Analytical Research on Agility Index of a Manufacturing System

Ezekiel Omoniyi, Peter Oyekola, KamalakantaMuduli, John Pumwa, Samuel Bara-Hart

Abstract— Agility level of any organisation portrays the degree of flexibility of the organisation in responding to customer needs. Hence, knowledge of agility level assumes its importance for developing the competitive strategies for any organisation including the manufacturing firms. In this line monitoring the level of agility and flexibility in a manufacturing organisation could be considered to be an important element for meeting the business objectives. However, proper evaluation of this agility metrics becomes deceptive to define owing to its vague nature and application in non-manufacturing related systems. In this regard an attempt has been made in this research to develop agility index of 3 types of plants. The results of this study revealed the Polyethylene plant has the highest agility index of 9.51 out of the three case plants. The results also revealed that the agility index of the Olefins plant is 7.32 and that of the Polypropylene plant is 6.37. Plants with a high agility index reflects its higher degree of agility level.

Index terms: Agile manufacturing, analytic hierarchy process, agility index.

I. INTRODUCTION

Recent mechanical advances have established frameworks for unique structure of modern business environment and this inclination is gradually increasing with competition and globalization. Now, customers demand for the best items at reasonable expense, lesser time and more customization. This in turn has increased pressure on companies to change their policies in order toretain or improve their share of the market. A wide range of arrangements have been advanced, for example, organizing, reengineering, measured associations, virtual enterprises, high performing associations, representative strengthening, adaptable assembling, and so forth. Nonetheless, the most conspicuous of the methodologies is the utilization of agility.

The concept of agility was first introduced in the Iacocca Institute which portrayed it as a crucial factor that influenced competition and as an assembly framework with the capacity to meet the dynamic necessities of the commercial centre. According to Prytz (2007) agility is characterised as a fast and proactive alteration of business mechanisms to abrupt unexpected variations. The concept adopted by Goldman et al. (1995) compared agility to an exhaustive reaction to challenges postured by a business sphere governed by variation and susceptibility. It can also be the ability to endure and flourishing in an aggressive business environment by quick and adequate response to change (Gunasekaran, 1998). It is seen that a large portion of the above stated definitions talk about regular attributes of agility such as time, adaptability of framework, and responsiveness. Hence, we express the associations which can respond and react to a domain that regularly weigh the firm to adopt changes that aims at satisfying customers and accomplishment of business targets as agile. Agility depends on abilities found in three primary venture measurements: manufacturing, product and market measurements. By extending this study, Jackson (2003) divided agility capacities into product related change abilities, operational change competency, internal and external collaboration and individuals, knowledge and creativity.

Agility is characterized as the capacity of a venture to work productively in a quickly changing and persistently dividing worldwide market condition by creating astounding, superior, client arranged merchandise and enterprises. It is the result of innovative accomplishment, progressed authoritative and administrative structure and practice, additionally a result of human capacities, abilities, and inspirations. In manufacturing sector, flexibility is proportional with product series utilizing a specific system whereas agility suggests quick overhaul or change of procedures or the capacity of adjustment to instantaneous impulsive changes in market openings and pressures, consequently it is more extensive than adaptability as it includes the capacity to change starting with one circumstance then onto the next, with every circumstance not generally characterized early.

The issues in measuring both adaptability and readiness are pretty much the same. Like the instance of measuring manufacturing adaptability, there is no direct versatile and comprehensive treatment of agility segments. In the work of Goldman et al., (1995), the general issue of agility estimation is restricted to three straightforward and essential inquiries of the factors to measure, measuring technique and evaluation of results since there is no direct synthesis technique to combine estimations and decide agility.

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In swift response to customers demand and market change, agility is necessary. In the strive for agility, profitability cannot be compromised due to the competitive nature of the market and to achieve this goal of flexibility, organisations

need to understand its concept relative to their scope of operation and business environment subsequently, the appropriate characteristics needed to achieve this can be acquired.

In this paper, a study of a manufacturing company in Nigeria was conducted to evaluate and validate a quantitative method employed in analysing agility index of the manufacturing system. The study identified various factors that can influence agility and the combination of this factors forms the agility index. The results show that a number of enablers exist and these factors must be efficiently managed to establish a high value of agility index. this approach helps in identifying the weak points in sub systems of the manufacturing system and help in determining appropriate strategy to improve their performance.

II. LITERATURE REVIEW

Although research geared towards the development agile model is ongoing, agility evaluation in itself is not extensively explored given that it has not been established and designed in an industry specific manner. Toward the start of the twentieth century, manufacturing was done as a procedure where people would make an item from start to finish. The assembly line remained the pillar of the manufacturing scene until W. Edward Deming introduced the concept of total quality management which includes quality into an item (Deros, (2011)). High quality items will cost less to keep up and develop than a modest item always waiting be improved even before the item hits the market. Lean manufacturing was later introduced as organizational technique to sort resources of specific job. A case of lean assembling could be that Ford makes a car in 15 days however Mercedes can make a similar car sooner due to better sorting of resources and cost allocation in production run which contrast with Ford's 15-day creation run. With lean manufacturing, workstations and process ergonomy is a need. Kariuki et al. (2013)

Agile manufacturing is a recent trend adopted by manufacturers which focuses on providing solutions to customers demand while simultaneously sustaining high quality products and reducing production costs Crişan et al. (2015). This idea is similar to lean manufacturing as expenses which are not directly allied with production are eliminated to ensure that customers need are swiftly and effectively responded to. Sometimes companies integrate both agile and lean manufacturing.

Business agility is becoming increasingly relevant due to market instability and volatile nature. The framework developed by Sherehiy et al. (2007) in implementing agility in various organizations involved determining the nature of environment of the organization, assessment of agility, gap analysis for presenting plan of action finally, agility providers are used to achieve agility upon which the capabilities of the organization can be realised. Similarly, Jackson et al. (2003) approach for agility assessment comprises evaluation of market tendencies, objectives and improvements.

Hoek, (2001) empirical model was however based on clients responsiveness, virtual, process and network integration and measurements where the total agility is the average of individual characteristics. Tsourveloudis et al. (2002) proposed a knowledge-based framework for evaluation of manufacturing agility which involves quantitatively distinct parameters projected and grouped into production, information infrastructures, individuals and market.

In the works of Giachetti et al. (2003), Yauch (2011), agility assessment was based on analytical hierarchy and quantitative index process While Ren et al. (2009) implemented pair wise comparison. Yauch (2011) study was however based on conceptualization as a performance result as indicated by the organizational success and environmental. The model however fits in the measures and parameters necessary to ascertain the agility levels of various manufacturing organization which contrast Arokiam et al. (2005) that proposed a model which combined peripheral parameters and pointers of agile competence.

Yang & Li, (2002) proposed a multi graded fuzzy approach for Mass Customizable (MC) organization where the model was based on weights and rankings matrices of various agility attributes given by specialists who evaluated the organization based on some crisp figures. Indirect approach has also been implemented in determining agility Metrix as seen in Arteta & Giachetti, (2004) who used complexity as a surrogate measure for agility.

Although some approaches are fairly understandable and easily implemented, their rating systems are regularly criticized, due to evaluator's subjective judgment, likelihoods of the different possibilities and vagueness characterised with assigning figures to qualities. In overcoming this issues, several logic based models were proposed. Klir, (1995) and Wedding (1997) concept enabled the use of verbal terms by assessors to evaluate pointers related to language countenance, where each verbal term is correspondingly connected with fitting membership role. The IF-THEN approach later proposed by Tsourveloudis & Valavanis (2002) was a build-up based on prior effort while Ganguly et al. (2009) measurement of responsiveness takes into consideration the market share and cost effectiveness which is a function of corporate agility. The combination of this model with Yang & Li, (2002) gives the agility level of any corporate initiative.

Finally, Jain et al. (2008) and Jain & Benyoucef, (2007), proposed a Fuzzy based approach which enhances flexibility in decision making for assessing agility using quantifiable and qualitative traits. It has been practically applied in the supply chains environment. This approach is practical in utilising the fuzzy association rules from the accessible record.

A. Agility Index

Various combination of factors affects agile manufacturing in organisations such as the type of technology implemented, production strategy, administrative involvement and rivalry.

In order to accomplish the dynamic expectations of patrons, organisation must ensure adoption of this drivers which are of utmost importance in effecting agile manufacturing model. Nevertheless, these measures are intended for specific requirements. Therefore, These measured index indicates the ability of a manufacturing plant to adapt to change in the market environment.
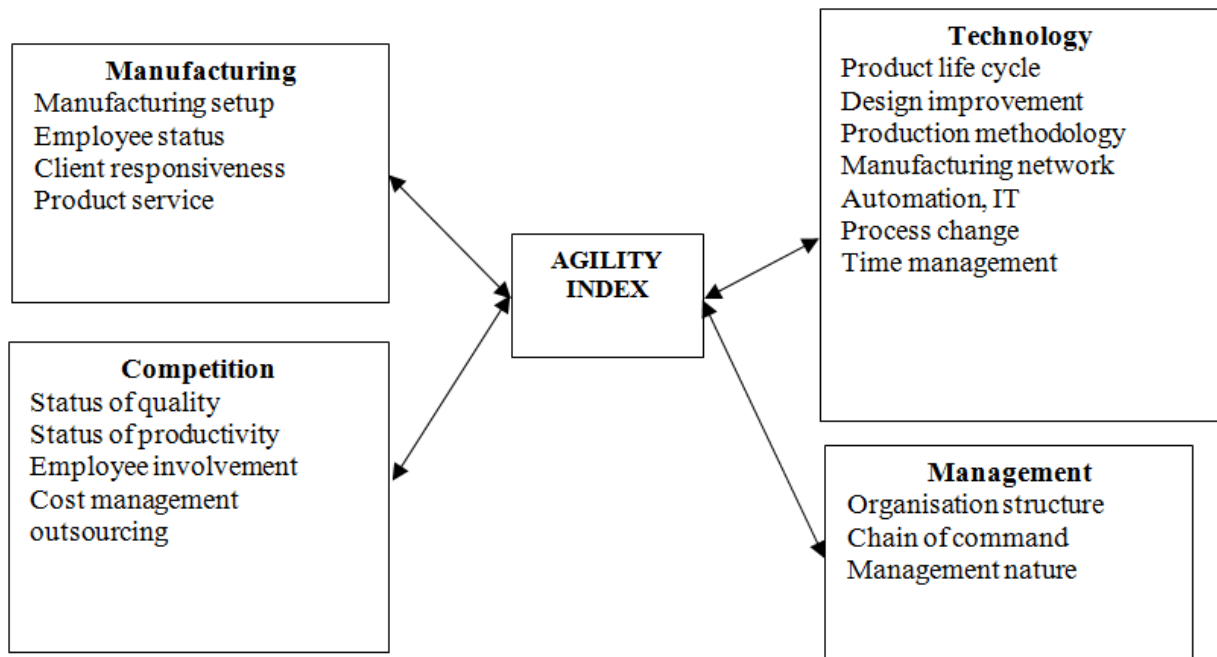

Figure 1: Classification of Agility Index

Evidently, the studies from the researchers shows the effort invested in establishing the different agile nature of organisations in the dynamic business environment. This paper however develops an analytical methodology to estimate the inherent characteristics of the production plant in the study.

III. METHODOLOGY

A Poly-Olefins producer of a range of Polyethylene and Polypropylene products was used as case study in determine the effectiveness and accuracy of the model. The company produced Ethylene and Propylene as its main product while pentane, fuel gas and hydrogen are by-products. The plant had three manufacturing units and five furnaces in use with one as standby and for de-coking. while pentane, hydrogen and fuel gas are the by-products.

In the Polyethylene Plant, Ethylene is used as the raw material. The plant has the ability of producing both high and linear low-density categories of Polyethylene using two different catalyst systems to tailor-make grades in short spans of time.

The Polypropylene plant uses propylene and PRF as raw materials and has the ability of producing homo-polymers, random-polymers and co-polymers widely used for woven sacks, household goods etc. This paper analyses and compare the agility index of each plants.

The model is subdivided into stages where each stage has its own constraints. The effect of these capabilities on responsiveness is determined by hierarchical analysis to determine the relative weight of each element and capability and also the use of analytic governing equation to estimate the values of each element and capability. The relative importance of the elements that make up a capability and the trade-offs associated with selection of any essential elements was evaluated. It is assumed that the trade-offs will not affect the accuracy and reliability of the results in this study. Also, the equations used have been obtained by the experts and are used to determine the elements of the analytic hierarch process (AHP) of each capability.

Table 1: Olefin manufacturing plants data

	Olefins Plant	Polyethylene Plant	Polypropylene Plant
Product	Propylene and Ethylene.	Polyethylene	Propylene
Quantity	Propylene – 360MTA	280000MTA	120000MTA
	Ethylene – 120MTA		
Price	raw material for propylene and ethylene plants	N2800/bag (HDPE), N2300/bag (LDPE)	N2500/bag

Manufacturing Life Cycle	360 days	360 days	360 days
Time of delivery	Continuous process (feed stock)	24hrs after payment	24hrs after payment
Flow time of product	Continuous process	< 1min	< 1min
Number of workers	300	375	250
Idle time	0	0	0
Max Output	160000 MTA	270000 MTA	18000 MTA
Number of equipment	Pumps, Compressors, Columns	Various Pumps (150ton/hr.), Column (30ton/hr.)	Various sizes of pumps about 100, Columns
Number of boilers	3	-	-
Capacity	150ton/hr.	-	-
Production line	2 (Propylene and Ethylene)	2 extruders, 2 bagging	2 extruders
Energy input	3 Megawatt	3.5 Megawatt	3.5 Megawatt
Material input	-	Ethylene gas	Propylene gas
Alternative for each	pairs	Pairs	Pairs

In the determination of Flexibility,

$$Routing \text{ Flexibility (RF)} = \frac{\sum_{i=1}\sum_{j=1}x_{ij}}{n(n-1)}$$ Nagarur, (1992) (1)

$$Delivery \text{ Flexibility (DF)} = \frac{\sum_{j=1}^{J}(\varepsilon_j-t^*)}{\sum_{j=1}^{J}(L_j-t^*)}$$ Beamon, (1999) (2)

Volume flexibility (VF) = $\frac{\sum_{t=1}^{T}V_i}{TC}$ Gerwin, (2005) (3)

Therefore, by combining routing flexibility, delivery flexibility and volume flexibility we can deduce equation for flexibility capability.

flexibility = $w_{f1}(f_1) + w_{f2}(f_2) + w_{f3}(f_3)$ (4)

for the modelling is assumed that f1 is routing flexibility, f2 is delivery flexibility and f3 is the volume flexibility which equals

$$= w_{f1}\left(\frac{\sum_{i=1}\sum_{j=1}x_{ij}}{n(n-1)}\right) + w_{f2}\left(\frac{\sum_{j=1}^{J}(\varepsilon_j-t^*)}{\sum_{j=1}^{J}(L_j-t^*)}\right) + w_{f3}\left(\frac{\sum_{t=1}^{T}V_i}{TC}\right) \quad (5)$$

Table 2: symbol representation for flexibility calculation

Symbol	Definition
Xij	Indicator variable (equals 1 if a route exists from i to j and 0 if otherwise)
n(n-1)	potential routes in a systems of n components
t*	current time period
Lj	due date period for delivery of j
Ej	Earliest date for delivery of j
Vi	production volume in sub-period time i
T	Time
C	production capacity of the assembly line

Furthermore, in determining competency, Machine utilization is given as

$$U_{mu} = \frac{T_a - (T_{idle} + T_d)}{T_a}$$ (Subramaniam et al. (2011) (6)

According to De Toni & Tonchia, (2001) Total quality offered is expressed as

$$TQO = \frac{\frac{(1+p_1)}{(1+p_1+p_2)}}{(1+p_1 r)}$$ (7)

Productivity(Pr) $= \frac{Output\ of\ all\ product\ sold}{C+L+E+M+Q}$ Grünberg, (2004) (8)

Therefore, by combining machine utilization, total quality offered and productivity, competency can be deduced as:

$$C = \sum_{i=1}^{n} w_{ci} c_i = w_{c1} c_1 + w_{c2} c_2 + w_{c3} c_3 w_{c1}(U_{mu}) + w_{c2}(TQO) + w_{c3}(Pr) \quad (9)$$

Table 3: symbol representation for competency calculation

Symbol	Definition
Ta	available time
Tidle	schedule idle time
Td	loss of utilization during operation
p1	reworked fraction
P2	scrapped fraction
r	input consumption rate
L	labour inputs
E	energy inputs
M	material inputs
Q	miscellaneous inputs
C	capital inputs

For Speed calculation, the equation governing batch production according to Groover, (2010) is given by

$$MLT_j = \sum_{i=1}^{o_j}(T_{suji} + QT_{cji} + T_{noji}) \quad (10)$$

While For flow production,

$$MLT = n_o(T_r + Max\,T_o) = n_0 T_c \quad (11)$$

Dabbas, (2001) also defined on time delivery (OTD) as

$$OTD = \sum_{I=1}^{n}\left[\frac{x_i}{\sum_{i=1}^{n}x_i}\right] \times \%OTD$$

Where

$$\%OTD = \frac{No\ of\ product\ shipped\ on\ time}{No\ of\ product\ i\ on\ time + No\ of\ products\ i\ early + No\ of\ product\ i\ late}$$ (12)

Flow time (F) was defined by Krajewski et al. (2008) to be:

$$F = \frac{\sum_{j\Phi}(P_j - r_j)}{N}$$ (13)

Therefore, by combining Manufacturing lead time, on time delivery and flow time, equation can be deduced for speed in manufacturing system.

$$\text{Speed} = \sum_{i=1}^{m} w_{si} s_i = w_{si}(F) + w_{si}(OTD) + w_{si}(MLT) \quad (14)$$

Table 4: symbol representation for speed and flow calculation

Symbol	Definition
i	operation sequence in the processing
Tsuji	setup time
Tcji	operation time
Tnoji	downtime time
Tc	cycle time of the production line
no	number of operations on the line
Tr	transfer time
Max To	operation time at the bottle neck
Xi	total number of products shipped for product typei
n	number of product type
N	number completed
Φ	set completed
rj	arrival time
pj	Completion time

Responsiveness R=

$$W_c \sum_{i=1}^{n} w_{ci} c_i + W_s \sum_{i=1}^{m} w_{si} s_i + W_f \sum_{i=1}^{p} w_{fi} f_i \quad (15)$$

$$\sum_{i=1}^{n} w_{ci} c_i \le 1 \, ; \, \sum_{i=1}^{n} w_{si} s_i \le 1 \, ; \, \sum_{i=1}^{n} w_{fi} f_i \le 1$$

$$W_{ci} + W_{si} + W_{fi} \le 1$$

C_i is the element i that contribute to the competency capability which might be appropriate technology, product quality, cost effectiveness etc. while S_i and f_i are the element i that contribute to speed and flexibility as agile capability respectively.

Similarly, w_{ci} is the weight density of specific element of competency (c) in relation to the element that contributes to competency. The weight density ranges from 0-1 for the specific element and the summation of the element weight density of a specific capability will be equal to 1 as stated in equation 16 below.

Also, w_{si} and w_{fi} are the weight density of specific element of speed and flexibility respectively.

Responsiveness therefore becomes;

$$R = W_c(C) + W_s(S) + W_f(F) \quad (16)$$

Where

$$W_c + W_s + W_f = 1$$

and W_c, W_s and W_f can be obtained either by empirical data from expert or from analytical method and is subjected to change as determined by operating conditions where W_c is the weight density of competency with respect to responsiveness, W_s is the weight density of speed with respect to responsiveness and W_f is the weight density of flexibility with respect to responsiveness.
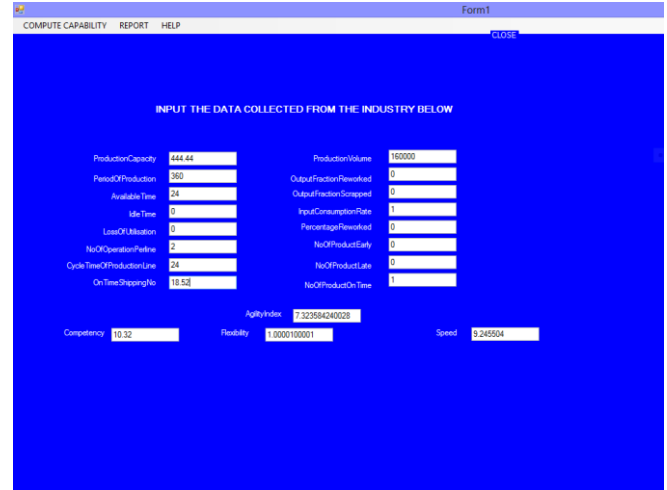

Figure 2: modelled agility index interface

IV. RESULTS AND DISCUSSIONS

From the results in figure 3 below, the Polyethylene plant has the highest agility index of 9.51. This falls within the range of good agility index. The Olefins plant comes next with an agility index of 7.32 which falls within an average agility index range while the Polypropylene plant comes last with an agility index of 6.37. This falls within the average agility index range.

Table 5: Olefins Plant Capabilities

PLANT	OLEFINS	POLYETHY LENE	POLYPRO PYLENE
Agility Index	7.32	9.51	6.37
Competency	10.32	10.32	10.32
Flexibility	1.00	0.96	0.98
Speed	9.25	15.36	6.62
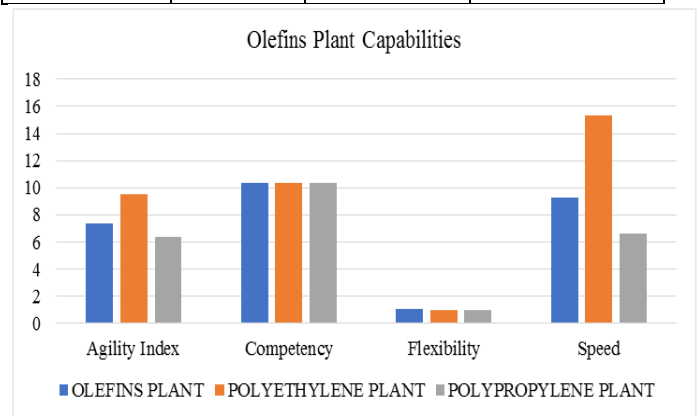
Figure 3: Comparison of Flexibility

From the calculated results, the Olefins plant flexibility was evaluated as 1.00 followed by Polypropylene plant and Polyethylene with 0.98 and 0.96 respectively. Also, speed of operation was determined as 9.25 in the Olefins plant, followed by Polyethylene plant with 15.36. Polypropylene plant scores 6.62 which is low compared to the other two plants.

V. CONCLUSION

The purpose of this paper was to estimate the level of agility of a Nigerian based manufacturing plant. The model showed that the company capacity depended on the ability to provide flexible services. It is seen that by controlling quality of service, agility is affected. Customers involvement also affects the level of agility. The computation was achieved from manufacturing system analytical equations gotten from existing literatures, which was further analyzed and coded using visual basics. From the results obtained, major improvement in manufacturing techniques were identified such as improved speed in the Propylene plant which affects the overall agility index and boost productivity. It therefore becomes evident that identifying agility index is a useful tool for increasing productivity and success of an enterprise as it aids in comparative analysis of set target and competitors influence.

The knowledge of agility helps in future management planning, optimization of production capability, execution of strategies and decision making through the application of manufacturing resource planning, real-time execution systems, etc. in a manufacturing plant. all of which would aid in the restructuring of the plant to management of change. The limitation of this study however is that the implemented model is specifically designed for a particular type of plant or manufacturing system and sector. Furthermore, some metrics involved in measurements are still qualitative and subjective. Therefore, a more generalized and robust model should be developed with a relative analysis on feasibility and application on a wider scope.

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