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Determination of Production System Effectiveness Based on Sustainable Global Standards

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ABSTRACT

Production system effectiveness determine to measure the sustainability of the established industries demands the development of a model for resolving global sustainable productivity challenges. The attributes (internal and external) of industrial failure were determined using questionnaire administration and oral interviews of industry experts in five (5) selected production companies in Nigeria: (Company A); (Company B); (Company C); (Company D) and (Company E). Production System Effectiveness (PSE) factors: Availability A, Performance P, and Quality Q were determined to arrive at manageable decision-making criteria under uncertainty, risk, or competition. Initial measures of PSE were based on the input internal factors (manpower, machine, material, energy, management, information/communication, money, and marketing), while sustainability decisions were determined using globally acceptable standards. The model was tested using data (weighted and normal) from the stated companies to determine their sustainability performances, while paired t-test statistic was used to test the levels of significant difference between weighted (WPSE) and normal (PSE) at 5%. The results indicated varying optimum decisions which were influenced by the nature/types of competition, risk, and standard of measure. The statistical result showed that there was a significant difference between the PSE and WPSE. These differences had little or no effect on optimum decision-making in all companies investigated.

Keywords: Global, Standard, Production, Effectiveness, Sustainability.

1 Introduction

Sustainability means meeting the needs without compromising the production system challenges [1]. Apart from material resources, machinery, manpower, energy, marketing, information technology, and money/funding sustainability are very important. Sustainable productivity performance of industries required optimum harmonization of the stated resources in the delivery of the core production process [2].

Efforts and programs targeted at improving productivity in Nigerian industries have not yielded significant results [3]. The distribution of labor productivity by age of firms reveals that an average productivity of NGN10, 198 per worker is recorded among firms above 20 years of age and that labor productivity increases with the firm's age [4].

With increasing globalization, human capital and manpower development, machine revolution, material advancement, modern communication, advanced marketing, and energy hybridization, a good sources utilization policy is required and can be accessed through qualitative education and training in sources management [5].

Human capital development is crucial and ultimate in propelling productivity. Technological advancements are products of human minds and can only be made productive by positive monitoring and competitiveness. The energy sector also contributed to the industrialization of many nations; its failure however has an advert effect on the nation's economic growth [4].

The manufacturing industry constitutes a large impact that undertakes a series of activities, which include the production of different items, machines, equipment, etc. There are a range of sections in the manufacturing industry, from the managerial section down to production, maintenance, and inspection departments. Due to the competition between corporations, industries, businesses, firms, and organizations, there is always the desiring need for something new. Every industry or firm must have competent management in place to ensure that the production process is always on the right track. For the manufacturing industries to compete favorably with one another, they must be innovative [6]. A competitive manufacturing industry is an ingredient of sustainable development [7]. Sustainable development also means attaining a balance between environmental protection and human capacity building and between present and future needs [8]. In all cases, manufacturing (production) industries played a very important role in achieving a sustainable development goal by 2030 [3].

Production industries required a good transportation system (by land, water, or air) which comprised automobiles, marines, and aeronautics. Transportation industries have played a good role in sustainable development in the areas of safe transportation of raw materials and finished goods to/from the production industries [9]. A good transportation system has enabled waste elimination, and prompt availability of raw materials and other production resources as and when required for production activities, thereby improving resource utilization, procurement management, and sustainability [10]-[12].

Developing countries need accelerated growth and the manufacturing industry provides the bulk of this transition to developed economies. This means a bulk of investment is

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necessary to develop infrastructure for the industries to thrive, reach their sustainable capacities, and attain accelerated Gross Domestic Product (GDP). On this basis, strategic planning geared towards promoting adequate investment in the manufacturing industry is necessary [13].

The global demand for effective utilization of both humans and machinery is increasing due to wastage incurred during product manufacturing. Excessive waste generation has made entrepreneurs find it difficult to break even. The development of a dynamic error-proof Overall Equipment Effectiveness (OEE) model for optimizing the operations of a complex production system is targeted at minimizing/eradicating generated wastes/losses [3].

There is a high need to move from ordinary mechanization to automation of industrial processes to improve efficiency [14]. Maximum productivity is highly needed hence, automation must be followed by a lean workforce [15].

The global mantra in the past four decades has culminated in the desire to achieve sustainability and sustainable development. This mantra has stemmed from concerns for the future, in terms of resource endowment, human health, and the environment. Nigeria has yet to meet this goal as there are several challenges to sustainable industrial development [16]. The progressive incorporation of information and communication technologies (ICT) [17] and their combination with production process technologies have made manufacturing operations more intelligent and sustainable [18].

Interestingly, the research that focused on contributing to sustainability was mainly dedicated to Europe, the Far East, and the Southeast regions of Asia. One reason for this result was huge EU funding for research, which meant that Europe's researchers had access to huge funds for industrial sustainability and digitalization. This funding initiative had contributed to the digital transformation of industries in Europe [18].

In advanced technology platforms, data are a crucial factor in promoting sustainable production and supply chain operations [19]. Sustainable manufacturing is positively mediated using sensors, intelligent algorithms, and actuators to permit data collection in the manufacturing environment [20]. Historic product characteristics can be saved in the blockchain, which allows users to identify the origin, quality, and lead time of the product [21]-[22]. Smart supply chains and transportation systems are critical to industrial productivity [23]-[24].

Design change propagation is a primary source of risk and innovation in complex product (CP) development of a production system which can affect processing sustainability [25]. Linking product design to customer behavior is a good factor in sustaining productivity in a dynamic production environment. The simulation concept was also used in making decisions as it affect productive processes in the past. However, with the availability of solutions and technologies, simulation is no longer a tool with limited scope and analysis. Artificial intelligence with physical systems was considered to allow virtual models to be sensitive to physical changes and aligned with the current state of production processes [26].

The application of an innovative energy system is capable of resolving the challenges created by the inadequacy of energy in the production system [27]-[28]. The effectiveness of operational level and management (EM) practices and their long-term impacts on material inventory was assessed using data from U.S. industrial facilities [29]. Demand-side mitigation solutions such as changing peoples' consumption behaviors can substantially help limit climate change. In the manufacturing realm, promoting, and directing the consumption behavior of customers is a good factor in encouraging sustainable industrial development [30]. Sustainability measures were being re-designed to provide a measurement of the production system within the link of accountability [1]. Measuring and evaluating the performance of production process sustainability is still not a common practice in some companies [31].

1.1 Production System Effectiveness (PSE)

PSE depends on availability rate, performance efficiency, and quality rate. Therefore, PSE increases with the increase of these three elements. An increase in availability rate reduces buffer inventories needed to protect downstream production from breakdowns and increases effective capacity. An increase in the rate of quality products means that there is less scrap and rework, reduces costs, and yields a higher rate of quality [32]-[33]. PSE is a complete performance measurement indicator, but to make it real it requires modification in terms of weights allocation [34], inclusion of production system dynamism, and consideration of production competitiveness. Factors affecting PSE are not equally important in all aspects and different weights of elements played a critical role.

Wudhikarn *et al.* [35] proposed a new PSE indicator without considering production competitiveness. PSE and weighted PSE measures are more realistic because of production dynamism, corruption, and competitiveness consideration.

Global sustainable standards in which production system effectiveness/productivity were been measured are enumerated in Table 1. In this study the choice of sustainable PSE was based on standards, this was rare in the past studies.

Table 1 Sustainable standard of production system effectiveness/productivity

Sustainable Standards/Classes	Effectiveness/Productivity Range	Sustainability Implication
Global Standard, P(G)	≥ 0.85	Sustainable , [36]-[37]

2 Methodology

2.1 Model Development

Factors that hindered productivity in terms of availability, quality, and performance in selected production systems were identified using questionnaire administration and oral interviews with manufacturing experts. These productivity challenges were caused by both external (outside production system) and internal (within production system) factors, individually and collectively. The identified internal factors are manpower, money, machine, energy, management, information/communication, material, and marketing while external factors are sustainable development trends, industrial revolution, and globally sustainable/acceptable standards. The block diagram that shows the relations among the internal, external, and production system effectively is given in Fig. 1.

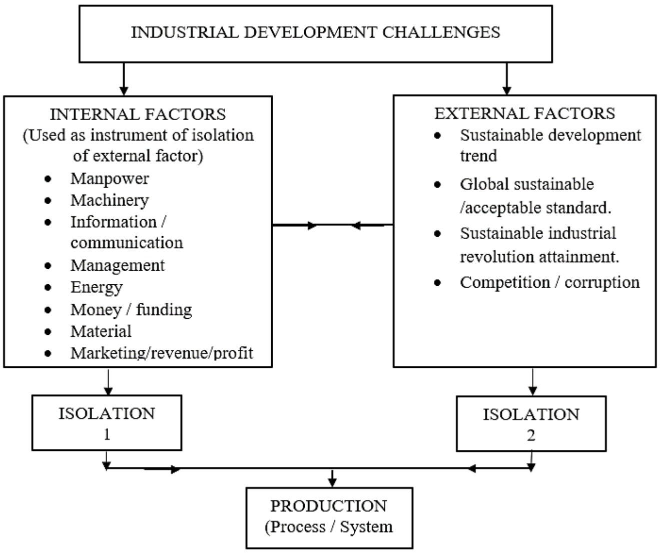

Fig. 1 Block Diagram of Production (Process / System)

The challenges posed by the internal/external factors hindered the attainment of the maximum obtainable productivity index of unity (1). That is for the N number of internal factors, productivity continued to decrease with an increased number of factors N called challenges. Therefore, traditionally, productivity or production system effectiveness (PSE) was mathematically presented as Eq. (1) was modified as in Eq. (2) to take care of the stochastic nature of the process.

$$PSE = APQ \tag{1}$$

$$PSE = P(S) = APQ \tag{2}$$

where,

PSE is production system effectiveness,
A is Availability, P is Performance, and Q is Quality.

Eqs. (1) and (2) are similar because their outcome is always less than 1 but they are different because the former is static while the latter is probabilistic, its outcome can change in space and time. This indicated the real nature of the production system. On this basis, Eq. (2), on consideration of the stated challenges was modified as Eq. (3).

$$PSE = P(S) = APQ < 1 \tag{3}$$

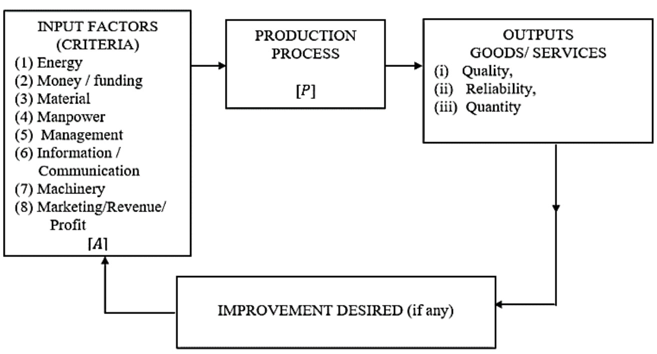

Fig. 2 Block Diagram of proposed Model Characteristic

The problem at hand is how to improve productivity such that external factors hindrance is mitigated. That is a globally accepted standard, $P(G)$, which is termed exogenous variables are satisfied as presented in Eq. (4).

$$P(S) = APQ \geq P(G) \tag{4}$$

Where, P(G) is global acceptable standard.

The block diagram shown in Fig. 2 depicted the improvement strategy developed at meeting the set standards, with the main objective of meeting the condition of productivity stated in Eq. (5).

$$P(S) = APQ = 1 \tag{5}$$

Eq. (5) was made robust to allow weighting of the production system effectiveness factors using the Rank-Order Centroid (ROC) method [34] in which rank 1, 2, and 3 were allocated for lowest, average and highest weights respectively to enable its application in all categories of production system productivity measures. The weighting production system effectiveness (WPSE) was calculated as stated in Eq. (6). Eq. (7) gives the general equations for assigning weight ranking which results to w_1, w_2 and w_3 as stated in Eqs. (8), (9), and (10) respectively [34].

$$P(S) = WPSE = w_1 I + w_2 P + w_3 O = 1 \tag{6}$$

Based on the ROC method [34]:

$$W_i = \left(\frac{1}{K}\right)\sum_{j-i}^{K}\frac{1}{r_k} \tag{7}$$

$$w_1 = \left(1 + \frac{1}{2} + \frac{1}{3} + \cdots \ldots . +1/K\right)/K \tag{8}$$

$$w_2 = \left(0 + \frac{1}{2} + \frac{1}{3} + \cdots \ldots . +1/K\right)/K \tag{9}$$

$$w_3 = (0 + 0 + 0 + \cdots \ldots . +1/K)/K \tag{10}$$

where:

r_k is the rank of the k^{th} objective
K is the total number of objectives
w_i is the normalized approximate ratio scale weight of the i^{th} objective.
w_1 is weight of availability P(I) attribute
w_2 is weight of performance P(p) attribute
w_3 is weight of quality P(O) attribute

It is inferable from the stated Eqns. that if,

$$P(S) = 1, \text{ no challenges in the system (fully sustainable)} \tag{11}$$

$$P(S) = 0, \text{ System has collapsed} \tag{12}$$

$$P(S) < 0{,}85, \text{ System is gradually collapsing but may be sustainable} \tag{13}$$

These outcomes (Eqs. (11)-(13)) led to the establishment of two major decision variables (sustainable or unsustainable, under three conditions (fully sustainable/unsustainable, fairly/averagely sustainable, and fully unsustainable/sustainable), respectively. These alternative decision outcomes are shown in Fig. 3.

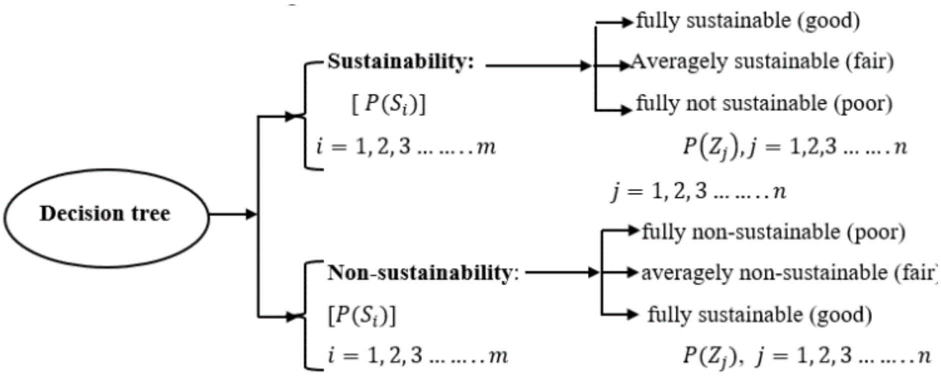

Fig. 3 Decision Tree on production process sustainability

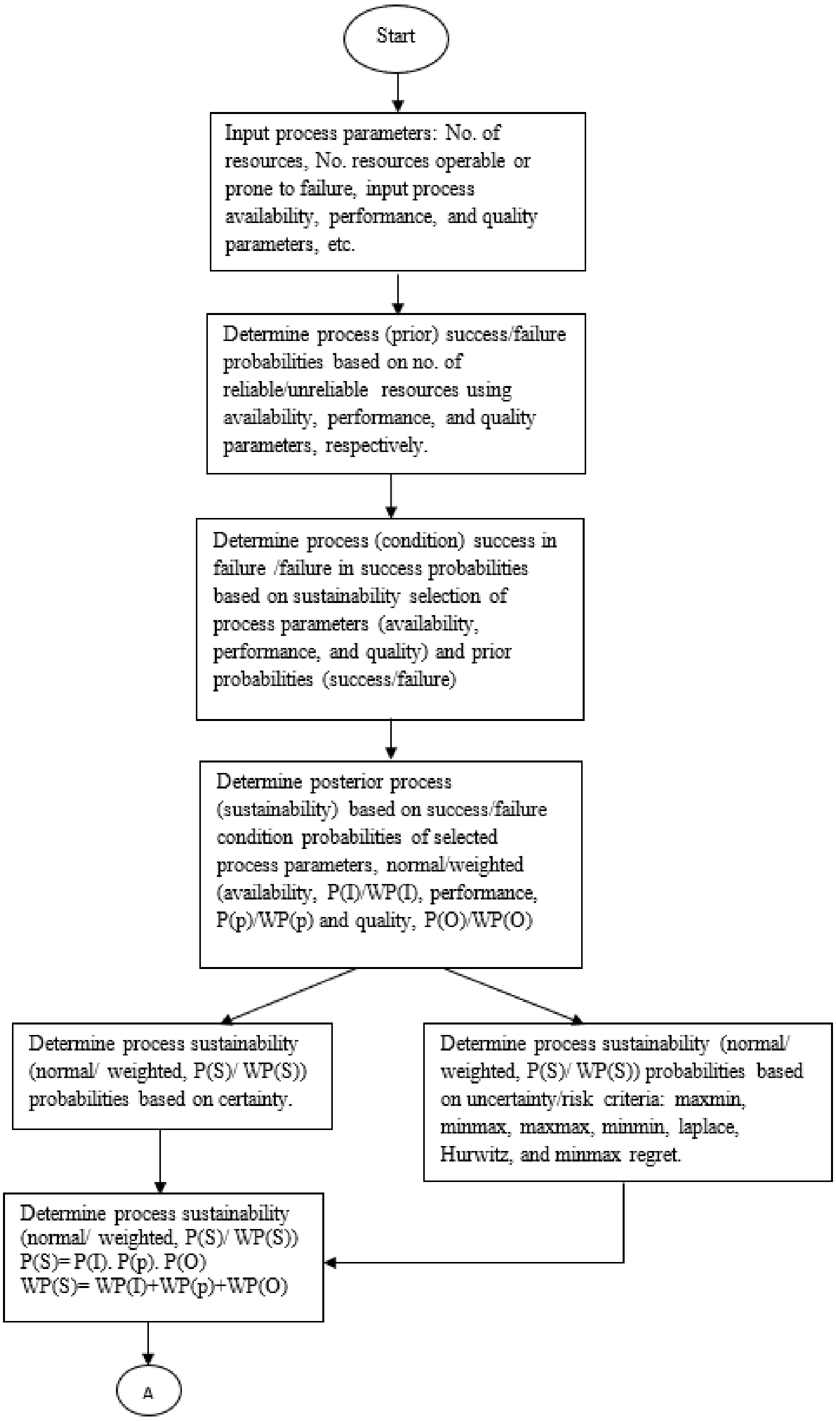

Fig. 4 System development flowchart

First, Availability A, performance P, and Quality Q productivity measures were modified to reflect the real and dynamic probabilistic situation of the production system (as probabilities of input resources availability A, process performance P and output quality Q. Second, outcomes from the first step were partitioned into either success (good), $P(\,)_S^*$, or failure (poor), $P(\,)_f^*$ productivity. Third, the binomial probability model was modified and applied to translate the process into three real-life productivity scenarios: good or sustainable; fairly or averagely sustainable; and poor or unsustainable. Forth, prior probabilities of process sustainability were measured based on the functionality of available production resources by focusing on radical production machinery. Fifth, process conditional probability was estimated based on success, failure, and success/failure sustainability scenarios. Sixth, process sustainability (posterior) probability, $P[S_i/Z_j]$ was established under normal and weighting for availability, performance, and quality, S_i respectively at a given condition, Z_j good, poor, or both. Next, Production System Effectiveness $PSE/P(S)$ was determined under normal and weighting conditions.

2.2 Flowchart for Computer Software programming

Flowchart (Fig. 4) of the Production Process starts from the identification of Production System Effectiveness (PSE) factors: Availability$A$, Performance P and Quality Q. The PSE using Traditional approach (APQ) for measuring the production system effectiveness based on the production input (internal) factors (manpower, machine, material, energy, management, information/communication, money, and marketing).

2.3 Model Validation and Performance Test

Data were collected to test the efficacy of the model. The model was tested using the first round of data collected (70 % of the data) while the second round of the data (30 %) was used for validation. Paired T-test statistics were used to test if there existed a significant difference between PSE (μ_2) and WPSE (μ_2) for a given production system (company).

Hypothesis:

$H_O: \mu_1 = \mu_2$

$H_1: \mu_1 \neq \mu_2$

Decision rule: reject H_0 if $P_{calculated}$<p-value.

Inference: Since P_{cal}<p-value. There is enough evidence to reject.

For industry $0.1 \geq 1$, it is expected that time losses due to failure / idle time should not exceed the minimum range of Availability, Performance, and Quality as established, in past studies [3], [38].

i. 0.1 – 0.50% for Industry 1.0 (poor, not sustainable)
ii. 0.51 – 0.84% for Industry 2.0 to 3.0 (fair, averagely sustainable)
iii. 0.85 – 1.0% for Industry 4.0 (excellent, and sustainable)
iv. Greater than or equal to 1.0 for Industry 5.0 (outstanding, super sustainable)

2.4 Collection of Data

Relevant data were collected using a questionnaire and oral interview conducted in five (5) selected companies, labeled A, B, C, D, and E. The data were collected on the production process, working hours, downtime, product rejection, etc. These data were used for estimating relevant parameters as contained in the developed model. Estimated parameters include Availability Rate, Production Process Performance, Quality rate, Overall Production System Effectiveness (PSE), and decisions on production system process sustainability were made based on $P(G)$, criteria established from the literature. The summaries and nature of the data collected from Company A were given in Table 3 and the same method was used for collection of data for Company B, C, D, and E. In addition, data collection on weights ranking on Production Process Effectiveness factors were also given in Table 4.

Table 2 Summary of the Mathematical Model Development

S/n	Parameter	Traditional / Convectional (Old Model)	Definition of symbols
1	Initial condition of the production process	Availability A= $\frac{\text{Operation time}}{\text{Loading time}}$	A=Availability
		Performance P= $\frac{\text{Net Processing time}}{\text{Operating time}}$	P=Performance
		Quality Q = $\frac{\text{Processed amount} - \text{defect amount}}{\text{Processed amount}}$	Q=processed amount
2	Sustainability evaluation		P(G),Global Acceptable standard ≥0.85, 1.0

Table 3 Data Collection on Availability, Performance, and Quality of Company A

Company A											
Process line Product: Cement processing line/Eight (8) hours shift											
Input Factor	Availability P(I) /hour = A		Performance P(p) /hour = P				Quality P(O)/quantities (kg) = Q				
	Plants Time/ (Set-up / h)	Loading Time = (Process + loading + off-loading) time /h	Process Time /h	Operating time (Cycle time)/h			Processed Amount/kg	Defect loses amount/kg			
				Idling losses/h	Minor stoppage /h	Reduced speed /h		Rework losses	Defect losses	Start-up loses	Scrapped loses
Manpower	8	8	8	1	2	0.5	1,200	25	10	5	2
Machinery	6	8	7	1	2	1	1,000	50	22	12	3
Info. /Comm	8	8	8	0.5	1	1	950	15	5	5	1
Management	6	8	7	0.5	0	1	700	20	14	5	2
Energy	7	8	6	0.5	0	3	1500	22	12	5	4
Money/fund	8	8	7	0.5	0	1	2000	50	15	7	5
Material	8	8	7	1	0.5	0.5	1150	12	20	20	7
Marketing	8	8	8	0.5	1	0.5	1100	11	20	18	2
$\boldsymbol{PSE = APQ}$	**0.9210**			**0.8806**			**0.9890**				
	$(0.9210 \times 0.8806 \times 0.9890) = \mathbf{0.8021}$										

Table 4 Data Collection on Weights Ranking on Production Process Effectiveness Factors

Attributes PSE	Ranking $(\boldsymbol{r_k})$	Numerical calculation	Weight
Company A			
P(I)	1	$W_1 = (1 + 1/2 + 1/3)/3$	0.61
P(p)	3	$W_2 = (1/3)/3$	0.11
P(O)	2	$W_3 = (1/2 + 1/3)/3$	0.28
Company B			
P(I)	3	$W_2 = (1/3)/3$	0.11
P(p)	1	$W_2 = (1 + 1/2 + 1/3)/3$	0.61
P(O)	2	$W_3 = (1/2 + 1/3)/3$	0.28
Company C			
P(I)	2	$W_1 = (1/2 + 1/3)/3$	0.28
P(p)	3	$W_2 = (1/3)/3$	0.11
P(O)	1	$W_3 = (1 + 1/2 + 1/3)/3$	0.61
Company D			
P(I)	1	$W_1 = (1 + 1/2 + 1/3)/3$	0.61
P(p)	3	$W_2 = (1/3)/3$	0.11
P(O)	2	$W_3 = (1/2 + 1/3)/3$	0.28
Company E			
P(I)	2	$W_1 = (1/2 + 1/3)/3$	0.28
P(p)	1	$W_2 = (1 + 1/2 + 1/3)/3$	0.61
P(O)	3	$W_3 = (1/3)/3$	0.11

3 Results and Discussion

A summary of the normal and weighted Production System Effectiveness (PSE and WPSE) results under traditional (APQ) was presented in Table 5. It can be revealed that the traditional approach under equal weights has not produced sustainable outcomes in all companies investigated, while companies A, D, and E had sustainable performance under the weighted arrangement. In this case, production system effectiveness was sustainable in all companies in both normal and weighted scenarios.

Table 5 and Fig. 5, show the summary of the Production System Effectiveness, PSE; Weighted Production System Effectiveness, WPSE; and the corresponding decision outcomes (sustainable, fairly sustainable, or unsustainable) for companies A, B, C, D, and E, under competitive production environment with reference to global acceptable standard factor.

Table 6 shows that only the Maximax criterion was sustainable (D_S) on Production System Effectiveness (PSE) and Weighted Production System Effectiveness (WPSE) which assumed no presence of competition. Also, Laplace and Hurwitz's criteria were sustainable (D_F) on WPSE only with the presence of fair competition. Maximin, Minimax, Minimin, and Minimax Regret criteria were unsustainable (D_U) on PSE and WPSE which assumed that full competition was in place. Therefore, company A can only survive under the Maximax criterion that is without competition. Hypothesis test (paired T-test) results $p_{cal} = 0.007$, p-value 0.05 ($p_{cal} < p_{-value}$) between PSE and WPSE indicated that there was a significant difference between the normal Production System Effectiveness (PSE) and weighted Production Effectiveness (WPSE) at 5% level of significance.

Similar decision outcomes were obtained for company B with little improvement. There were better decision outcomes in terms of sustainable productivity in Company C as a majority of the good decisions fell under either sustainable or sustainable processes. However, PSE and WPSE results were significantly different at the 5 % level.

Decision results from Company D indicated that the company cannot sustain productivity under keen competition. The decision results from Company E were very close to that of Company D, with similar significant difference characteristics between PSE and WPSE. In all cases, however, there was no wide gap in overall decision-making related to the PSE and WPSE outcomes.

4 Conclusion

A model capable of resolving sustainable productivity challenges of production industries was established in this study. The model was tested using data obtained from five Nigerian Companies (Company A, B, C, D, and E). Production System Effectiveness (PSE) factors: Availability P(I), Performance P(p), and Quality P(O) were determined using the Modified Bayesian Approach (MBA) to arrive at manageable decision-making criteria under a normal and/or competitive production environment. The results obtained from the model revealed that varying system sustainability decision-making was due to competitiveness and standard of measure. There was a statistically significant difference between the PSE and WPSE in many industrial cases tested, but these differences had little or no effect on optimum decision-making in all companies investigated.

Decision outcomes were obtained for companies A and B with little improvement. There were better decision outcomes in terms of sustainable productivity in Company C as the majority of the good decisions fell under either sustainable or sustainable processes. However, PSE and WPSE results were significantly different at the 5 % level.

Company D indicated that the company cannot sustain productivity under keen competition. The decision results from Company E were very close to that of Company D, with similar significant difference characteristics between PSE and WPSE. In all cases, however, there was no wide gap in overall decision-making related to the PSE and WPSE outcomes.

Table 5 Normal Production System Effectiveness (PSE)

Company	Conventional/ Traditional Approach (APQ) (normal PSE, and weighed WPSE	Industrial revolution standards	Sustainability Global limit	Sustainability Revolution class
	$PSE = APQ$	≥0.85, 1.0		
A	0.8016	I2.0	0.51 – 0.84%	Fairly sustainable
B	0.4849	I2.0	0.1 – 0.50%	Not sustainable
C	0.3430	I1.0	0.1 – 0.50%	Not sustainable
D	0.6970	I2.0	0.51 – 0.84%	Fairly sustainable
E	0.7128	I2.0	0.51 – 0.84%	Fairly sustainable

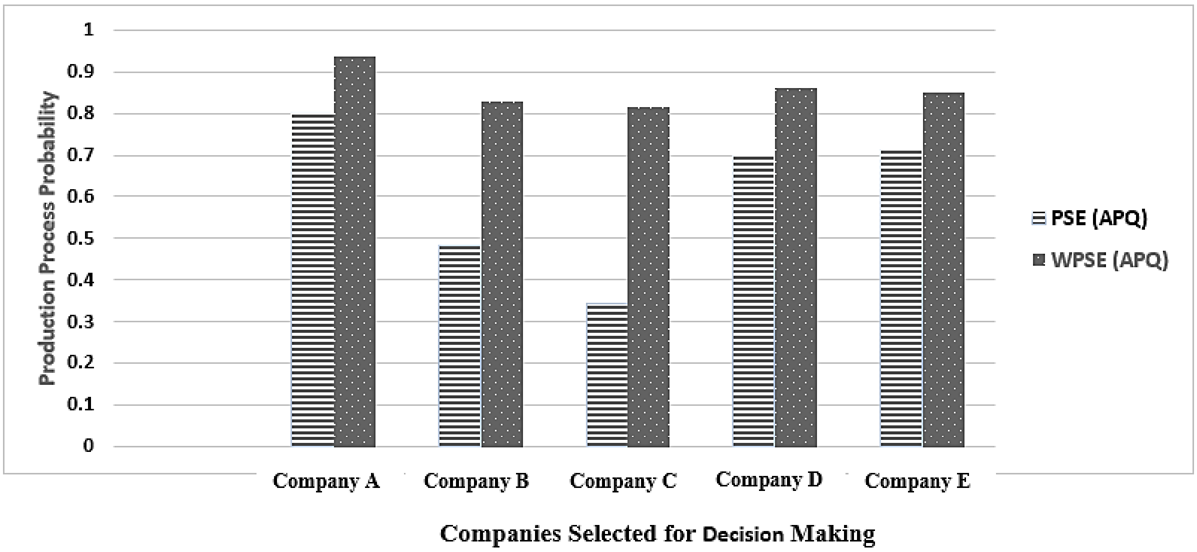

Fig. 5 PSE and WPSE Comparison under Conventional Approach

Table 6 PSE and WPSE Sustainable Decision Analysis under Competitive (Uncertainty)

Company Type	Decision-Making Criteria													
	Maximin		Minimax		Maximax		Minimin		Laplace		Hurwicz		Minimax Regret	
	PSE	$WPSE$	PSE	$WPSE$	PSE	$WPSE$	PSE	$WPSE$	PSE	$WPSE$	PSE	$WPSE$	PSE	$WPSE$
Company A	0.0176	0.4721	0.1240	0.4088	0.9230	0.9583	0.0001	0.0256	0.4255	0.8102	0.3219	0.7778	0.0904	0.3617
Company B	0.0008	0.1873	0.3978	0.8127	0.9761	0.9947	0.0000	0.0034	0.3470	0.6857	0.2324	0.5910	0.3820	0.8074
Company C	0.0004	0.0768	0.7863	0.9230	0.9949	0.9983	0.0000	0.0017	0.2744	0.6501	0.1551	0.5376	0.7820	0.9213
Company D	0.0000	0.1512	0.3445	0.8488	0.9716	0.9949	0.0000	0.0033	0.1910	0.4958	0.2726	0.5731	0.3276	0.8438
Company E	0.0000	0.0222	0.8758	0.9778	0.9963	0.9995	0.0000	0.0007	0.1402	0.5505	0.1431	0.5108	0.8507	0.9771
Decision:														
$P(T), \geq 0.85$	D_U	D_U	D_S (E)	D_S (C, D, E)	D_S	D_S	D_U	D_U	D_U	D_U	D_U	D_U	D_S (E)	D_S (C, D)
$P(G) \geq 0.85$	D_U	D_U	D_S (E)	D_S (C, D, E)	D_S	D_S	D_U	D_U	D_U	D_U	D_U	D_U	D_S (E)	D_S (C, D)
$P(R) = 0.1 - 0.5$, (I1.0 − I2.0)	D_U	D_F (A, B, D)	D_F (A, B, D)	D_S (A)	D_S	D_S	D_U	D_U	D_F	D_F (D)	D_S	D_S	D_F (B, C)	D_F (A)
$P(R) = 0.51 - 0.84$, (I2.0 − I3.0)	D_U	D_U	D_S (C)	D_S (B)	D_S	D_S	D_U	D_U	D_U	D_F (A, B, C, E)	D_U	D_S	D_F (C)	D_S (B, D)
$P(R) = 0.85 - 1.0$, (I4.0 − I5.0)	D_U	D_U	D_S (E)	D_S (C, D, E)	D_S	D_S	D_U	D_U	D_U	D_U	D_U	D_U	D_S (E)	D_S (C, E)

Decision:
D_S is (Sustainable)
D_F is (Fairly sustainable)
D_U is (unsustainable)
P(T) is sustainable trend
P(G) is global acceptable standard
P(R) is industrial revolution
I is industrial revolution

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