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Application of Concurrent Engineering Technique in a Small-Scale Industry: A Case Study of Bread Production

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Abstract

In present day manufacturing field, variety of products are usually common and competition is a growing concern. In this situation, customer satisfaction is essential if any organization desires to remain relevant and profitable. In shop floor, elimination of waste and reducing delay time can reflect in market price and customer satisfactions. This can be achieved by designing low-cost processes with enhanced through-put time. In this study, production of short-large bread with quantities of 300 loaves per production batch was investigated. The various activities were grouped into four modes with the assumption that only one worker performs each of the various activities in each of the modes in sequence. The mode one consists of dough preparation activities, mode two consists of dough trough preparation activities, while mode three consists of bread baking through to packaging. Also in this study, linear regression using the least square method was used to forecasts the demand for bread, using Statistic Package for Social Sciences (SPSS) top analyze the data obtained in order to develop a model for the demand function. From the analysis of results, a reduction of 27.88% of production lead time was achieved through the application of concurrent engineering technique in bread production, when compared to the traditional serial engineering approach. This reduction was achieved through better utilization of machines capacities and economic deployment of manpower.

Keywords: Manufacturing field, Concurrent Engineering, Production, Linear Regression, Machines

1. Introduction

Manufacturing is becoming more competitive as companies globally strive to increase their efficiency due to intense competitive pressure and globalization. Hence, they cannot afford to operate with waste in their processes. This is especially so for small and medium scale enterprises (SMEs). In order to overcome these difficulties, it has become more imperative to find an adequate means of producing goods that satisfies customers, while positioning the manufacturers, in the most profitable pedestal. Nevertheless, the application of Concurrent Engineering (CE) principles in assembly line of industries worldwide has gained importance in the light of increased competition and globalization. In the context of manufacturing industries, CE helps companies shorten the product development cycle and quickly bring products to the market. For instance, machine learning is used in engineering particularly within CE practices to optimize design [1], improve processes [2, 3], and enable faster, more efficient product development by analyzing vast datasets [4,5]. CE is a multi-disciplinary approach, and it is concerned with all elements of the product life cycle from conception through disposal. CE also helps in achieving higher quality of the product and higher productivity. In automobiles, approximately 80% of the overall product manufacturing/assembly cost is committed at the end of the design process [6,7]. The application of CE in oil and gas projects [8], and has been introduced in developing various products, from electronics to aircraft, and from domestics' households to military equipment [9, 10].

In application of CE in any project differently, the tools required to implement the methodology may vary. Juárez *et al.* [11] proposed a systematic approach, which included concurrent work from the development of the product, from conception generated by the marketing department to the product's distribution and consumption. As a result of introduction of CE, there is a reduction in the cycle time of the processes, elimination of rework and errors, standardization of activities, the optimization of resources, positive impact on customer satisfaction, among other aspects [10, 12]. Sapuan *et al.* [9] suggested that CE is a systematic way of working out the integrated and recent design of products and their related processes including support and manufacturing. David [8], examined that in traditional manufacturing the product design, process planning and production departments are re-strictly separated and this prevents achieving efficient plans that can keep up with the increased product variety or types and shorter delivery dates demanded by customers in today's competitive business environment. Besides, CE begins by changing the organizational culture and the training of employees to work collaboratively [6]. As a result of introduction of CE, there is a reduction in the cycle time of the processes, elimination of rework and errors, standardization of activities, the optimization of resources, positive impact on customer satisfaction, among other aspects [10, 12].

Similarly, Zhu *et al.* [13] related that the production costs increase due to improvement in design and processes to meet production on the customer's date. Ullah *et al.* [14] stated that the changes in the stages can affect productivity up to 24% and delivery time up to 44%. Doing this delivers improvements on resources administration, equipment, time, money, and design method, Deshpande [15], and Roias-Millan *et al.* [16] explained that it is very possible to develop a sequence operation according to the projects real needs and to avoid delay, it enables the employees to concentrate on planning the implementation test. Also, CE implementation's awareness phase did not have the resistance that some researchers have explained [17, 18]. Organizations should conduct a self-check to determine if all documents are complete and that the required system components are addressed Before implementation. Gherardini *et al.* [19] argued that a framework that integrates engineering methods with Web-based software tools, which could be complex for SMEs with limited IT and software resources is possible. However, product development processes in many organizations, present many problems with respect to required product quality delivery time and cost affordability. Addressing these problems entails a new approach in the utilization of resources. Also, the increasing competitiveness in the business environment makes it imperative for organizations to determine how well they are faring relative to their competitors. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, productivity, speed (time to market and response time), and user requirements (include functionality and reliability). Manufacturing technology could be defined as a field of study which focused on improvement of manufacturing processes, techniques, or equipment in order to reduce costs, increase efficiency, enhance reliability, or to incorporate safety and anti-pollution measures [20-22] opined that he efficiency of the decision process and the effectiveness of information flow.

Furthermore, every production organization, be it medium or large-scale production is characterized by the use of a group input (resources) which are transformed by one form of activity or other, into desired outputs. These resources which are largely materials, machinery and plants, manpower, money and time, must be well proportioned in the transformation process in order obtain desired products (goods). The consumers' needs are unlimited, but there is a limit to the economy can produce because of resources scarcity. Wisdom, therefore, dictates that these scarce resources should be optimally utilized in appropriate proportion [23, 24]. In other works, the resources needed to achieve desired results are acquired and managed with due regard effectiveness and efficiency [25]. Concurrent engineering has shown promise of combining high quality, low production costs and relatively short delivery times, when applied to construction processed and assembly lines. It makes used of method study and work measurement to ensure the best possible use of human and material resources in carrying out a specific activity [26]. In this study, Statistical Package for Social Sciences (SPSS) was used to analyzed a linear regression model for demand of breads, using available total annual sales records over a period of ten years (2015 - 2024), and five years forecast for annual total demand for breads was then made using the model.

2. Materials and Methods

This research work investigated the activities involved in bread baking operations using God's Favour Bakery located at Ughelli in Delta State, as case study, with a view to suggesting ways of improving the operations in bread baking using concurrent engineering technique.

2.1 Bread Production

Bread production involves a series of unit operations comprising dough mixing, molding, dividing and panning, proving, baking, cooling and wrapping. Measurements of final product quality are made, typically after baking, and few measurements are made at intermediate stages of processing (e.g. dough properties). The quality of the final product and the processing requirements of the dough are critically dependent on the flour properties. Flours are therefore supplied to specifications, typically measured by the supplier using laboratory methods including Near Infrared Reflectance (NIR) and reference methods, supplemented by on-line NIR measurements. Relevant specifications include protein content and water absorption, which determine dough-handling characteristics after mixing, and the rheological characteristics of the dough and its ability to retain gas during proof and baking. Mixing is performed as a batch operation and is critical to final product quality. During this process, the ingredients are combined in weighed quantities, the dry ingredients absorb water, the protein structure is developed to form an elastic gluten network and air bubbles are entrained into the dough. Ingredient temperatures are measured and controlled to achieve the required final dough temperature, important for dough handling. The mixing time and the amount of mechanical work applied to the dough have a critical effect on the development of the required dough rheological properties. The optimum time and work input requirements depend on the properties of the flour, but these are not monitored on- line and mixing is normally done for a fixed time based on the flour specifications or, in some cases, to a fixed work input based on on-line measurement of power consumption.

2.2 Research Design

In order to determine the level of overall effectiveness of the operations in this bakery, work study method was used as a tool to investigate the activities involved in bread baking business. Data on the periodic customers demand for bread and the internal production capacity of this bakery were obtained in order to find out their level of customer service and customer satisfaction. Their operations scheduling programme was also looked into, and then a forecasting technique was used to establish the future viability of bread baking business.

2.3 Data Collection Approach

The activities involved in the production process were observed and these operations were broken into elemental tasks. Electronic stopwatch was then used to time the completion time of each of the various tasks for each of five cycles.Ten years demand records from the bakery which spanned from 2007 to 2016 were obtained.

2.4 Method of Analyses

In this research, work measurement, also known as time study technique was used to measure the various completion time of all the various tasks involved in the bread production process. The time study is the application of techniques designed to establish the time for an average worker to carry out a specific manufacturing task at a defined level of performance. It is concerned with the length of time it takes to complete a task assigned to a specific job.

$$Normal\ time = Observed\ Time \times Rating\ Factor\ /\ 100 \quad (1)$$

Also, the linear regression (using the least square method) was used to forecast the demand for bread, using statistic package for social sciences (SPSS) to compute and analyze the parameters of the regression model for the demand function. The model used in establishing this relationship is expressed as follows:

$$Y = \mathrm{AX} + \mathrm{B} \quad (2)$$

Where,

Y = Quantity demand
X = Period
A = Annual rate of change in demand (coefficient)
B = Minimum demand

2.5 Oral Interview Approach

Also, a direct interview was conducted with the manager of the bakery. Other key staff were also interviewed to obtain relevant information that aided the success of the study.

2.6 The Bakery Production Systems

The production system of the bakery consists of manual system and automated system. But as at the time of this research work, the manual system was faulty and non-serviceable. Consequently, only the automated system was considered in this report. Table 1 shows the tabulated supply of raw materials.

Table 1. Supply of raw materials

S/N	Raw materials	Monthly supply quantities
1	Flour (50kg/bag)	400 bags
2	Groundnut oil (25litters/ Gallon)	20 gallons
3	Salt (50kg/bag)	4 bags
4	Sugar (50kg/bag)	40 bags
5	Butter (15kg/bag)	16 cartons
6	Yeast (g)	12 packet
7	EDC (20L/galloon)	4 gallons
8	Preservative (25g)	2 bags

2.7 Operations Activities

The sequence of the various activities and tasks involved in the production process are listed below.

1. Transfer of baking flour from store room to floor.
2. Emptying of ingredients into the mixer
3. Mixing of the ingredients
4. Milling of dough
5. Cutting of dough into sizes
6. Weighing of cut-to size dough
7. Molding of dough into shape
8. Cleaning of dough trough
9. Transfer of dough trough
10. Oiling of dough trough
11. Oiling of dough and loading into dough trough
12. Transfer of dough trough into oven
13. Heating of dough in the oven
14. Unloading of dough trough from oven
15. Removal of baked bread from dough trough and inspection for physical defects.
16. Transfer of bread to store room
17. Slicing of bread
18. Packaging of bread

2.9 Loaves of Bread Production

Various sizes of loaves of bread are produced in this bakery. These different sizes are categorized by different names, as well as the oven capacity and the yield per bag of baking flour are presented in Table 2.

Table 2. Loaves of Breads Production

S/N	Size of bread	Quantity of loaves yield per bag of baking flour	Oven capacity
1.	Extra large	60	120
2.	Large	85	170
3.	Short large	150	300
4.	Quarter larger	300	600
5.	Shekube	400	1000

3. Results and Discussion

This research work was carried out using work measurement technique. An electronic stopwatch was used to carry out time study of the various activities and tasks involved in the bread baking operations in their sequence. Five cycles of operations of the tasks were timed, and then the normal time for each activity was determine with correspondent performance ratings (Table 3). The SPSS was used to develop a linear regression model for demand of breads, using available total annual sales records for years (2015 - 2024), and ten years forecast for annual total demand for breads was then made using the model (Table 4).

3.1 Analysis of Data

In this study, a case study of production of short-large bread with a quantity of 300 loaves per production batch was investigated. The various activities were grouped into four modes with the assumption that only one worker performs each of the various activities in each of the modes in sequence. The mode one consists of dough preparation activities, mode two consists of dough trough preparation activities, mode three involves oven preparation tasks, while mode four consists of bread baking through to packaging (Table 4).

3.2 Work and Material Flow in Bread Baking

Figure 1 shows the flow of the main input material through the bakery system. It involves the conversion of baking flour into dough and subsequent conversion into loaf of bread through heating in an oven. Also, Figure 2 shows the outline process chart using CE.

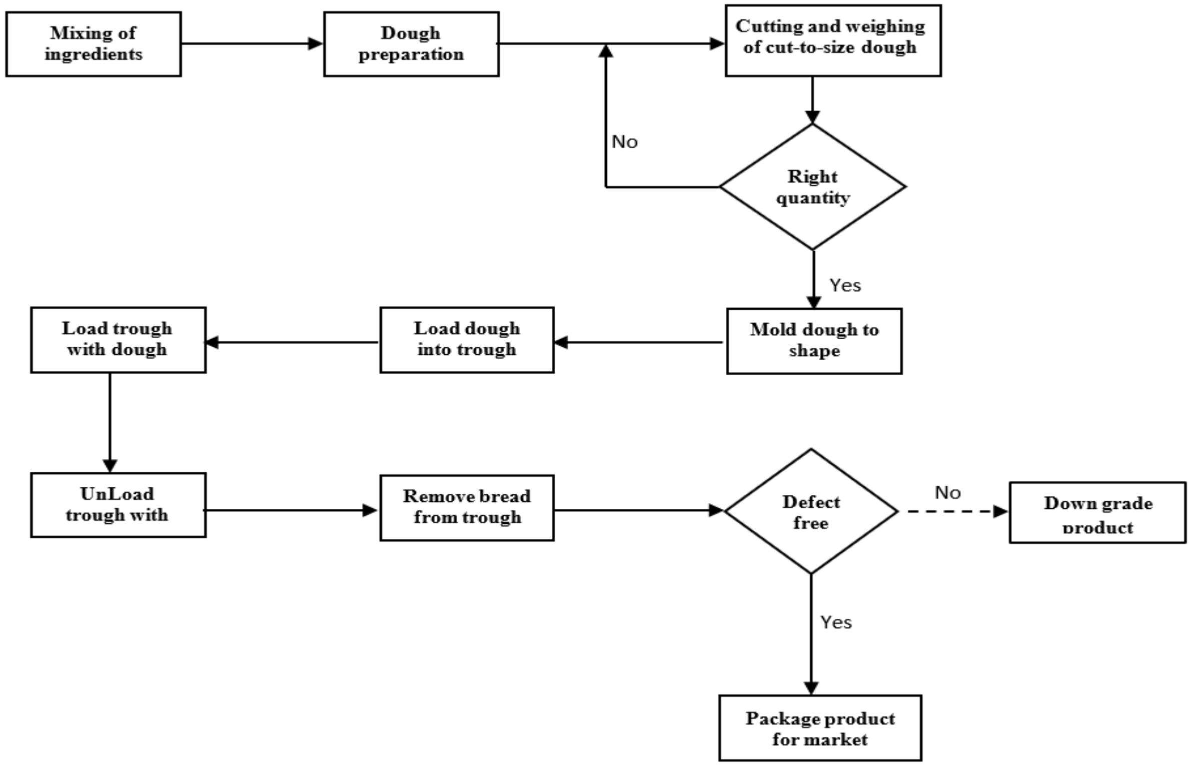

Figure 1. Work flow diagram of bread production

Table 3. Activities time study

C	Activities	Cycle time (s)					Average cycle time (s)	Rating Factor (%)	Normal time (s)	Completion time of 300 units (s)
		1	2	3	4	5				
1	Transfer of baking flour from store room to floor	20.00	20.02	18.60	20.10	20.01	19.75	90.00	17.77	17.77
2	Emptying of ingredients into mixer	150.00	150.00	151.00	150.00	148.90	149.98	90.00	134.98	134.98
3	Mixing of flour and	448.20	480.00	450.00	448.20	480.00	461.28	100.00	461.28	461.28

	other ingredients									
4	Milling of dough	180.00	173.00	210.00	194.00	195.00	190.40	100.00	190.40	190.40
5	Cutting of dough into size (20 pieces per cut)	5.00	5.00	5.00	5.00	5.00	5.00	100.00	5.00	75.00
6	Weighing of cut-to-size dough	5.00	4.50	5.10	5.00	5.00	4.92	85.00	4.18	1,254.00
7	Molding of cut to size dough into shape	5.00	5.00	5.02	4.98	5.05	5.01	90.00	4.51	1,353.00
8	Cleaning of dough trough	51.00	53.00	52.00	57.00	51.00	52.80	90.00	47.52	14,256.00
9	Transfer of dough trough (10 pieces per transfer)	22.00	21.00	22.00	24.00	27.00	23.20	95.00	22.04	661.20
10	Oiling of dough trough	5.00	4.50	5.10	5.00	6.00	5.12	90.00	4.61	1,383.00
11	Oiling of cut to size dough	25.00	25.10	25.50	25.00	24.00	24.92	90.00	22.43	6,729.00
12	Loading of cut to size dough into trough	3.00	3.10	2.55	3.00	3.10	2.95	90.00	2.66	798.00
13	Transfer of trough to oven room (10 pieces per transfer)	12.00	12.05	12.01	11.97	11.95	12.00	95.00	11.40	342.00
14	Loading of trough into oven (10 pieces per transfer)	58.00	60.00	58.00	59.00	60.50	59.10	90.00	53.19	1,595.70
15	Heating of dough in oven	1,500.00	1,500.00	1,500.00	1,500.00	1,500.00	1,500.00	100.00	1,500.00	1,500.00
16	Unloading of trough from oven (10 pieces per transfer)	120.00	120.00	120.80	118.00	120.40	119.84	90.00	107.86	2,696.50
17	Removal of baked bread from trough and inspection for defect	5.00	4.80	4.70	5.02	5.80	5.06	90.00	4.56	1,368.00

18	Transfer of bread to shelves in store room (12)	18.00	18.00	17.50	17.00	17.03	17.51	90.00	15.76	394.00
19	Packaging of bread	5.00	4.90	4.80	5.05	5.07	4.96	90.00	4.47	1,341.00
TOTAL TIME										36,550.83

Table 4. Activities time study using CE

Mode	**S/No.**	**Activities**	**Completion time of 300 units (s)**	**Total time (s)**
1	1	Transfer of baking flour from store room to floor	17.77	10,215.43
	2	Emptying of ingredients into mixer	134.98	
	3	Mixing of flour and other ingredients	461.28	
	4	Milling of dough	190.40	
	5	Cutting of dough into size (20 pieces per cut)	75.00	
	6	Weighing of cut-to-size dough	1,254.00	
	7	Molding of cut to size dough into shape	1,353.00	
	8	Oiling of cut to size dough	6,729.00	
2	1	Cleaning of dough trough	14,256.00	16,300.20
	2	Transfer of dough trough (10 pieces per transfer)	661.20	
	3	Oiling of dough trough	1,383.00	
3	5	Loading of cut to size dough into trough	798.00	10,035.20
	6	Transfer of trough to oven room (10 pieces per transfer)	342.00	
	7	Loading of trough into oven (10 pieces per transfer)	1,595.70	
	1	Heating of dough in oven	1,500.00	
	2	Unloading of trough from oven (10 pieces per transfer)	2,696.50	
	4	Removal of baked bread from trough and inspection for defect	1,368.00	
	5	Transfer of bread to shelves in store room	394.00	
	6	Packaging of bread	1,341.00	

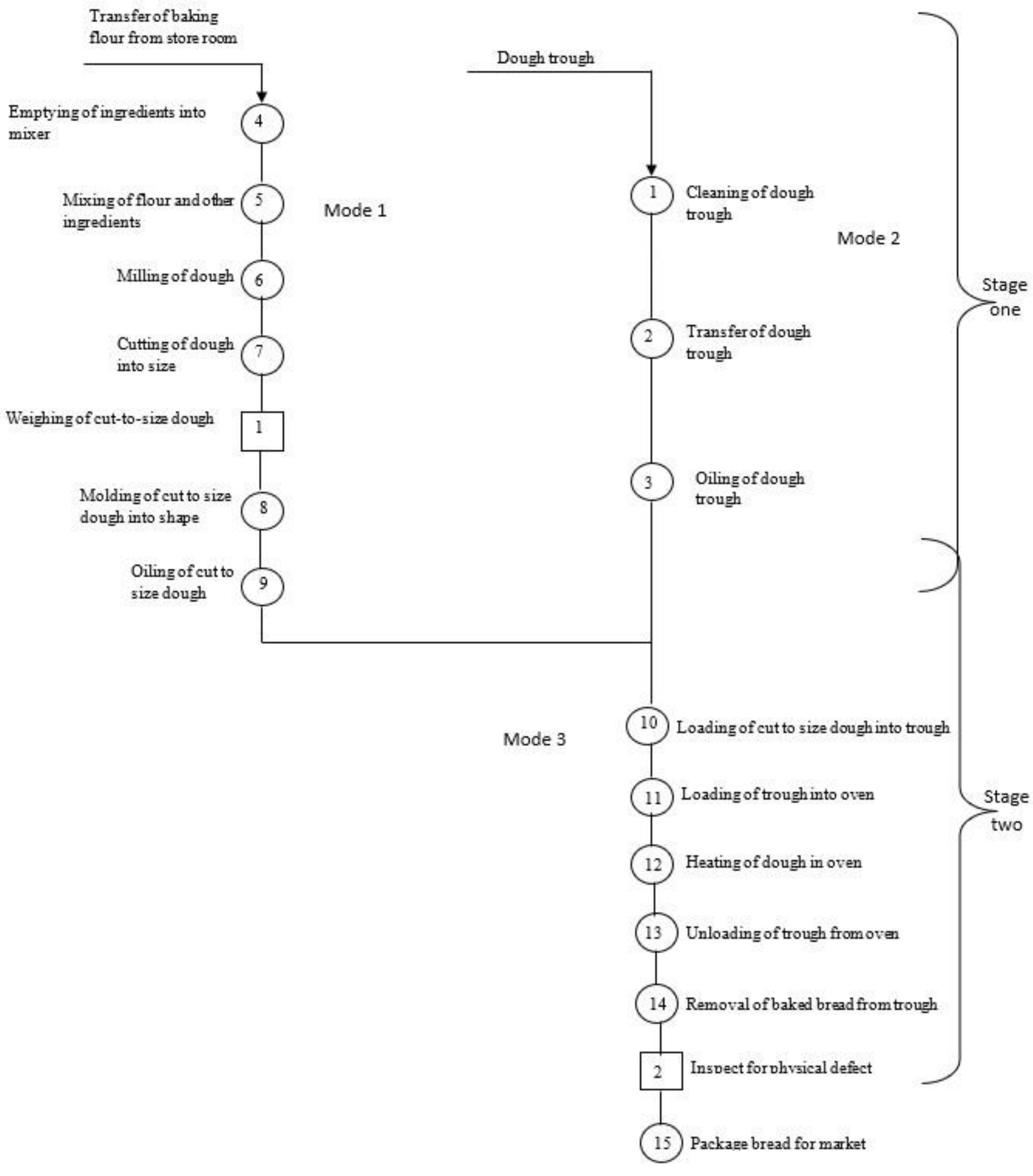

Figure 2. Outline process chart using CE

3.3. Serial Engineering Approach

Suppose a single worker were to perform each of the activities in the various modes of the production process in sequential order (Table 3), the total time of production (batch) using this approach is as follows:

$Production\ lead\ time\ (TSE) = 36{,}550.83\ seconds = 10.15\ hrs.$

3.4 Concurrent Engineering Approach

In this approach, activities were grouped into three modes and two stages (figure 4.1). Stage one consists of two independent modes (1) and (2). They do not rely on the completion of other modes before commencement. Stage two consists of one dependent mode (3); it requires the completion of modes (1) and (2) before it can commence.

$$Production\ lead\ time\ (TCE) = Tin + Tdp \tag{3}$$

$= 16{,}300.20 + 10{,}035.20 = 26{,}335.40\ seconds = 7.32\ hrs$

Where,

T_{in} = Longest duration of independent stage mode

T_{dp} = Duration of dependent stage mode

3.5 Improvement in Production Lead Time

Percentage improvement in production lead time is as follows:

$$Improvement\ in\ production\ lead\ time = \frac{TSE - TCE}{TSE} \times 100\%$$

$$Improvement\ in\ production\ lead\ time = \frac{10.15 - 7.32}{10.15} \times 100\% = 27.88\%$$

3.6 Forecasting

The annual demand figures for breads in the bakery are as presented in Table 5.

Table 5. Annual demand records

Year	Demand
2015	796,420
2016	820,900
2017	825,080
2018	830,140
2019	857,585
2020	967,935
2021	980,565
2022	1,078,570
2023	1,050,845
2024	1,106,895

The plots of the data help to analyze and determine the characteristics of yearly demand model for bread. As shown in Figure 3 above, this plot is not a smooth line and cannot be used to make forecast. However, it shows that the yearly demand increases annually with the exception of years 2015 where it declined slightly to give a lower demand. Nonetheless the graph can be linearized using linear regression to make it possible for projections for future yearly demands.

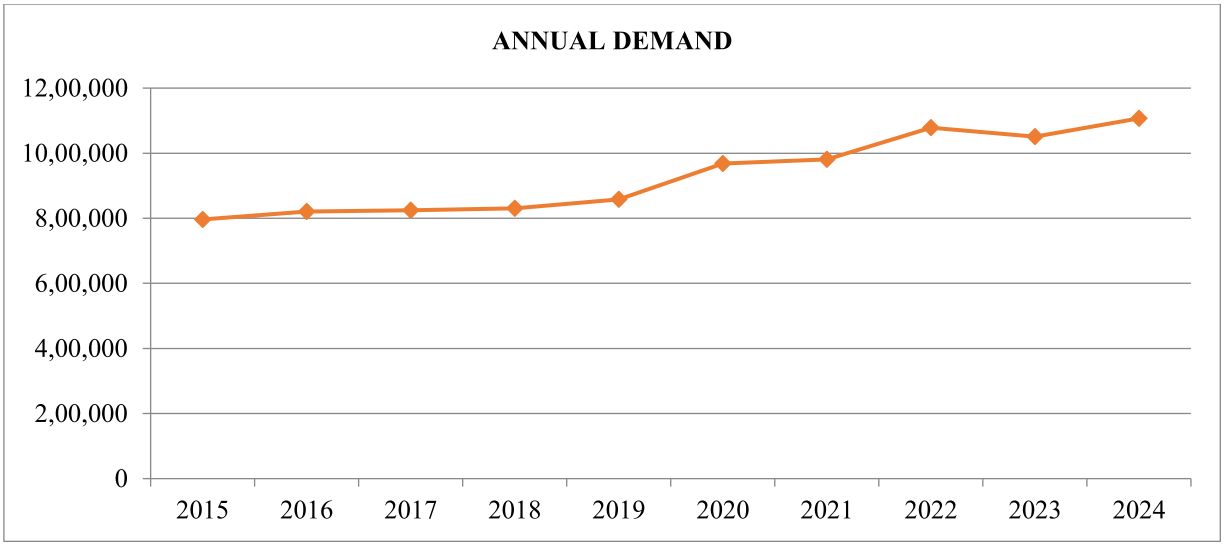

Figure 3. Graph of periodic demand for bread.

3.7 Computing a linear regression model using SPSS.

Table 6. Annual demand records

S/N	Year	Demand
1	2015	796,420
2	2016	820,900
3	2017	825,080
4	2018	830,140
5	2019	857,585
6	2020	967,935
7	2021	980,565
8	2022	1,078,570
9	2023	1,050,845
10	2024	1,106,895

Table 7. Coefficients

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	723728.000	24375.560		29.691	0.000
	S/NO	37775.545	3928.477	0.959	9.616	0.000

a. Dependent Variable: DEMAND

Table 8. Descriptive Statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
DEMAND	931493.50	119216.219	10
S/NO	5.50	3.028	10

Table 9. Model Summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.959[a]	0.920	0.910	35682.167

a. Predictors: (Constant), S/NO

Recall:

$$Y = AX + B \quad (4)$$

From Table 7, A = 931493.50

From Table 6, B = 37775.545

Hence the demand model is:

Y = 37775.5X + 931493.0

From the model, Y = 37775.5X + 931493.0, the demand for subsequent years can be forecasted as demand (Y) is a function of year (X). Using this model, forecasted demand over a 10-year period is shown in table 4.7.

Table 10. Annual demand forecast

S/N	Year	Demand
1	2025	1,139,258
2	2026	1,177,034
3	2027	1,214,809
4	2028	1,252,585
5	2029	1,290,360
6	2030	1,328,136
7	2031	1,365,911
8	2032	1,403,687
9	2033	1,441,462
10	2034	1,479,238

However, the coefficient of determination (R^2) and the coefficient of correlation (R) from table 4.6 above shown that the value of R (0.959) is tending toward 1; the model is meritorious as it evidently shows that there is association between the two variables. However, the dependent variable is able to account for 91% of the yearly demand.

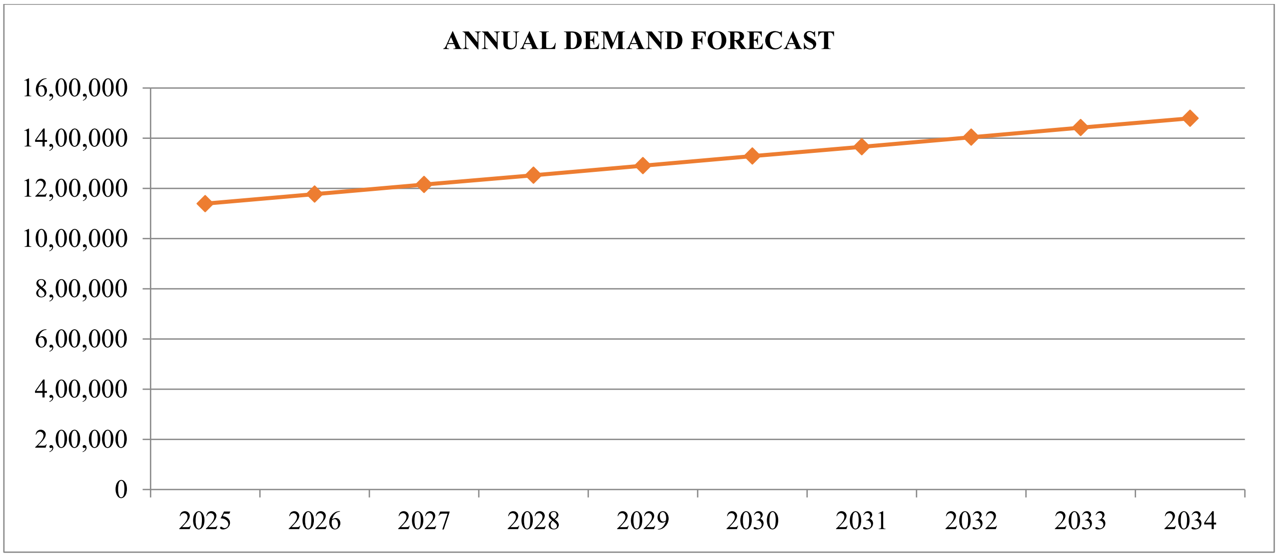

Figure 4. Graph of annual forecasted demand for bread

4. Conclusion

This study shows that concurrent engineering can be implemented within organizations practicing traditional product development system. Using concurrent engineering techniques will benefit the organization on their resulting products. In addition to reduction in production lead time, the improvement are especially noticeable on the level of innovation since each team are better specialized in only relatively few groups of activities, product cost, and quality. However, these improvements were achieved at the expense of slight increase in the number of manpower requirements. Therefore, the application of concurrent engineering is useful for small and medium scale enterprises for their process of improvement.

Declaration of Conflicting Interests

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