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Optimization Technique to Minimize In-process Inventory Costs in Multi-stage Electric Cable Production Environment.

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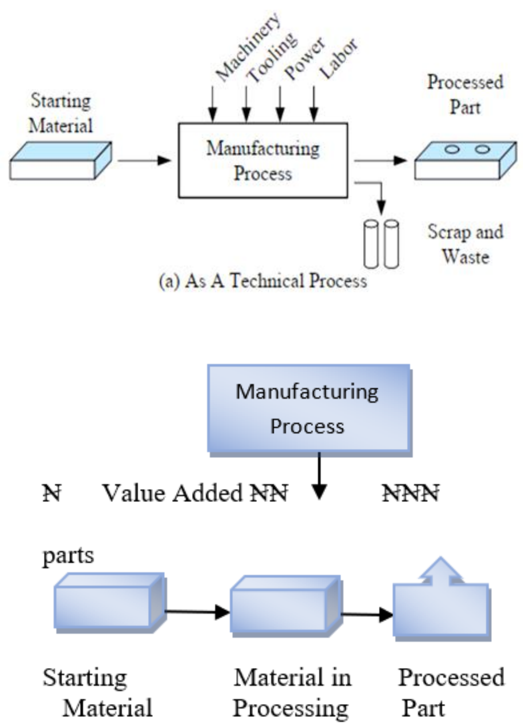
Abstract- Manufacturing firms are involved in an organized formal effort to manage manufacturing resources as well as uncertain associated costs prevalent in their inventory control policies. This uncertainty is faced by multi-product manufacturing organizations in their in-process inventory cost decision making. Realizing the significance of this inherent uncertainty, the in-process inventory costs (Ip) of a cable and wire industry located in the southern part of Nigeria where three products (Coaxial cable, Twin-axial cable and Core cable) are produced in multi-stage were investigated for a period of six months. The company's analytical method which it has been adopting to reduce in-process inventory costs was first utilized. The obtained results indicate that the average in-process cost (Ip) and the total process cost (Tc) within the time under review were twenty-six million, seven hundred and two thousand naira (₦26.72m) and thirty-five million, four hundred and two million naira (₦35.42m) respectively. To optimize the in- process inventory cost and control policies of the manufacturing company, a mathematical model is derived in this research and solved using Lingo software (15.0 version). The optimal solution result indicated a cost reduction from twenty-six million, seven hundred and two thousand naira (₦26.72m) to thirty-five million, four hundred and two million naira(₦23.85m) which accounts for 8% cost effectiveness for the firm. This has demonstrated the capability of the proposed model in handling in-process inventory cost optimization for similar companies.

Indexed Terms- Multi-Product, In-Process Cost, Inventory Management, Control Policy, Cost Optimization

I. INTRODUCTION

A manufacturing scenario consists of work stations that execute specific operations to create a predesigned product (Uzorh *et al*., 2016). Manufacturing generally is vital for societal development, technologically, economically and historically. The application of science to provide men and his environment with their desirables is termed technology. Those important means through which a nation creates material wealth defines manufacturing economically. People's cultures that were better at making things were more successful is the historical definition of manufacturing (Groover 2007).

Manufacturing encompasses a myriad of inputs, processes, products and capitals. In modern context, manufacturing can be defined in two aspects as shown in figure 1, one technological and another economic (Groover 2007). In technologic, manufacturing deals with application of chemical and physical processes to transform the geometry, properties as well as the appearance of a given starting materials or products. Notably, manufacturing includes assembling multiple components or members to create predesigned products. However, the processes to achieve manufacturing entail a combination of power, machinery, tools and manual labour.



(b)Manufacturing as An Economic Process.

Figure 1.0: dual definition of manufacturing (author's definition).

Manufacturing in economic approach involves raw materials transformation into superior value through one or more processing or assembly operations as shown in figure 1.0. Generally, therefore, manufacturing is the process of transforming raw materials, parts or components into finished goods where materials and intermediate products values are increased through altering raw materials' shape or properties or through combination with other materials (Davis and Kennedy 2013). On the other hand, companies are increasingly embedded in complex global supply networks with a large number of actual or potential supplier and customers (Lang 2010).

Recent global and domestic competitions have allowed only the fittest companies to survive recently. For any manufacturing company to be successful, there is the need for continual study and get improved in their manufacturing process through the application of several modern advanced management technology and manufacturing . In addition, efficiency and benefit are the two main goals in operating a modern manufacturing enterprise (Funk 2019). Tremendous growth of modern manufacturing and management technologies have resulted in making the manufacturing environment so complex such that more comprehensive control inputs are required for effective completion in today's manufacturing organization. Meanwhile, modern manufacturing environment has in the last two decades, advanced in manufacturing management approaches or strategies, focused factory, lean production, Just-In-Time manufacturing, total quality management, agile manufacturing, flexible manufacturing system, supply chain management, focused factory, lean manufacturing and so on (Hackman and Reachman 2017). These changes and development in manufacturing showcase the critical need for an efficient authoritative reference tool for manufacturing managers who are now expected to think more boldly than their counterparts about two decades ago (Swamidass 2000). The key to enhancing productivity and economic effectiveness of manufacturing is via efficient advanced manufacturing management.

All aspects of the product production process is termed manufacturing management. It is technically agreed that managing a manufacturing plant includes responsibility for the processes, from assembly design to packaging then transportation of the finished items.

Multi-stage product production is quite common in manufacturing industries both in the developed and under developed economy. The inherent challenge of multi-product, multi-stage production is the propagation and accumulation of uncertainties, which influences the conformity of the output (Portues *et al.*,2010). Uncertainty is unacceptably present in every manufacturing environment. These uncertainties affect the process performance as well as its service level as it relates the terms of fill rate or delivery lead time, which in turn positively affects the bottom line of enterprises in today's competitive world environment (Liu *et al.,* 2004). An item undergoes multi-stage when during the processing of the items, the items pass through various workstations where value is being added at each stage of production. A workstation may have one or more machines stationed to take part in item processing. In most cases, multi-stage production might involve creating one item or product and it is known as multi-stage, single product manufacturing process. In multi-stage multi-products, the items pass through many workstations of different number of machines being separated by the inventory of work-in-progress. Here, the products require processing in strictly ordered stages. Sarkar (2012) maintained that there is a tendency in multi-stage production process for the In-process inventory to increase at all stages unless the production flow is being synchronized adequately. Multi-stage production is quite common in today's manufacturing outfits. Here, products undergo multi-stages where values are being added to the uncompleted item. Multi-stage processes have fundamental challenges of propagation accumulation of uncertainties which enormously affect the output (Uzor *et al.,* 2016). The items undergoing multi-stage pass through different workstations during the processing. In multi-stage, multi-product manufacturing process, unfinished products pass through several workstations (assembly of machines). In-process inventory includes the set at large of unfinished items for products in a production process. These items are not yet completed but either just being fabricated or waiting in a queue for further processing or in a buffered storage. The term is used in production and supply chain management (Kim *et al.,* 2010). Optimal production management aims to minimize in-progress. In-progress requires storage space, represents bound capital that is not responsible for investment and carries an inherent risk of earlier expiration of shelf life of the products. A queue leading to a production step shows that the step is well buffered for shortage in supplies from preceding steps, but may also indicate insufficient capacity to process the output from these preceding steps.

A manufacturing system which procured raw materials and converted them to finished products of varying demand content was considered by Sarker (2012), The author has proposed a creative decision rule to determine the production start time, manufacturing set-up, raw material and finished product holding**,** lot and batch sizes with minimum cost of ordering raw materials, Kim *et al.,* (2010) in their work synchronized the production flow in a serial production process by transferring a lot from a stage to the next with equal-sized batches. The batches are transported from a stage to the next processing without waiting for the entire production lot to be processed at the earlier state before being moved to the next stage. Zhang and Gerchack (2017) developed a modification to the model of Goyal, which enables a number of properties that the optimal solution must satisfy to be determined. An algorithm giving the optimal solution was then derived based on these properties. Notably, the model of Zhang and Gerchack (2017) is a particular case of the modified model of the Kiy and Kim (2001) with exception in the set up and transportation times and avoidance of the capacity constraint on the transport equipment.

II. MATERIALS AND METHODS

Besides discussing the inventory management related issues, a questionnaire was designed related to in-progress inventory costs of a multi-stage multi-product manufacturing company.in the eastern part of Nigeria to identify views of the production manager about in-Progress cost in inventory management (IM). The data collected from the production manager and data collected from observations made on the process lines were analysed appropriately. In this research, optimization of in-process inventory costs in multi-stage multi- product production process had been studied from an electric cables and wire industry in Nigeria by implementing linear programming technique and solved with Lingo software aimed at exploring the potential model to provide valuable insights in their application in determining in-process inventory costs in developing business economy where the subject has been under studied which will improve operational efficiency and provide manufacturing companies with cost-effective and sustainable solutions. The company manufactures three products which undergo four stages of production in four different work stations as shown in tables 1, 2 and 3. The company is operating at about 84 percent of maximum production. Table 1 shows the average coaxial cable production parameters and cost element (July – December,2023), table 2 shows the average Twin-axial cable production parameters and cost element (July-Dcember, 2023) while table 3 depicts average core-cable production parameters and cost element (July-December,2023)

Table1: Average Coaxial cable production parameters and cost element (July – December,2023)

Variable/Parameters	Stage1 Wire Drawing	Stage2 Annealing	Stage 3 Twisting&Stranding	Stage 4 Extrusion cabling
S	2	2	3	1
C(₦)	4.00	5.00	5.00	4.00
t(hr)	0.1	0.2	0.3	0.5
A(₦)	80,000.00	75,000.00	80,000.00	75,000.00
Є(%)	0.5	0.6	0.7	0.7
α	950.00	800.00	800.00	650.00
β	1,000.00	1,000.00	1,000.00	850.00
$\varphi x10^3$ (₦)	60.00	60.00	60.00	60.00
Tc (₦)	11,679,958.00			
Ac(₦)	393,651.00			
Dq (units)	426,916			
Co (₦)	4,508,428.00			
Q(units)	300,035			

Table 2: Average Twin-axial cable Production parameters and cost element (July-December, 2023)

Variable/Parameters	Stage1 Wire Drawing	Stage2 Annealing	Stage 3 Twisting&Stranding	Stage 4 Extrusion&cabling
S	2	2	3	1
C(₦)	5.00	5.00	4.00	3.00
t(hr)	0.2	0.4	0.4	0.3
A(₦)	80,000.00	82,000.00	80,000.00	78,000.00
Є(%)	0.5	0.4	0.6	0.6
α	900.00	900.00	900.00	800.00
β	1,000.00	950.00	1,000.00	1000.00
$\varphi x10^3$ (₦)	60.00	60.00	60.00	60.00
Tc (₦)	12,063,568.00			
Ac(₦)	0.00			
Dq (units)	528,450			
Co (₦)	3,846,338.00			
Q(units)	325,000			

Table 3: Average Core-cable production parameters and cost element (July- December,2023)

Variable/Parameters	Stage1 Wire Drawing	Stage2 Annealing	Stage 3 Twisting&Stranding	Stage 4 Extrusion&cabling
S	2	2	3	1
C(₦)	4.00	5.00	6.00	6.00
t(hr)	0.2	0.4	0.4	0.3
A(₦)	80,000.00	82,000.00	80,000.00	78,000.00
Є(%)	0.4	0.5	0.6	0.6
α	900.00	900.00	900.00	800.00
β	1,000.00	950.00	1,000.00	1000.00
$\varphi x10^3$ (₦)	60.00	60.00	60.00	60.00
Tpc (₦)	11,670,607.00			
Ac(₦)	0.00			
Dq (units)	370,630			
Co (₦)	3,9850,333.00			
Q(units)	304,085			

The following assumptions were made to optimize the in-progress inventory cost for the multi-stage products outfits.

i. Demand for the products is uniform, known and deterministic.
ii. Set-up cost per set-up is independent of set-up sequences undergone
iii. Once the product goes out of control, the machines automatically stop producing defective items.
iv. There is no finished product inventory cost as the products will be dispatched once the processing is completed at the final stage of the production.

The total cost of production consists of:

i. Set up cost
ii. Imbalance cost
iii. Cost due to work-in-progress

The total set-up cost considering all products and stages is given by

$$\sum_{i=1}^{M} \sum_{j=1}^{N} \begin{pmatrix} \text{Dij} \\ \text{Qij} \end{pmatrix} \text{A} = \text{Cs} \quad (1)$$

The processing time for a batch is expressed as

$$\text{Tij} = \Phi\text{ij x tij} \quad (2)$$

The total time spent by a batch per drift is estimated thus

$$\frac{1}{\beta ij - \alpha ij} \quad 3$$

Average time spent by the batch due to process drift while processing that batch equals

$$\text{Tij} \left\{ \frac{\alpha ij}{\beta ij - \alpha ij} \right\} \quad 4$$

The number of production cycles per unit time for each product per stage expressed

$$\text{Rij} = \frac{\text{Dij}}{\text{Qij}} \quad 5$$

the average cost per unit product has been accounted to compute the imbalances.

$$\text{Cij} = \frac{\text{Cij} - 1 + \text{Cij}}{2} \quad 6$$

Production process tends to implement job production to balance the production rates between successive production stages. The aspect of quality at the source have been modeled by Goyal and Gunasekaran (2020).

Production rate for a particular product from that stage j is given by

$$\lambda ij = \frac{Eij \times Sij}{1ij} \qquad (7)$$

Where: $\sum_{i=1}^{M} \sum ij = 1$ for j = 1, 2, …..N

Here, we have considered a penalty cost balance among production rates which encompasses all costs associated with imbalance in production rate.

The cost due to imbalance in production rate between a given stage and the next stage can be expressed thus

$$/\lambda ij - \lambda ij/ \times \Phi ij \qquad (8)$$

Given that Φij = Penalty cost

Total cost due to imbalance:

$$\sum_{i=1}^{M} \sum_{j=1}^{N} /\lambda ij - \lambda ij + 1/\Phi ij \qquad (9)$$

Set up cost considering all stages of production:

$$\sum_{i=1}^{M} \sum_{j=1}^{N} \left(\frac{Dij}{Qij}\right) A = Cs \qquad (10)$$

Where: A = set up cost per set-up for product I at j stage.

Set-up cost and cost due to imbalances for coaxial, twin-axial and core cables are derived from equations 1 to 10 as shown in table 4.

Table 4: Cost Elements Per Product

Cost Element	Cost Per Product (₦)		
	P_1 (Coaxial cable)	P_2 (Twin-axial cable)	P_3 (Core cable)
T_c	11,679,958	12,063,568	11,670,607
C_s	441,130	576,710	544,000
C_{im}	2,400,000	2,400,000	2,400,000

Table 5: In-Process, In-balance, Set-up and Total production Cost, Per Product

Cost Element	Cost Per Product (₦)		
	P_1 (Coaxial cable)	P_2 (Twin-axial cable)	P_3 (Core cable)
T_c	11,679,958	12,063,568	11,670,607
C_s	441,130	576,710	544,000
C_{im}	2,400,000	2,400,00	2,400,000
Ip	8,838,828	9,146,858	8,726,607

The table 6 shows the average cost elements and quantity produced per product of the company.

Table 6: Cost Element and Quantity Produced Per Product

Cost Element	Cost Per Product (₦m)			No of products
	P_1	P_2	P_3	
T_c	8.84	9.14	8.72	3

C_s	0.44	0.51	0.54	3
C_{im}	2.4	2.40	2.40	3
Qnty. produced	300035	325000	304085	

Model Notations and Formulation

S Number of machines at each stage
i Product index
j stage index
C Cost/Unit product at each stage
λ Production rate of a product
t Processing time per unit of product at each stage
A Set up cost per set-up for each product at each stage
₤ Priority assigned in processing each product in each stage
a. Mean process drift rate while processing each product at each stage
β. Mean service rate for bringing the process to normal operating condition for a particular product at particular stage.
P_1 coaxial cable
P_2 twin-axial cable
P_3 core cables
R. Number of the production cycle for the given demand of each product
G. Average cost per unit of each product between a stage and subsequent one.
φ. Penalty cost due to imbalance in production rate between a particular stage and the next.
Dq Demand for each product
Co. Raw material cost per product
C_{im} Cost due to imbalance
S_c Set up cost considering all stages
T_{pc} Total Process cost
Ac Assembly cost
Q Quantity produced
ŋ Ratio of in-process cost to total process cost
IP In-process cost

The objective function

The objective function is to minimize the in-process inventory cost Z including total process cost, set-up cost, imbalance cost and number of products

$$Max\ Z = \sum_{i=1}^{n} TpcXi - Sc\,Xi - CimXi \qquad 11$$

Subject to :

$$\sum_{j=1}^{N} \; = \; \text{Si for i} = 1,2, \dots \dots \qquad 12$$

Type equation here.

And Xi ≤ 0 for all i
i = 1, 2, 3 ……..n
Using double-subscripted decision variables, with
X_{11} = Number of P_1 with respect to T_C
X_{12} = Number of P_2 with respect to T_C
X_{13} = Number of P_3 with respect to T_C
X_{21} = Number of P_1 with respect to C_S
X_{22} = Number of P_2 with respect to C_S
X_{23} = Number of P_3 with respect to C_S
X_{31} = Number of P_1 with respect to C_{im}
X_{32} = Number of P_1 with respect to C_{im}
X_{33} = Number of P_1 with respect to C_{im}

Where Z is Objective function that determines the in-process cost
X = Cost variable
S = Constraint or restriction placed upon the model problem

Using survey data in table 6, the objective function can be stated thus:

Minimize $Z = (8.84X_{11} + 9.14X_{12} + 8.72X_{13}) - (0.44X_{21} + 0.51X_{22} + 0.54X_{23}) - (2.40X_{31} + 2.40X_{32} + 2.40X_{33})$
12

IP cost (IW) of the three products.
Subject to
$X_{11} + X_{12} + X_{13} \geq 3$ 13
$X_{21} + X_{22} + X_{23} \geq 3$ 13a

$X_{31} + X_{32} + X_{33} \geq 3$
13b
$X_{11} + X_{21} + X_{31} \geq 300035$
13c
$X_{12} + X_{22} + X_{32} \geq 325000$
13d
$X_{13} + X_{23} + X_{33} \geq 304085$
13e

This implies cost of the product quantity of the three products (P_1, P_2, P_3) and X_{11}, X_{12} ……… X_{33} all such values are ≥ 0

III. RESULTS AND DISCUSSION

Using table 6, the in-process inventory cost (Ip) was analytically (company's approach) calculated to be twenty-six million, seven hundred and twelve thousand, two hundred and ninety-three naira (₦26,712,293.00k) and the total production cost (Tpc) at thirty-five million, four hundred and fourteen thousand, one hundred and thirty-three naira (₦35,414,133.00k). Figure 1 shows the cost elements of the products under investigation. The developed model was solved with Lindo software which reduced the in-process cost to twenty-three million, eight hundred and forty-seven thousand, three hundred and fifteen naira (₦23,847,315) which accounts for 8% of the overall cost.

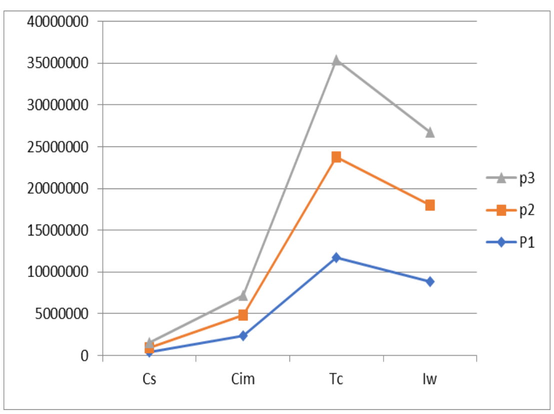


Figure 1: Relationship in cost Elements of the Products

The model cost result of ₦23,847,315 represents the minimum in-progress cost (Ip) for the company to produce the three products and still meet the customers demands. From the output result sheet, variable $X_1 = X_{11}$ which is number of P_1 with respect to T_c is zero, this depicts that P_1 with objective coefficient of 9.70 has no objective value contribution. It is important to notice the results were obtained at iteration 12. The In-Process cost (Ip) accounts for huge sum in manufacturing processes be it multi-stage, single product process; single-stage or single product process. It is advisable that managers should focus on these objective coefficients that have a narrow range of optimality and coefficients near the end point of the range.

IV. CONCLUSION AND RECOMMENDATION

This research work underscores the credibility of employing the developed model in solving in-process inventory cost problems that are prevalent in multi-product manufacturing industries in their inventory policy making. The proposed model addressed the research objective and employed advanced methodology which demonstrated significant cost efficiency when compared with the outdated technique as employed by the company over the years. The research contributed immensely to the growing body of knowledge on in-process inventory management and provides a practical technique for industries to enhance their competitiveness and inventory management efficiency. We recommend that this model can not be applied to servicing companies and that further research can be conducted in that direction.

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