$$

Where; A, B, C, D, and E refer to the coded value of production volume in sub-period time, machine flexibility index, probability of operation, flow index, and volume ordered respectively.
The F-value and p-value on the ANOVA were used to determine the statistical significance of the parameters considered in

the model that has a direct influence on the volume and delivery flexibility. Also, the F-value was used to compare the model variance with a residual variance while the p-value is the probability of the statistical test and was calculated by having the degree of freedom and F-value. ANOVA was considered to evaluate the significance of the factors on the mathematical models and the accuracy of the model was ascertained by evaluating the R-square and improving the adjustable R-squared and predicted R-squared value in the ANOVA analysis. Additionally, ANOVA was considered to choose the significant interaction terms fit for the response model. The model is acceptable at a higher F-value and a significant p-value less than 0.05 [32, 33].

Table 2: Analysis of Variance (ANOVA) for Delivery flexibility

Source	Sum of Squares	Dgree of freedom (df)	Mean Squares	F-value	P-vale probability >F	Remark
Model	1.53	7	0.51	6.29	0.017	Significant
A-Volume ordered	0.88	1	0.88	5.63	0.032	Significant
B-Machine flexibility index	0.71	1	0.71	4.91	0.039	Significant
C-Flow index	0.92	1	0.92	5.7	0.024	Significant
D-Probaility of operation	0.68	1	0.68	4.73	0.042	Significant
AB	0.51	1	0.51	3.2	0.026	Significant
BD	0.9	1	0.9	5.67	0.026	Significant
CD	0.58	1	0.58	3.6	0.04	Significant
Error	3.66	23	0.16			
Lack of fit	2.42	17	0.14	0.63	0.75	Not Significant
Pure error	1.24	6	0.21			
Cor Total	5.19	30				
R^2 =98.34%; Adjusted R^2=96.25%; Predicted R^2 = 87.76%; CV% = 5.95						

For delivery flexibility, the F-value (6.29) which is close to 1, is acceptable. While the adequate precision is greater than 4 and the lack of fit is 0.63 which implies that it is not significant to the model and the model fits the data. Furthermore, probability values greater than 0.1000 specify model terms are not significant. For delivery flexibility, the significant model terms are A, B, C, D, and their interactions AB, BD, and CD with C being the most significant having F-value of 5.7.

The coefficient of determination, R^2 for the delivery flexibility model is 98.34 %, thereby making the model responsive and reliable. The adjusted R^2 is another regression parameter considered to determine the adequacy of the model corresponding to the value of 96.25 %. It could be observed that the adjusted R^2 value is comparably high, which shows that the quadratic response surface model selected for the responses sufficiently defined the dataset within the operating conditions selected. Furthermore, the predicted R^2 value for delivery flexibility (87.76 %) is in reasonable agreement with corresponding adjusted R^2 values. The coefficient of variation (CV) defines the measure of the reliability of the model which is the error in the percentage of the mean. The corresponding value of CV (5.95) indicates that the dataset is reliable. Also, the limit for the significant variable was set at $p < 0.05$; this implies that the confidence level of this work is more than 95%. Therefore, any variable with a low p-value < 0.05 was considered statistically insignificant to the response.

3.3 Comparison between Actual and Predicted Data

The predicted values are closely packed around the regression line as shown in Fig. 1. The calculated data and predicted values for delivery flexibility are in agreement. Hence, the model can reproduce the experimental results accurately.

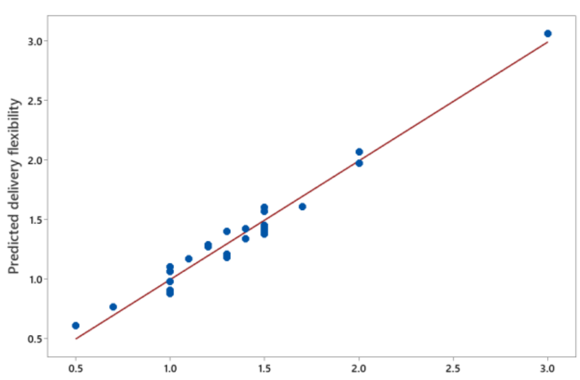

Fig. 1: Comparison plot between actual and predicted delivery flexibility

3.4 Combined effect of two significant operating factors

To maximize the agile manufacturing flexibilities parameters considered in this study which includes the following parameters; production volume, machine flexibility index, flow index, and probability of operation were maintained within the range of experimental condition studied while the delivery flexibility responses were minimized (Table 1).

Figs. 2 – 3 show the combined effect of the two most significant operating factors that are significant to delivery flexibility. The relationship between the flow index, and machine flexibility, among other factors are well fit into the graph to depict how each factor influences the other.

In Fig. 2, machine flexibility showed a negative effect on delivery flexibility, as delivery flexibility peaked at 1 in between the increasing stage and decreasing stage corresponding to an increase in machine flexibility. The interaction between volume ordered and delivery flexibility shows good agreement between the two factors as an increase in volume order improved the delivery flexibility rate at constant flow index (0.66) and probability of operation (0.65). Also, Fig. 3 shows the interaction of delivery flexibility, flow index, and probability of operation at a constant volume ordered (320) and flow index (0.66). Delivery flexibility peaked at 2 in between varying flow index of 0.5 – 0.8 while an increase in the probability of operation shows good agreement with delivery flexibility as an increase in the earlier factor will lead to an increase in the later factor.

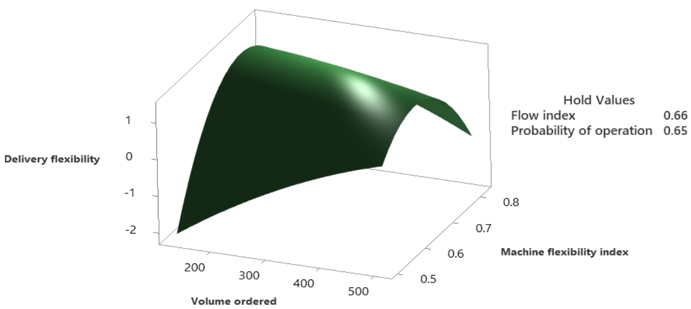

Fig. 2: Combined effect of volume ordered and machine flexibility index for delivery flexibility

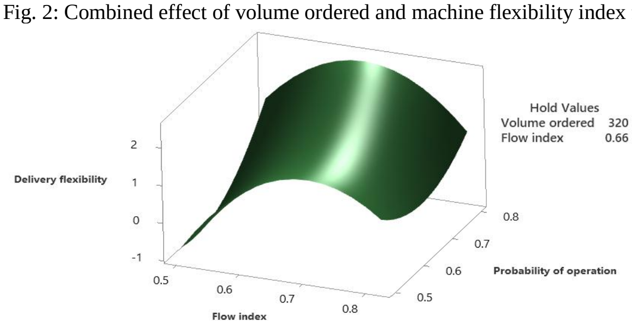

Fig. 3: Combined effect of Flow index and probability of operation for delivery flexibility

3.5 Response Optimization Result

The optimization graph obtained from the response surface model (Fig. 4) determines the value of the operating parameters required for optimum delivery services. As shown in Fig. 4, the plots generated the maximum, minimum, and optimal delivery services. The response optimization result showed that varying independent variables such as the production volume, period time, and volume ordered had a great effect on delivery flexibility. Delivery flexibility peaked (at 2.0) when the volume ordered, machine flexibility index, flow index, and probability of operation were 242, 0.6, 0.7, and 0.8 respectively. Any values outside of this range will reduce the target outputs. Finally, Fig. 4 showed a good contribution by the factors towards the optimization of the target.

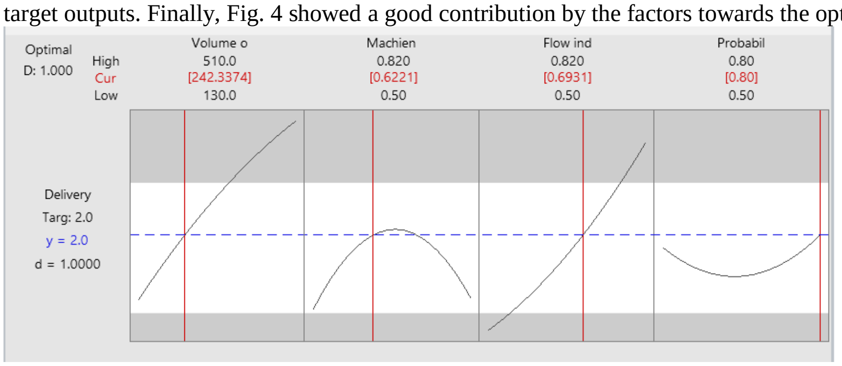

Fig. 4: Response optimization: Delivery flexibility

4.0 Conclusion

Agility as a subject is still a conceptual work, although, various stakeholders are starting to pick up interest in the employment of the agile concept in their respective businesses and services. This study is aimed specifically at providing research on how theoretical approaches can be considered to create statistical models for evaluation and optimization of delivery flexibility. Relying on data sourced from a real-life case study, the case study considered is a SMEs outlet that carries out water services. With the application of the mathematical models, this study was able to effect variations in the desired output of the company's services. With the two seasonal periods considered in the data input, the results were able to identify how best the independent variables could be combined to achieve optimum outputs and greater operational efficiency.

Based on the statistical analysis, the delivery flexibility peaked at 1.0 and 2.0 as against rise and fall in the machine flexibility index and flow index respectively. But volume ordered showed high significant contribution to the peak value obtained for delivery flexibility. In addition, the calculated values from the data obtained from the case study showed good agreement with the predicted values for delivery flexibility. Hence, the model can rely on reproducing the experimental results accurately.

The response optimization result showed that varying independent variables such as the production volume, period time, and volume ordered had a great effect on delivery flexibility Delivery flexibility peaked (at 2.0) when the volume ordered, machine flexibility index, flow index, and probability of operation were 242, 0.6, 0.7, and 0.8 respectively. Any values outside of this range will reduce the target outputs.

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