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Performance Evaluation of Production Lines in a Manufacturing Company Using Data Envelopment Analysis (DEA)

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ABSTRACT

The concept of producing more output(s) with less input(s) has always been one of the goals of every manufacturing industry. However, continuous evaluation of production systems will ensure that production targets are not only being met but also to ensure that each decision-making unit produces at an optimal level compared to the laid down standard(s). This work evaluated the efficiency of the six most productive production lines in a brewery plant using one of the non-parametric efficiency measurement techniques in data envelopment analysis (DEA). The DEA model for each of the lines was formulated. The relative efficiencies of each of the lines were calculated and the most efficient was chosen as a benchmark. The slacks and surpluses in each production line relative to the benchmark were obtained. The model result revealed that two of the production lines as the most efficient, a reduction in manpower and an increment in product output in some of the lines are required to meet the production benchmark. It may be observed that not all seemingly effective production lines are effective when compared with others within the same system.

1. INTRODUCTION

Every production system takes in a set of inputs to return one or more outputs be it service or manufacturing industry. Measures of how well these inputs have been utilized to produce the set(s) of output(s), and the efficiency of the system have over time become a matter of concern. Assessment of technical, allocative efficiency and cost efficiency plays important role in evaluating how inputs are transformed into outputs [1, 2]. Efficiency is a measure of how inputs are utilized to produce desired outputs forms the pivot of manufacturing industries in the market. It is expected that the rate of utilization of inputs should not exceed the corresponding outputs being produced if the efficiency of the system concerned is to be maximized. Furthermore, the efficiency of a system can be increased either by increasing the outputs and reducing the inputs, increasing the outputs at the same input consumption or holding outputs constant while the input resources are decreased.

Manufacturing industries are often faced with the challenge of meeting customers' demands and competing effectively with rival industries. An itch-free production system is needed to bring the organizational goals to reality. Focusing on the effectiveness of production systems is not enough, it is expedient to continually determine how efficient these systems are, for improved system performance [3].

Certain units in production systems seem to be efficient, however, when compared with other more efficient units, turn out to be less than a benchmark [4, 5]. The use of data envelopment, a variant of linear programming, as a performance metric can determine if a system is operating at an optimal level or not [6]. It also spells out the level of inefficiency of the inefficient units [7, 8]. Also, the measurement of the technical efficiency of manufacturing units using DEA differentiates highly productive units from inefficient ones [9]. The efficiency of manufacturing systems could therefore be measured using this approach to determine the lags in the inefficiency of seemingly efficient units of the system which this paper seeks to explore. However, the concept of technical efficiency using DEA seems novel in its application to manufacturing systems. This paper aims at applying data envelopment analysis (DEA) as a performance measurement technique to evaluate the efficiency of selected production lines in a manufacturing industry. Results from this analysis will provide insight into the production lines that are most efficient in manpower reduction and increment in product output.

This paper is structured thus: A brief introduction that describes the research problem. Then a review of relevant literature on organisational performance using DEA. A description of the methodology comprising the model formulation, data collection and analysis is presented. The key findings of the performance evaluation and the results are discussed next. Finally, conclusions on the main insights are stated.

2. LITERATURE REVIEW

Performance evaluation is an everyday activity especially in the production and manufacturing industries [10, 11], transportation schemes [12], the performance of retail food companies, efficiency of primary healthcare centres and the tourism sector. One of the goals of every working system is to optimally transform inputs into desired outputs such as. Thus, system evaluation is considered a means of determining how well system inputs are converted into desired outputs [10]. Performance measurement is the science of determining what a designed program accomplishes in terms of the desired and undesired outputs [11]. The procedure was created to improve accountability and monitor the effectiveness of organizations, initiatives, and services. Performance measures can identify the type or level of program activities carried out (process), the direct products and services supplied by a program (outputs), and perhaps the outcomes of those products and services (outcomes) [12]. A "program" could be any activity, project, function, or policy with a clear goal or desired outcomes.

Organizational performance is a complex and critically important multi-dimensional construct. It is however important to spell out in clear terms what the word ‘performance’ entails as well as what it means in terms of measurement. Identifying that organizations are structures of productive assets (which would include individuals and actual and potential assets) that collaborate to achieve economic advantage, performance measures could perhaps compare the value of the organization's output utilising productive input assets to the value that large shareholders expect [13].

Benchmarking aims at setting standards to identify areas of inefficiency in a system’s current operations for improvement in future strategy [3, 14]. It looks at how the organization’s performance compares with a standard. Performance has been measured traditionally using productivity index effectiveness, quality and timeliness [12]. These three approaches have several techniques by which they are evaluated. Several efficiency measuring techniques have been harnessed over the years ranging from the parametric to the non-parametric approaches [15]. The parametric techniques include the stochastic frontier approach, Thick Frontier Approach (TFA), and Distribution Free Approach (DFA). The data envelopment analysis (DEA) is a non-parametric approach [16]. The use of data envelopment analysis (DEA) as a means of efficiency evaluation has therefore received a warm embrace since its development and use by Charnes et al. in 1978 to evaluate non-profit and public sector organizations. It transcends the measurement of how outputs meet the set objectives of the organization (effectiveness) to how scarce resources are being utilized to produce desired outputs (efficiency) [17].

DEA models are variants of linear programming models used to measure the relative efficiency of organizational units often referred to as decision-making units (DMUs) [18]. It measures the relative efficiencies of an organization or a section relative to the best practice either within the organization or outside [19]. It generates slacks of inefficiency for performance improvement when compared with other existing models [20]. Data envelopment analysis entails technical efficiency, cost efficiency and allocative efficiency [21].

DEA in have been applied in several fields of performance evaluation transportation, academic performance, environmental performance, human resource, banking sector, project management, information and communication technology (ICT), tourism etc. [22-25]. It was applied in evaluating forecasting techniques [26, 27]. With many different methods in forecasting, understanding their relative performance is critical for a more accurate prediction of the quantities of interest. Conclusions about the accuracy of various forecasting methods typically require comparisons using arrange of accuracy measures [27]. To rank forecasting techniques, several other approaches have been introduced in the literature using Machine Learning, Data Mining techniques and forecasting with Neural Networks based on their measures [27, 28]. However, the performance is relative and concerns only the comparison of two algorithms given a compromise (trade-off) between two criteria [27].

In Transport Management**,** DEA was applied to evaluate transportation schemes [29, 30]. In their work, technical efficiency was evaluated as a function of service efficiency and operational or cost efficiency. The performance of a given transit system, as well as transit route, was classified into three dimensions: technical efficiency (also termed cost efficiency), operational effectiveness (also termed cost-effectiveness), and service effectiveness. The transit agency invests capital in transit vehicles, fuel, information systems, employees, maintenance, and other costs (inputs). This investment will produce certain services for a community such as vehicle kilometres, seat kilometres, and seat hours which form the outputs. An agency is considered to be more effective when it can minimize inputs while producing a set number of outputs, or if it can enhance outputs while using comparable or fewer inputs. However, the transit company's service effectiveness establishes a link between produced outputs and consumed service, or how well a service offered by operators can be consumed by society [30].

Human resource management has also witnessed the application of DEA [31]. The human resource department works with control to test employees’ performance and to find out the level of performance appraisal system. In their work, DEA was used to compare the solutions obtained by several authors to obtain the best criteria for candidate selection based on the information technology (IT) companies being evaluated as well as created schemes of DEA were suggested for use in comparing productivity and utilization of employees in companies with more than one branch [31].

DEA has been applied in Environmental Performance Measurement [32, 33]. In reality, a production system often yields both desirable outputs as well as wastes. A good example is seen in the emissions of Carbon dioxide and Sulphur dioxide when coal is burnt to generate electricity in a fossil-fired power plant. In the conventional DEA models, all the outputs in the model are assumed to be of benefit with more outputs produced given the input constraints. This assumption, nevertheless, does not apply to unfavourable outputs in the aspects of their 'undesirable' attribute, which should be meticulously modelled into the DEA framework [32].

In other applications, the data envelopment analysis (DEA) model was applied to study the technological innovation efficiency of high patent-intensive industries in China based on input-output indicators [34]. A new method for project selection was proposed tailored toward energy service companies based on centralized data envelopment analysis models with limited available resources in the Spanish energy service [35-38]. This proposed approach not only identifies the combination of projects that provide maximum expected profit but also identifies and removes the inefficiencies that may be present in these portfolios of projects. By design, the proposed approach obtains the largest expected profit for the selected projects given the availability of discretionary inputs.

The Data Envelopment Analysis (DEA) method was used analyse the performance of retail food companies in Hungary's Northern Great Plain region [36]. The companies analysed were chosen from the region as "food retail grocery store". A data envelopment analysis was used to evaluate the efficiency of primary healthcare centres in a health district using variable inputs such as the ratios of general practitioners, nurses, and costs; with output variables such as those included were consultations, emergencies, avoidable hospitalisations, and prescription efficiency [37]. In their work, the DEA allows an evaluation of efficiency that is focused on achieving better results and proper distribution and use of healthcare resources with clearly identified desired goals by the healthcare managers. DEA method found its usefulness in evaluating the tourism sector [38]. The paper focuses on the evaluation of the overall development and current level of efficiency of spas through the application of DEA models.

3. METHODOLOGY

A brewery in Nigeria was considered as a case study with six (6) suggested most productive production lines selected. These lines were evaluated for efficiency using data envelopment analysis as a performance measure.

Relevant data were collected for the three most productive production lines based on the daily production records for one year. The production lines operate on the batch production system. Several products are produced from these lines with the same machines but different local contents. The data collected includes;

a. Available Production Time per month (in hours)
b. Total downtime per month (in hours)
c. Number of rejects and reworks
d. Total Number of Products per run
e. Total Number of runs per month
f. Number of personnel on each line per month

Choice of Inputs, Outputs and Decision-Making Units

Decision-making units (production lines) were chosen based on the perceived most efficient production lines in the system. Non-highly correlated variables were selected as inputs and outputs to forestall redundancy. Input variables which translated to measurable outputs were chosen for the study. These inputs and outputs include:

Input Variables

a. Actual Production Time per month (Hours) (APT)
b. Manpower (M)

Output Variable

a. Number of Products (Good + Rejects+ Reworks) (NP)

The virtual efficiencies were calculated with the aim of drawing the production possibility curve and determining the system benchmark. These metrics were computed using the Frontier Analyst Application tool and evaluated against the most efficient line chosen as the benchmark. The model developed using these inputs and outputs was also solved using the Frontier Analyst Software.

The DEA Model Formulation

The DEA model entails the identification of inputs into systems and the corresponding system output. The following notations hold for the mathematical model:

Notations

j= Number of service units to be evaluated
θ= Efficiency rating of the service unit to be evaluated
y_{pj}= Amount of output p used by the service unit j
x_{ij} = Amount of input i used by service unit j
p= Number of outputs generated by the service units
m_p= Coefficient or weight assigned by DEA to output p
n_i= Coefficient or weight assigned by DEA to input i

Model Assumptions

For the model development process, the following assumptions hold:

1. Efficiency relative to collected samples can be measured with DEA models.
2. A constant return to scale is assumed (i.e. increase in an input variable causes an increase in the output produced).

Benchmarking

Benchmark for a DEA model is obtained to evaluate the performance of other decision-making units (DMUs) against the selected benchmark. This enables decision-makers to know the extent to which other decision-making units fall short of the benchmark. To obtain the benchmark, equation 1 is used as the objective function. Aggregate inputs are used against the output. A production line with the highest efficiency is used as a benchmark. The production frontier curve is drawn using these aggregated inputs and output.

The Objective Function

An objective function was developed and applied to each of the six lines. The objective function of the model is aimed at maximizing the efficiency of each line in the system subject to the constraint. This is done such that none gives an efficiency greater than 100%. For instance, for any of the production lines, the objective function is derived using Eq. (1) subject to the service unit constraints (Eqns. (3)-(5))

Mathematically we have the following:

$$Maximize\ \theta = \frac{m_1y_1 + m_2y_2 + m_3y_3 + \cdots + m_py_p}{n_1x_1 + n_2x_2 + n_3x_3 + \cdots + n_ix_i} \tag{1}$$

Generically written as:

$$Maximize\ \theta = \frac{\sum_{i=1}^{P} m_iy_i}{\sum_{j=1}^{P} n_ix_i} \tag{2}$$

Subject to:

$$Service\ Unit\ 1 = \frac{m_1y_1 + m_2y_2 + m_3y_3 + \cdots + m_py_p}{n_1x_1 + n_2x_{21} + n_3x_3 + \cdots + n_ix_p} \leq 1 \tag{3}$$

$$Service\ Unit\ 2 = \frac{m_1y_{12} + m_2y_{22} + m_3y_{32} + \cdots + m_py_{p2}}{n_1x_{12} + n_2x_{22} + n_3x_{32} + \cdots + n_ix_{i2}} \leq 1 \tag{4}$$

$$Service\ Unit\ p = \frac{m_1y_{11} + m_2y_{21} + m_3y_{31} + \cdots + m_py_{p1}}{n_1x_{11} + n_2x_{21} + n_3x_{31} + \cdots + n_ix_{i1}} \leq 1 \tag{5}$$

$$m_1, m_2\ \ldots m_p\ > 0;\ n_{1,}\ n_2, \ldots n_i\ \geq 0$$

However, for the problem to be solved, the specific model becomes for each of the lines is derived thus using Eqns. (1)-(5);

Line 1

$$Maximize\ \theta_1 = \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{11} + n_2\ \sum_{i=1}^{12} M_{21}} \quad (6)$$

Subject to:

$$For\ Line\ 1 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{11} + n_2\ \sum_{i=1}^{12} MP_{21}} \leq 1 \quad (7)$$

$$For\ Line\ 2 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{12} + n_2\ \sum_{i=1}^{12} MP_{22}} \leq 1 \quad (8)$$

$$For\ Line\ 3 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} OLE_{13} + n_2\ \sum_{i=1}^{12} MP_{23}} \leq 1 \quad (9)$$

$$For\ Line\ 4 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{14} + n_2\ \sum_{i=1}^{12} MP_{24}} \leq 1 \quad (10)$$

$$m_1 , > 0;\ n_{1,} n_2\ \ \geq 0$$

Line 2

$$Maximize\ \theta_2 = \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{12} + n_2\ \sum_{i=1}^{12} MP_{22}} \quad (11)$$

Subject to:

$$For\ Line\ 1 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{11} + n_2\ \sum_{i=1}^{12} MP_{21}} \leq 1 \quad (12)$$

$$For\ Line\ 2 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{12} + n_2\ \sum_{i=1}^{12} MP_{22}} \leq 1 \quad (13)$$

$$For\ Line\ 3 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{13} + n_2\ \sum_{i=1}^{12} MP_{23}} \leq 1 \quad (14)$$

$$For\ Line\ 4 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{14} + n_2\ \sum_{i=1}^{12} MP_{24}} \leq 1 \quad (15)$$

$$m_1 , > 0;\ n_{1,} n_2\ \ \geq 0$$

Line 3

$$Maximize\ \theta_3 = \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{13} + n_2\ \sum_{i=1}^{12} MP_{23}} \quad (16)$$

Subject to:

$$For\ Line\ 1 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{11} + n_2\ \sum_{i=1}^{12} MP_{21}} \leq 1 \quad (17)$$

$$For\ Line\ 2 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{12} + n_2\ \sum_{i=1}^{12} MP_{22}} \leq 1 \quad (18)$$

$$For\ Line\ 3 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{13} + n_2\ \sum_{i=1}^{12} MP_{23}} \leq 1 \quad (19)$$

$$For\ Line\ 4 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{14} + n_2\ \sum_{i=1}^{12} MP_{24}} \leq 1 \quad (20)$$

$$m_1 , > 0;\ n_{1,}, n_2\ \ \geq 0$$

The effectiveness of the four systems was compared using the coefficients applied to their inputs and outputs.

Line 4

$$Maximize\ \theta_4 = \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{14} + n_2\ \sum_{i=1}^{12} MP_{24}} \quad (21)$$

Subject to:

$$For\ Line\ 1 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{11} + n_2\ \sum_{i=1}^{12} MP_{21}} \leq 1 \quad (22)$$

$$For\ Line\ 2 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{12} + n_2\ \sum_{i=1}^{12} MP_{22}} \leq 1 \quad (23)$$

$$For\ Line\ 3 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{13} + n_2\ \sum_{i=1}^{12} MP_{23}} \leq 1 \quad (24)$$

$$For\ Line\ 4 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{14} + n_2\ \sum_{i=1}^{12} MP_{24}} \leq 1 \quad (25)$$

$$m_1 , > 0;\ n_{1,} n_2\ \ \geq 0$$

The effectiveness of the four systems was compared using the coefficients applied to their inputs and outputs.

Line 5

$$Maximize\ \theta_5 = \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{15} + n_2\ \sum_{i=1}^{12} MP_{25}} \quad (26)$$

Subject to:

$$For\ Line\ 1 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{11} + n_2\ \sum_{i=1}^{12} MP_{21}} \leq 1 \quad (27)$$

$$For\ Line\ 2 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{12} + n_2\ \sum_{i=1}^{12} MP_{22}} \leq 1 \quad (28)$$

$$For\ Line\ 3 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{13} + n_2\ \sum_{i=1}^{12} MP_{23}} \leq 1 \quad (29)$$

$$For\ Line\ 4 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{14} + n_2\ \sum_{i=1}^{12} MP_{24}} \leq 1 \quad (30)$$

$$m_1 , > 0;\ n_{1,} n_2\ \ \geq 0$$

The effectiveness of the four systems was compared using the coefficients applied to their inputs and outputs.

Line 6

$$Maximize\ \theta_6 = \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{16} + n_2\ \sum_{i=1}^{12} MP_{26}} \quad (31)$$

Subject to:

$$For\ Line\ 1 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{11} + n_2\ \sum_{i=1}^{12} MP_{21}} \leq 1 \quad (32)$$

$$For\ Line\ 2 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{12} + n_2 \sum_{i=1}^{12} MP_{22}} \leq 1 \quad (33)$$

$$For\ Line\ 3 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{13} + n_2 \sum_{i=1}^{12} MP_{23}} \leq 1 \quad (34)$$

$$For\ Line\ 4 \Longrightarrow \frac{m_1 \sum_{i=1}^{12} NP_{11}}{n_1 \sum_{i=1}^{12} APT_{14} + n_2 \sum_{i=1}^{12} MP_{24}} \leq 1 \quad (35)$$

$$m_1, > 0;\ n_{1,} n_2 \ \geq 0$$

The effectiveness of the four systems was compared using the coefficients applied to their inputs and outputs.

Frontier Analyst Software

The computation was performed using the Frontier Analyst software. Model data in the form of inputs and outputs were extracted from the Operation Performance Indicator (OPI) worksheet. The constant rate of return model was selected (this reveals that an increase in the number of inputs causes a corresponding increase in the units of outputs produced). The output maximization model was selected from the model option panel. With these in place, the model was run and the results generated were reported in chapter four of this project.

Process Evaluation

Based on the results obtained, evaluation of the lines based on the slacks obtained from the model will be carried out on production lines with low overall performance efficiency ratings and low coefficients of inputs and outputs as obtained from the DEA model and necessary recommendations made.

4. RESULT AND DISCUSSION

Shown in Table 1 is the model data. An aggregate of these variables was for the year was computed and relative efficiencies of the production lines calculated using the output to input ratio.

Table 1. Model variables

Relative efficiency				
Production Line (DMU)	**P/APT**	**P/M**	**P/APT (%)**	**P/M (%)**
Gulder	0.244	0.781	24.492	78.051
Star	0.246	0.641	24.597	64.076
Goldberg	0.251	2.529	25.119	252.899
Amstel	0.269	0.893	26.856	89.323
Maltina	0.266	0.948	26.575	94.848
Fayrouz Pineapple	0.263	0.353	26.339	35.283

The values of the products produced for the year were reported in hundreds of thousands as shown in Table 1. The relative efficiencies of each of these decision-making units were calculated and tabulated as in Table 2.

However, using the additive DEA model, and from the efficiency plot shown in Figure 1, relative to the actual production time, the Fayrouz pineapple used less production time to achieve an efficiency of about 98%. However, Goldberg obtained an efficiency of 100% but with a higher production time. Maltina being higher in the number of products is expected to have a higher efficiency score than Amstel, however, Amstel production (100%) used less production time compared to Maltina production line (99.5%) as shown in Figure 1. Manpower input for all the production lines is the same, however, from Figure 2, Amstel and Goldberg achieved an efficiency of 100% relative to the manpower used.

Table 2. Relative efficiency

Unit	Actual Prod Time (APT)(Hr)	Manpower (M)	Products (P) (00,000)
Gulder	1376.70	432	337.181
Star	1125.39	432	276.807
Goldberg	4349.36	432	1092.523
Amstel	1436.84	432	385.875
Maltina	1541.84	432	409.745
Fayrouz Pineapple	578.68	432	152.420

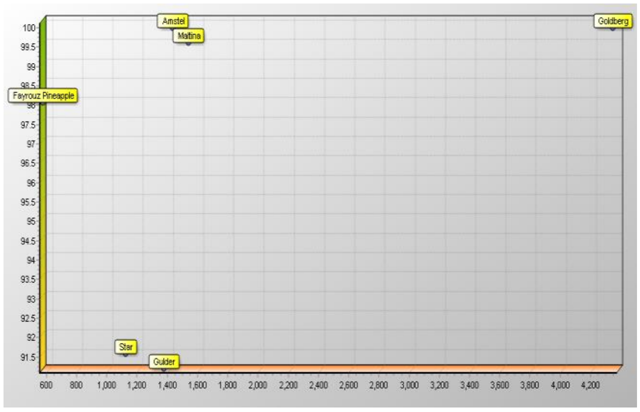

Figure 1. Efficiency plot (relative to actual production time)

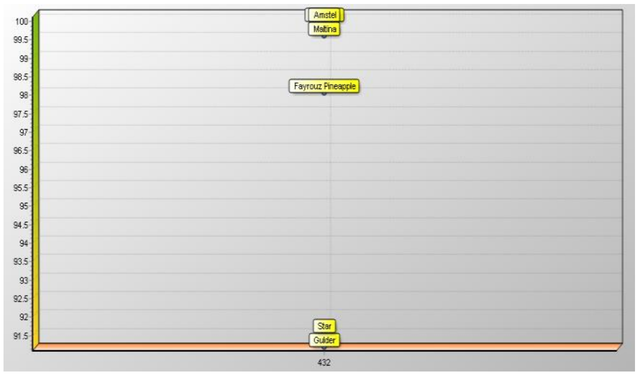

Figure 2. Efficiency plot (relative to manpower)

The result revealed that out of the six production lines, two are the most efficient (has an efficiency score of 100%). One of these was made the benchmark to which others were compared. Also, Table 3 shows the efficiency scores of each of the units. It was observed that two of the six units utilized input resources to optimally produce the system output.

Table 3. Unit efficiency

Units	Comparison 1		
Unit name	**Score**	**Efficient**	**Condition**
Amstel	100.0%	√	○
Fayrouz Pineapple	98.1%		○
Goldberg	100.0%	√	○
Gulder	91.2%		○
Maltina	99.6%		○
Star	91.6%		○

4.1 Production frontier plot

This reveals the efficiencies of the efficient units and to what extent the inefficient units lag compared to the benchmark. This reveals the ratio of inputs to output in the output maximization problem. This is shown in Figure 3.

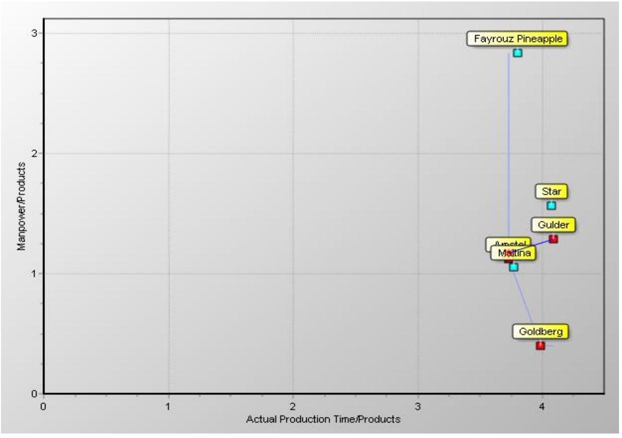

Figure 3. Production frontier plot

4.2 Potential improvement and evaluation

For all the production lines considered and their inputs with their respective outputs, the percentage to which inputs or output can be improved to achieve the efficiency of the benchmark are described for each unit as follows:

4.2.1 Gulder

Table 4 shows the potential improvement in the input and output of the Gulder production line.

Table 4. Potential improvement (gulder)

Efficiency = 91.20%			
Variable	**Actual**	**Target**	**Potential improvement**
Actual Production Time	1376.7	1376.7	0.00%
Manpower	432	413.92	-4.19%
Products	337.18	369.72	9.65%

For this production line to meet up with the relative efficiency of the benchmark, the manpower should be decreased by 4.19%. Out of a total of 432 personnel on the line for a whole year, approximate 414 personnel be made to run the shifts for a year. Also, the units of products produced should be increased by 9.65% to meet up with the benchmark. This means that approximate 37,000,000 units of products are expected to be produced to meet up with the efficiency of the benchmark.

4.2.2 Star

Shown in Table 5 is the potential improvement in the input and output in the Star production line.

For the Star production line to meet up with the relative efficiency of the benchmark, the manpower should be decreased by 21.68%. Out of a total of 432 personnel on the line for a whole year, approximate 338 personnel be made to run the four shifts for a year on this line. Also, the units of products produced should be increased by 9.19% to meet up with the benchmark. This means that approximately 30, 224,884 units of products are expected to be produced to meet up with the efficiency of the benchmark.

Table 5. Potential improvement (star)

Efficiency = 91.59% Star			
Variable	**Actual**	**Target**	**Potential improvement**
Actual Production Time	1125.39	1125.39	0.00%
Manpower	432	338.36	-21.68%
Products	276.81	302.23	9.19%

4.2.3 Maltina

Shown in Table 6 is the improvement potential for Maltina production line.

Table 6. Potential improvement (maltina)

Efficiency = 99.61%			
Variable	**Actual**	**Target**	**Potential improvement**
Actual Production Time	1541.84	1541.84	0.00%
Manpower	432	432	0.00%
Products	409.74	411.35	0.39%

For the Maltina production line to meet up with the relative efficiency of the benchmark, the manpower was efficiently utilized. However, the units of products produced should be increased by 0.39% to meet up with the benchmark. This means that approximately 41,133,799 units of products are expected to be produced to meet up with the efficiency of the benchmark.

4.2.4 Fayrouz pineapple

Shown in Table 7 is the improvement potential for the Fayrouz Pineapple production line.

Table 7. Potential improvement (fayrouz pineapple)

Efficiency = 98.08% Fayrouz Pineapple			
Variable	**Actual**	**Target**	**Potential improvement**
Actual Production Time	578.68	578.68	0.00%
Manpower	432	173.99	-59.73%
Products	152.42	155.41	1.96%

For this production line to meet up with the relative efficiency of the benchmark the manpower should be decreased by 59.73%. Out of a total of 432 personnel on the line for a whole year, approximately 174 personnel be made to run the four shifts for a year on this line. Also, the units of products produced should be increased by 1.96% to meet up with the benchmark. This means that approximately 15,541,000 units of products are expected to be produced to meet up with the efficiency of the benchmark.

5. CONCLUSION

Performance measurement of decision units in manufacturing industries is fast becoming a concern. In response to this, several techniques are being developed both parametric and non-parametric measures. These methods are being adopted by both researchers and management to evaluate production systems. Data envelopment analysis (DEA) is one of the non-parametric measures of a production system where dimensional inconsistency does not affect output.

Some production lines often appear productive to management, however, when subjected to specific analysis may prove less efficient compared to others in the same system. Two inputs and one output were considered in this analysis: the manpower and actual production time, and the number of products respectively. It was observed that some production lines have more of these inputs than required by the number of products produced per time. This can be seen in the case of product F, product B as well as product A production lines which have more manpower than required. In contrast, some other product lines are observed to be producing less than the most efficient production line. This is the case of product A, product B, product F and product E production line which produces 9.65%, 9.19%, 1.96% and 0.39% respectively less than the most efficient production line.

Additionally, waste in the aspect of manpower is predominant in the system analysed. There is more of the production workforce than necessary compared to the capacity of the plant. To address this, the following recommendations were made that can aid management in decision-making. Even though investment in the area of skills has been made in the workforce in this production system. It is therefore expedient that the excess workforce should be laid off or another product line is created to which they can be deployed based on the desired production level. If considering the financial status of the industry, the man-hour cost of the excess workforce cannot be afforded by the industry, laying off the excess workforce could be a decision that can only be guided through continuous evaluation for performance improvement.

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APPENDIX

Production Time Per Month
Product A

Month	Actual production time	Manpower	Products
January	234.06	36	4818564
February	132.02	36	3193968
March	125.31	36	3212100
April	31.39	36	841560
May	80.25	36	2029044
June	124.38	36	3326388
July	56.56	36	1383912
August	113.01	36	2509896
September	227.68	36	6005328
October	29.43	36	720360
November	74.24	36	1863012
December	148.37	36	3813972

Product B Production Line

Month	Actual production time	Manpower	Products
January	122.04	36	2512344
February	140.63	36	3402276
March	50.88	36	1304136
April	49.83	36	1335852
May	85.58	36	2163696
June	79.29	36	2120508
July	180.29	36	4411152
August	17.4	36	386400
September	74.64	36	1968768
October	194.59	36	4762908
November	57.19	36	1435356
December	73.03	36	1877304

Product C Production Line

Month	Actual production time	Manpower	Products
January	283.68	36	5840088
February	299.22	36	7239336
March	418.74	36	10734000
April	515.5	36	13819848
May	501.83	36	12687708
June	424.33	36	11347920
July	244.16	36	5973912
August	159.24	36	3536436
September	293.95	36	7753212
October	413.89	36	10130676
November	398.08	36	9990324
December	396.74	36	10198848

Product D Production Line

Month	Actual production time	Manpower	Products
January	101.23	36	2479248
February	148.29	36	3691752
March	85.84	36	2297496
April	101.11	36	2663136

May	130.71	36	3303528
June	158.03	36	4496592
July	90.13	36	2592048
August	83.98	36	2256768
September	40.15	36	988656
October	123.5	36	3118968
November	121.57	36	3246528
December	252.3	36	7452744

Product E Production Line

Month	Actual production time	Manpower	Products
January	249.53	36	6111072
February	114.34	36	2846736
March	106.16	36	2841336
April	76.37	36	2011512
May	136.44	36	3448368
June	170.8	36	4859736
July	68.94	36	1982592
August	116.34	36	3126312
September	43.86	36	1079832
October	68.95	36	1741152
November	206.81	36	5522712
December	183.3	36	5403096

Product F

Month	Actual production time	Manpower	Products
January	55.33	36	1355136
February	25.68	36	639408
March	50.47	36	1350792
April	42.43	36	1117632
May	50.26	36	1270200
June	47.37	36	1347816
July	91.52	36	2631912
August	0	36	0
September	42.43	36	1044720
October	35.9	36	906528
November	94.86	36	2533176
December	42.43	36	1044720