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Development of Cellular Manufacturing Model for Product Varieties Management in Industries

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

The increasing demand of customers in terms of speed of service and reduced cost at higher quality has generated a new platform on which manufacturing companies compete. The purpose of this report is to develop a Cellular Manufacturing Model, which is actually an application of group technology, which has been described as a stepping stone to achieving world class manufacturing status. Required strategic decisions were identified and the mathematical models required were developed. The models were integrated to form the logic with the aid of a flow chart. The formulated model was implemented with a software using C – Sharp (C-#). The identified strategic decisions which are the input variables are: Quantity input total cost rate, waiting time, setup time, work start time, delivery time, cycle time and average product demand. Processing this data using the developed mathematical models resulting into total productivity, production lead time, unit cost, cycle time, and delivery time determination. Statistical analysis of both input and out data was carried out the correlation coefficient (r) of the data was 0.95 which gives a very strong relationship. Graphs were also drawn to represent the output quantity against value added time and also graph of delivery ready goods against total cost rate. At the end of it all, a useful way of implementing this aspect of cellular manufacturing was suggested.

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Keywords: Cellular manufacturing; group technology; product varieties; strategic decisions; software development; waste control.

1. INTRODUCTION

Cellular Manufacturing is the linking of manual and machine operations into the most efficient combination of resources to maximize value-added content while eliminating waste [1].

Manufacturing industries are under intense pressure from the increasingly-competitive global marketplace. Shorter product life-cycles, time-to-market, and diverse customer needs have challenged manufacturers to improve the efficiency and productivity of their production activities. When processes are balanced, product flow is more continuous and customer demand is more easily met.

The adoption of group technology (GT) has consistently formed a central element of many of these efforts and has received considerable interest from both practitioners and academicians. GT is an approach to manufacturing and engineering management that helps manage diversity by capitalizing on underlying similarities in products and activities. Within the manufacturing context, GT is a manufacturing philosophy identifying similar parts and grouping them together into families to take advantage of their similarities in manufacturing and design.

One application of GT philosophy is cellular manufacturing (CM) [2]. Studied the manufacturing flexibility to sustain competitiveness via grouping the products into families. They focus on the design for new product introduction and analyze reconfigurable manufacturing systems. The product variety management should be effectively put into operation in today's world. Today's high product variety environments come not only with the high number of different products with high and design changes but also with high variations in demand and lower volumes of production.

We believe that the new era of higher product variety environments should be analyzed together with all the associated costs. The proposed model captures all these characterizations of the new manufacturing environment. The model determines the product families and machine groups while deciding the technology of each cell individually such that we can analyze product variety management in cellular manufacturing systems by integrating technology selection decision in the model. In order to hedge against the market variability we make use of flexible machining systems and dedicated manufacturing systems at the same facility. The model forces the parts with high demand and/or design variability to the cells with flexible machining systems. The parts with stable demand and/or design patterns are processed in dedicated manufacturing cells.

The most efficient combination implies the concept of process balancing. A balanced process is necessary for a product to flow continuously. Other effects of a balanced process are minimization of parts movement, reduction of wait time between operations, reduction of inventory and an increase in productivity. Manufacturing systems must be able to output products with low production costs and high quality as quickly as possible in order to deliver the products to customers on time. In addition, the systems should be able to adjust or respond quickly to changes in product design and product demand without major investment. Traditional manufacturing systems, such as job shops and flow lines, are not capable of satisfying such requirements.

2. LITERATURE REVIEW

The principle of cellular manufacturing (CM) is to break up a complex manufacturing facilities into several groups of machines (cell), each being dedicated to the processing of a part family. Therefore each part type is ideally produced in a single cell. Thus, material flow is simplified and the scheduling task is made much easier [3].

The major objective of this project work is to actualize the application of Group Technology; which lead to specific objectives as to: identified parameters required for cellular manufacturing models, design cells in such a way that some measures of performances are obtained (e.g Productivity and Cycle time); measure some production parameters for productivity such as: Unit cost, On-time delivery, Lead time, reduced distance travelled by materials, inventories and cumulative lead times, develop software for implementing the model developed and validate the developed software using a case study.

However, Nigerian industries including the Small Manufacturing Enterprises (SMEs) find it difficult to adopt the concept. The reasons are: the huge capital involved in the reconfiguration of the whole production system, inability to embrace changes and fear of the unknown instability of the market. This study focused on the product varieties management of cellular manufacturing model in Nigerian industries with the sole aim of reducing their production lead times through the elimination of wastes and adoption of continuous improvement. Some of the past research work done includes: Fuzzy linear programming (FLP) approach to layout design of dynamic cellular manufacturing systems [4-6] developed a comprehensive mathematical model for dynamic manufacturing cell formation considering multi-item and multi-level lot sizing aspect; and the impact of lot size on product quality was developed.

Since this study develops a new (FLP) approach to solve the mathematical model that incorporates layout problems in designing a Cell Manufacturing System (CMS) with alternative process routings under dynamic and uncertain environment, the literature is reviewed under these topics: FLP approaches in CMS, CM design with alternative process routings, layout problems in CMS and dynamic cellular manufacturing systems. Due to the numerous researches implemented in the mentioned topics, we only focus on recent studies. Fuzzy logic is a strong tool for expressing the uncertainty existing in the real life problems through the expert's knowledge. Fuzzy approaches considered to encounter uncertainty in CMS parameters are divided into two groups. The first group includes: new fuzzy clustering algorithms, fuzzy versions of existing ones, extension or adaptation of the fuzzy C-mean algorithm and fuzzification of the part features. The second group is on the mathematical programming field using fuzzy parameters in the mathematical model developed for the design problem [7].

Tavakkoli-Moghaddam et al. [8] proposed a new fuzzy linear mix-integer programming model with fuzzy part demands and changing product mix solved by a genetic algorithm. The objective of the proposed model was to minimize the sum of costs of machine amortization/ operation/ relocation and inter-cell movements. [5] presented a comprehensive model for designing a cellular manufacturing system by combining the cell formation problem, the machine allocation problem and the part routing problem by considering multiple process plans for each part. The comprehensive mathematical model for dynamic manufacturing cell formation, considering a multi-item and multilevel lot sizing aspects and the impact of lot size on product quality was developed by [9]. They formulated a model incorporating a number of manufacturing features such as: dynamic system configuration, alternative routings, sequence of operations, machine capacity constraint, workload balancing, cell size limit and machine closeness requirements.

Arıkan and G¨ung¨or [7] proposed a two-stage approach for solving cell formation problem as well as cell layout problem, sequentially. In the first stage, machine cells and part families were identified by a mathematical model. In the second stage, a macro-approach carried out to investigate the cell formation problem with consideration of operation sequence minimized inter-cell movement. [10] developed a hierarchical genetic algorithm to simultaneously identify manufacturing cells and the group layout. He also proposed a new approach to determine simultaneously the cell formation, group layout, group scheduling and developed a mathematical model integrating these decisions. [11] developed an algorithm using sequence data in CMS to identify the part families and machine groups as well as the layout (sequence) of the machines within each cell, simultaneously. [11] developed an heuristic algorithm based on flow matrix for cell formation and layout design using sequence data, and proposed three measures of performance, average cell movement index, average cell utilization index and overall movement index for the evaluation of solution. [12] applied the multiple attribute decision making (MADM) concepts and proposed a two-stage method to determine cell formation, intra cell machine layout and cell layout.

Defersha and Chen [9] proposed the comprehensive mathematical model incorporating dynamic cell configuration, alternative routings, lot splitting, and sequence of operations, multiple units of identical machines, machine capacity, and workload balancing among cells, operation cost, subcontracting cost, tool consumption cost, setup cost, cell size limits, and machine adjacency constraints. [13] modelled the problem of designing cellular manufacturing systems with multi period production planning, cell reconfiguration, operation sequence, duplicate machines, machine capacity and machine procurement as well as the introduction of routing flexibility by the formation of alternate contingency process routings in addition to alternate main process routings and solved through a comprehensive mixed integer programming formulation. [14] presented the dynamic cell formation model in which the number of formed cells at each period can be different with the objective of minimization of machine cost, relocation and the inter-cell movement costs.

Saidi-Mehrabad and Ghezavati [15] developed a mixed-integer programming model considering the batch inter/intra-cell material handling by assuming the sequence of operations, alternative process plans, and machine replication to design the cellular manufacturing systems under dynamic environment with the objective of minimising the sum of the machine constant and variable costs, inter-cell and intra-cell material handling costs, and reconfiguration costs. [12] formulated the integrated approach to CMS design as the mixed integer non-linear programming model incorporating production planning and system reconfiguration decisions with the presence of alternate process routings, operation sequence, duplicate machines, machine capacity and lot splitting. [2] presented a nonlinear mixed integer program to model dynamic cell formation problem in presence of machine flexibility, alternative process plans and machine relocation. The multi objectives of the proposed model to be minimized simultaneously were the total cell load variation and the sum of costs of machine, inter-cell material handling, and machine relocation.

Ahkioon et al. [13] presented the dynamic cell formation model in which the number of formed cells at each period can be different with the objective of minimization of machine cost, relocation and the inter-cell movement costs. He discussed that in the previous models presented in the literature there are some essential errors declining their advantageous features and presented a new improved formulation for a dynamic cell formation (DCF) problem. [16] developed a new model to deal with simultaneous dynamic cell formation and worker assignment problems by considering part routing flexibility, machine flexibility and promotion of workers from one skill level to another. The objective function consists of two distinct constituents: Machine-based costs, such as production cost, inter-cell material handling cost, machine costs in the planning horizon and human issues consisting of hiring cost, firing cost, training cost and salary. [17] presented an integer mathematical programming model for the design of DCMS by considering operation time, alternative workers, duplicate machines, removing idle machines from system or returning them to system, machine capacity, hiring and firing of workers, production volume of parts, part movements between cells, cell reconfiguration and production planning.

Barve and Khodke [18] presented a new multi-objective mixed integer model for DCMS by considering some real-world critical conditions in lean production. Their model solved the part and machine grouping simultaneously with labour assignment to minimize the sum of the machine constant/variable costs, inter/intra-cell movements; as well overtime working costs, labour transferences costs and machine purchase costs, and maximize utilization rate of human resource. [19] presented a comprehensive mathematical model for integrated cell formation and inventory lot sizing problem. The proposed model seeks to minimize the total cost of machine procurement, cell reconfiguration, preventive and corrective repairs, material handling (intra-cell and inter-cell), machine operation, part subcontracting, finished and unfinished parts inventory, and defective parts replacement, while dynamic conditions, alternative routings, machine capacity limitation, operations sequences, cell size constraints, process deterioration, and machine breakdowns are also taken into account. [20] proposed a DCMS model integrating concurrently the manufacturing attributes such as machine breakdown effect to incorporate reliability modelling, production planning in terms of inventory holding, internal production, and part outsourcing, process batch size, transfer batch size for intra-cell travel and inter-cell travel, lot splitting, alternative process routing, sequence of operation, multiple copies of identical machines, machine capacity, cutting tooling requirements, work load balancing, machine adjacency constraint, and machine procurements and dynamic cell reconfiguration. By considering the previous works reviewed above, we can understand that there is no research incorporating with layout problems in the DCMS context, and there is a meaningful gap in this field. Then, we integrate the DCMS and intra-cell layout to overcome this disadvantage of the existing literature. Furthermore, none of the CMS models which have incorporated fuzzy concept in their parameters does not considered asymmetric trapezoidal fuzzy numbers to present uncertainty in part demand fluctuations and machine capacity. But in our model, this aspect is considered to present uncertainty emerging in real industrial problems.

In designing Cellular Manufacturing Systems under Uncertainty, there exists considerations in designing and planning of CMS in different areas such as cell formation problem, considering layout problem in CMS [21-23] producing planning concurrently in CMS and simultaneously scheduling in CMS [24] etc. Of these issues, the cell formation problem is an area that has been more researched in literature [25,26]. Exceptional elements are defined as parts which must be processed in different cells and therefore they have intercellular movements. [27,28] developed a model which introduces different states for exceptional elements considering inter-cell and intra-cell movement, machines duplication and subcontracting costs. Saad proposed an integrated approach to redesign CMS considering emphasis on redesign aspects.

If probability information is known, uncertainty is described using a (discrete or continuous) probability distribution on the parameters, otherwise, continuous parameters are normally limited to lie in some pre-determined intervals [29]. There are some approaches such as stochastic programming, queuing theory and robust optimization which can be applied for uncertainty modelling. In this study, it’s assumed that random parameters have continues probability distribution. Also, queuing theory will be applied to reach desired results.

Queuing theory can be applied to any manufacturing or service systems (also, in cellular manufacturing systems). For example, in a machine shop, jobs wait to be machined. In a queuing system, customers arrive by some arrival process and wait in a queue for the next available server. In the manufacturing framework, customers can be assumed as parts and servers may be machines. The input process shows how parts arrive at a queue in a cell. An arrival process is commonly identified by the probability distribution of the number of arrivals in any time interval. The service process is usually described by a probability distribution. The service rate is the number of parts (customers) served per unit time. The arrival rate of a queuing system is usually given as the number of parts (customers) arriving per unit time. Thus, measurements of a queue system such as maximization the probability that each server is busy (utilization factor), minimization waiting time in queues (that leads to minimization work in process in cells) and etc can be optimized and cells will be formed optimality. In addition, we consider sub-contracting or outsourcing as a penalty cost for exceptional elements. In this way, if a part needs to be operated on a machine isn’t located together in a same cell, due to use subcontracting, the total capacity of machine is not used completely and the machine will be idle. Therefore, by minimizing costs related machines’ idleness rate (the probability that a machine is idle), cells with the most similarities in processing and also, optimized part families will be formed, concurrently. Sample of a manufacturing cell modelled as a queuing system is shown in Fig. 1.

In [30], the assignment of workers to cells beside parts and machines where generic algorithm was prepared in the study for cubic cell-formation problem was considered. While [31] carried out an improved artificial bee colony algorithm for flexible job. Shop scheduling problem with fuzzy processing time, multiple-objective optimization for sustainable supply chain network design considering multiple distribution channels was carried out by [32].

New criteria for confirmation of Cellular manufacturing considering product mix variation was investigated by [33] while [34,35] developed a comprehensive mathematical model for dynamic cellular manufacturing system and a robust optimization model for cellular manufacturing system into supply chain management respectively. Handling ties in heuristic for the permutation flow shop scheduling problem was done by [36]. [37] carried out study on assembly line workers assignment and balancing problem with stochastic worker availability. While analysis of approximately balanced production lines was carried out by [38]. In addition to the aforementioned authors and their contribution, current works done in these areas of cellular manufacturing are hereby summarized in Table 1.

Considering the previous works reviewed, it seen that there is no research on computer aided system for cellular manufacturing of product varieties management. Hence this research addressed this research gap.

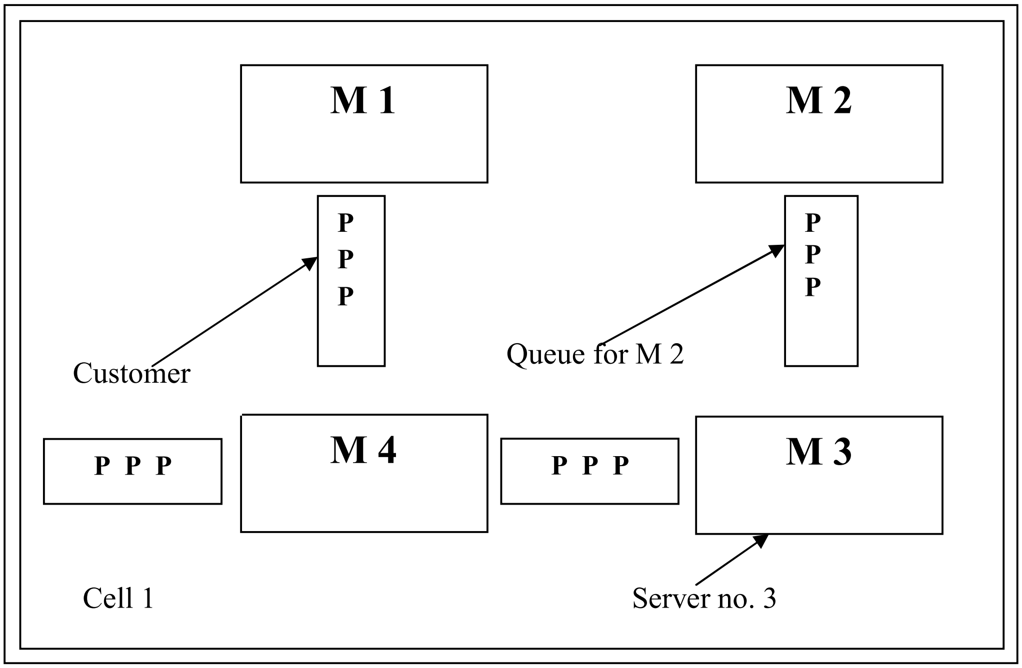


Fig. 1. Sample of a cell in a CMS problem formed as a queuing system
M: Machine; P: Product
Source: [29]

Table 1. Summary of current work done on cellular manufacturing

S/N	Author	Contribution (s)
1	[39]	Designed dynamic cellular remanufacturing system (DCRS)
2	[40]	Carried out review on dynamic cellular manufacturing system
3	[41]	Cellular manufacturing system considering machines reliability and parts alternative process routings was designed by the author.
4	[42]	Their study was towards a psychological consistent cellular manufacturing system
5	[43]	Designed a cellular manufacturing system considering decision style, skill and job security by NSGA – II and response surface methodology.
6	[44]	Dynamic Virtual cellular manufacturing was developed through agent– based modelling
7	[45]	Application of effective two – phase P – median approach for the balance call formation in the design of cellular manufacturing system was carried out by the author.
8	[46]	Developed a real options model of phased migration to cellular manufacturing
9	[47]	Agent – based dynamic part family formation for cellular manufacturing applications was carried out by the authors
10	[48]	The author designed and reconfigured models for dynamic cellular manufacturing to handle market changes.

3. METHODOLOGY

This sturdy covered, strategic decisions required, procedure for the model development, the required software for the model implementation and its application.

3.1 Procedures for Model Development

Notations

Indexes

i – Product indexes
j – Machine indexes
k – Cell indexes

Parameters

P – Number of products
M – Number of machines
C – Number of cells
M_c – Maximum machines allowed in a cell
ID_{rate} – Idleness rate
A_u – Average utilization
M_{int} – Intercellular movement
PR_{tot} – Total productivity
LT – Lead time
CT – Cycle time
U_{cost} – Unit cost
Del_{time} – On-time delivery
LT_{av} – Average lead time
D_{av} – Average demand
V_{add} – Value added time
NV_{add} – Non-value added time
OP_q – Output quantity
IP_q – Input quantity
T_{cost} – Total cost
O_p – Output
I_p – Input
W_c – Work commence
PRLT – Productivity lead time
St – Set-up times
D_r – Delivery ready
W_t – Waiting time
ASS_{cost} – Cost of assigning a product to a cell
PR_{vol} – Production volume coefficient
D_{var} – Demand variation
STB_{des} – Design stability coefficient

3.2 Model Formulation

$$PR_{tot} = OP_q / IP_q \quad (1)$$

$$PRLT = V_{add} + NV_{add} \quad (2)$$

$$CT = W_c + D_r \quad (3)$$

$$U_{cost} = T_{cost} / OP_q \quad (4)$$

$$Del_{time} = PRLT_{av} \times D_{av} \quad (5)$$

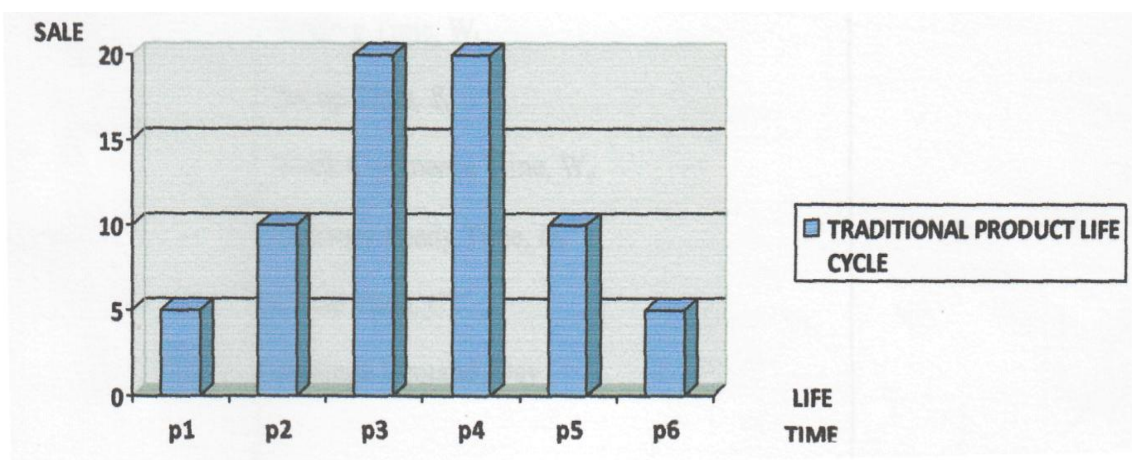


Fig. 2. The traditional product life cycle

The proposal product variety cost function parameters is as shown in Table 2. The traditional product life cycle is also shown in Fig. 2.

3.3 Software Development

The flow chart for the software development is as shown in Fig. 3.

3.4 Software Development Tools

The software of this project was developed using C-SHARP program which gives desired output based on the availa (Ip_q), Output quantity (Op_q), Total cost rate (T_{cost}) Waiting time (W_t) Setup time (S_t), Work start up time (W_c), Delivery ready time (D_r) Cycle time (CT), Average demand (D_{av}), The outputs derived from the software are: Total productivity (PR_{tot}) Production lead time (PRLT) Unit cost (U_{cost}), Circle time (CT) and On-time delivery (Del_{time}).

Table 2. Proposed product variety cost function parameters

Production volume	PRvol	Effect in $ASS_{cos}t$
High	1	PRvol
Medium	2	PRvol
Low	3	PRvol
Position in the life cycle	**D_Var**	**Effect in ASS_{cost}**
P3,p4	1	J-'var
P2,P5	2	i-'var
PI,p6	3	-Uvar
No of design changes/ product age	**STBdes**	**Effect in $ASS_{cos}t$**
Low	1	STBdes
Medium	2	$STB_{des}{}^3$
High	3	$STBd_{es}$

Today's high level programs are transformed into machine–executable form by the computer. They were designed with the subject of making it easier to express algorithms fully while still generalizing machine language procedures [49] the programming languages such as C–sharp (C#) and visual Basic use a different approach. Object – oriented programming (OOP) and event- driven programming [50].

The C – sharp was designed and implemented with the Microsoft visual C# programming language on the Microsoft. Net Platform. The C–sharp and Net platform were created in 2001 by Microsoft to ease the pain of software development [51,52]

These tools have some unique features that makes software development extremely easy in a connected world [49]. To speed up the development process, Microsoft ® visual studio ®2005 was used. This tool makes it easier and faster to write visual C# ® on the Microsoft. Net R platform [53,54].

3.5 Software Application

In this research, we assume each machine to be a server and each product to be a customer where servers should serve customers.

C sharp language (C#) was used in developing this software because it is very easy to use and understand. It presents computation, visualisation and programming in an easy to use environment where problems and solutions are expressed in simple and easier mathematical notation.

The C# programming language is used in many different areas of application, but the most prolific area is UNIX operating system application. The C# language is also used in computer games.

UNIX operating systems, Computer games, for creating software like" UNIX" "WINDOWS" many antivirus e.t.c.

C# is used to write programs like "Embedded Device" chip designing, industrial automation products e.t.c.

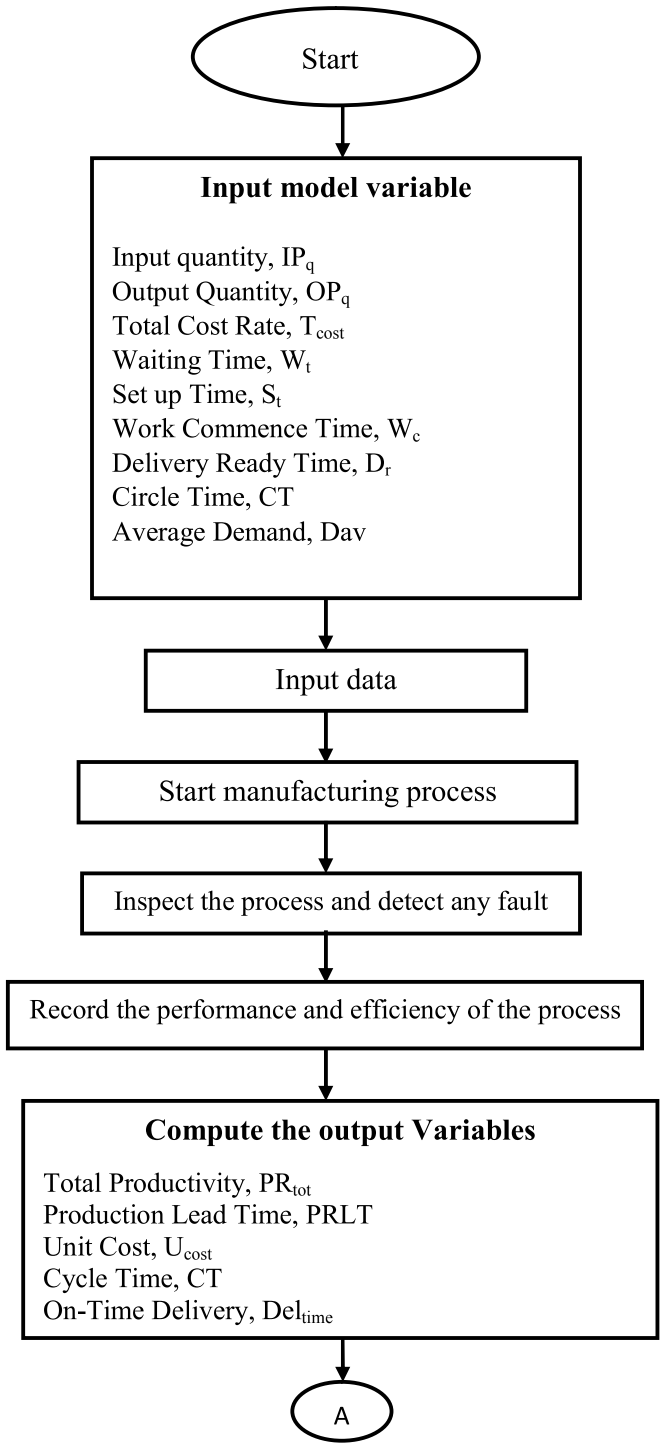
Case Study: Coop Cocoa Processing Industry was used as case study for this research. The company was located at Kilometre 5, Ilesa / Owo road Akure Ondo State Nigeria. The company was established to process dried cocoa beans into semi-finished products (cocoa liquor, cocoa butter, and cocoa cake).

Fig. 4 is the description of all the interface in the development of the progress. This is the C-Sharp interface, it contains of the work space, the file structure, the menu bar, the standard tool bar, the tools bar, and the properties bar.

Base on the data collected from Case study, the model as well as its developed software were ntested for their performance evaluation. The results are as shown in Fig. 6.

This study has actualized the application of group Technology, through which cells were designed in such a way that some measures of performance were obtained e.g. productivity cycle time, productivity lead time, unit cost and on-time delivery. The developed model and its software are capable of reducing companies' production lead time through the elimination or reduction of waste in their production lines.

Flow chart



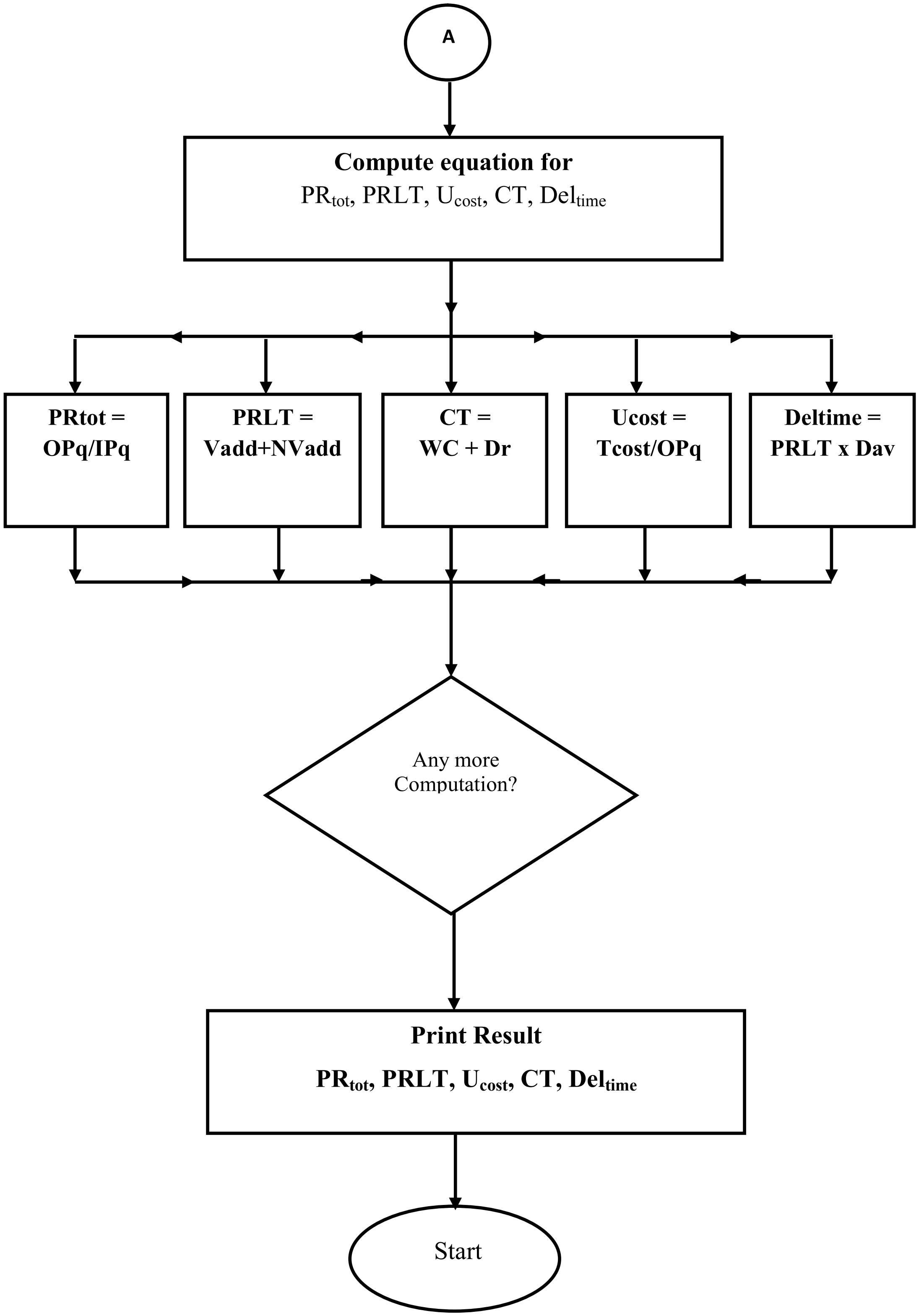


Fig. 3. Flow chart for software development

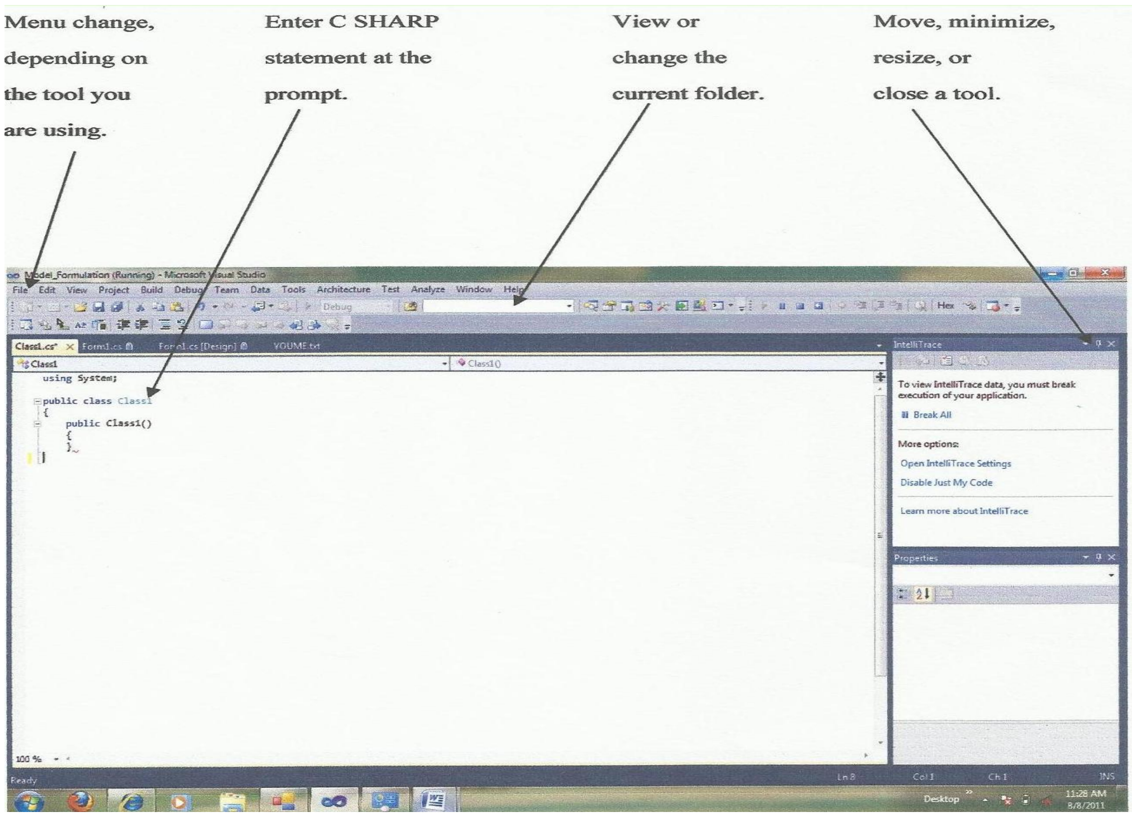


Fig. 4. Description of the C-SHARP interface

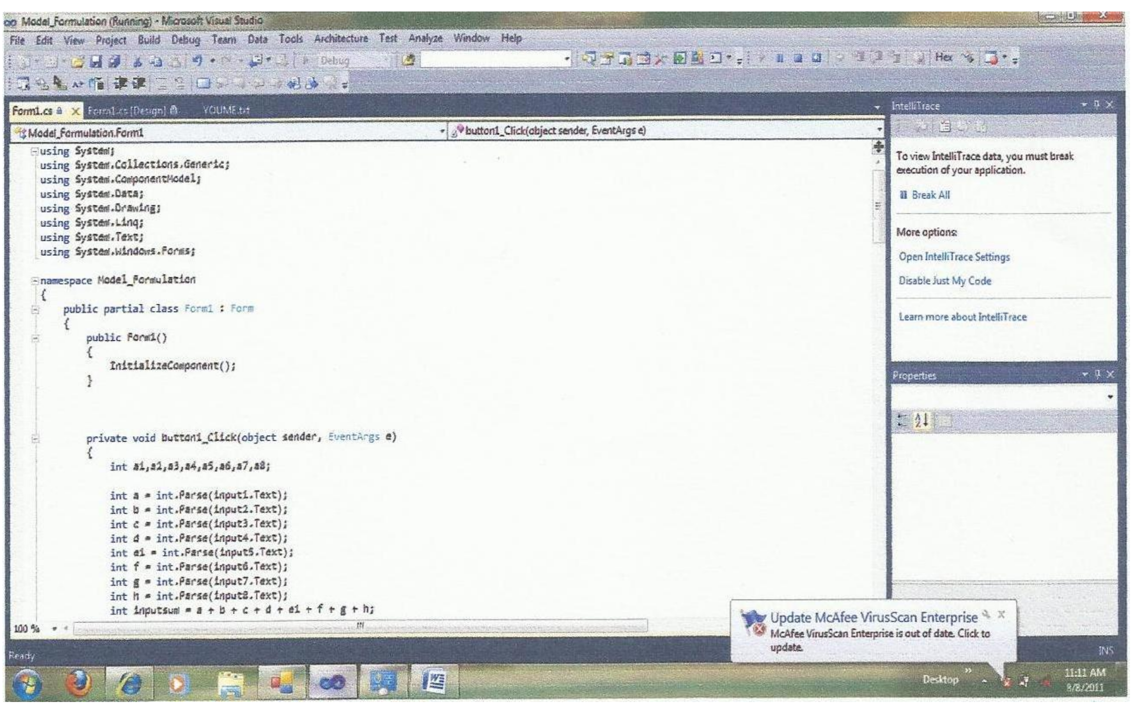


Fig. 5. Coding environment

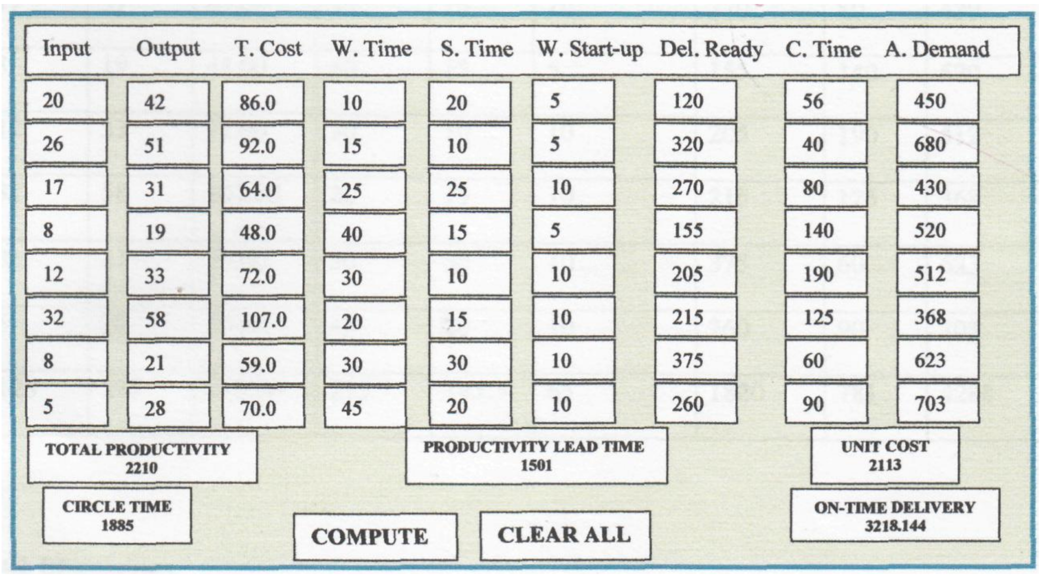


Fig. 6. Result sheet displaying the generated results from the software

4. RESULTS

From the mathematical model identified and the software development, Table 3 is the summary of the numerical results generated from the software.

The major objectives of this study which are to actualize the application of Group Technology have been achieved. The calls have been designed in such a way that some measures of performances were obtained such productivity and cycle time. Production parameters for productivity i.e unit cost, on-time delivery and lead time were measured. In addition to the above the distance travelled by materials, the inventories and cumulative lead times were reduced.

The correlation coefficient of both the input and output data is hereby determined.

X	Y	X^2	Y^2	XY
20	42	400	1764	840
26	51	676	2601	1326
17	31	289	961	527
8	19	64	361	152
12	33	144	1089	396
32	58	1024	3364	1856
8	21	64	441	168
5	28	25	784	140
128	283	2686	11365	5414

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - (\sum x)^2}.\ \sqrt{n\sum y^2 - (\sum y)^2}.}$$

$$r = \frac{8(5414) - (128x\ 283)}{8(2686) - (128^2 .\ \sqrt{8(11365) - (283)^2}}$$

$$r = \frac{7088}{71.442\ \times 104.072}$$

$$r = \frac{7088}{7435.118} = 0.95331372011$$

$$r = 0.95\ 95\%$$

The result of 0.95 shows a strong correlation between the input and output data. This shows the error is 1-0.95=0.05 or 5%.

5. DISCUSSION

In the system, when the overall averages were analysed, we observed that the justification of high investment of flexible system is achieved easily. The last objective is the on-time delivery objective. The solution is constructed to form independent cells, feasibility forces the product made intercellular movements at the last step. The number of intercellular movement of product in this approach is less than the dedicated challenger. Integration of flexible systems decreases the exceptional products in the system, increasing the efficiency of the Cellular Manufacturing System Design (CMSD).The graph of output quantity against value added is shown in Fig. 7.

Table 3. Summary of numerical result generated

Input (tonne)	Output (tonne)	Total cost rate ($)	Waiting time (min)	Setup time (min)	Work start-up time	Delivery ready (min)	Circle time (min)	Average demand (tonne)
20	42	86.00	10	20	5	120	56	450
26	51	92.00	15	10	5	320	40	680
17	31	64.00	25	25	10	270	80	430
8	19	48.00	40	15	5	155	140	520
12	33	72.00	30	10	10	205	190	512
32	58	107.00	20	15	10	215	125	368
8	21	59.00	30	30	10	375	60	623
5	28	70.00	45	20	10	260	90	703
128	283	598.00	215	145	65	1820	781	4288

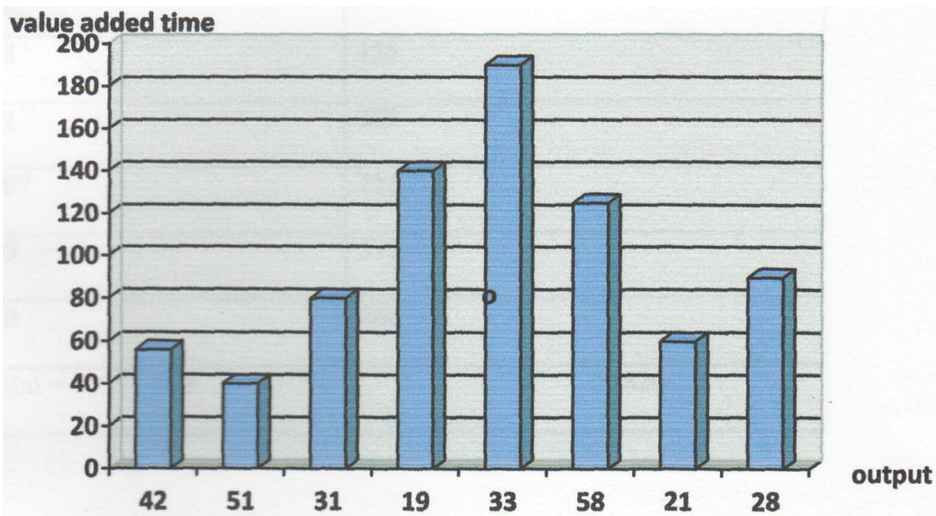


Fig. 7. Output quantity against value added time

Fig. 8. Graph of delivery ready goods against total cost rate

Plotting a chart which shows the relationships between the output quantity and the value added time. The higher the output quantity, the lower the value added time, or vice versa, meaning that the values don't only rise alone it sometimes falls also.

And plotting another chart that shows the relationship between the delivery ready goods and total cost rate here the values in the goods ready for delivery is always greater than the total cost in all the processes involved because a greater amount of output is often expected when we have an effective cell formation layout. This is shown in Fig. 8.

The chart of Output quantity against value added time associated solutions when proposed model is solved for 8 times where all parameters applied in the model are fix expected rate cost are obtained. It's known that for a cellular manufacturing system one of the important factors in order to identify ideal cells is to have minimum intercellular movements.

6. CONCLUSION

In today's world, while the customers are expecting product variety, it makes the manufacturing processes considerably difficult. This has implications for integration of flexible manufacturing systems. Group technology applications has further benefits at the production floor. We propose a model that makes technology selection and cell formation to hedge against the changing market dynamics. In our multi-objective study, we modified a well known similarity measure to handle the operational capability of available technology. In order to integrate the market characteristics in our model, we proposed a new cost function. The study shows the significance of hybrid technology implementation at the production floor to cope with the variations in the market. We also show the necessity of integration of operational capability of machines in the similarity context. Integration of flexible systems decreases the exceptional parts in the system, while increasing the efficiency of the CMSD.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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