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Providing a Model for Assessing the Health of Automotive Production Lines' Quality through Relative Indicators Using Network Data Envelopment Analysis

M.Komijani[1], F.Hoseinzadeh Lotfi[2,*], A. Gholamabri[3] , N.Shoja[4] , S.A.shayannia[5]

This research uses Network Data EnvelopmentAanalysis (NDEA) by undesirable factors to analyze and evaluate the performance of automotive industry. The modeling used is applied to five production lines of an automobile company by 16 indicators. The data used are for the year 2019. The main purpose is to provide a model to improve the quality of the product by evaluating the performance of quality health in production lines able to rank by providing appropriate quality indicators to identify, formulate and achieve corrective measures. Accompanied with accurate problem solving and operational scheduling according to the most efficient organization/production line and so investigating the source of the problem and preventing the occurrence of the problem. Because determining the direction of performance and key performance indicators (KPI) of the organization and measuring them to increase its health efficiency requires an efficient and integrated system. On the other hand, creating a homogeneous and orderly development process between the elements of the organization as a common language to solve the quality problems by aiming the improvement of the performance, customer satisfaction, sustainable production and cost management has been proposed.

***Keywords**: Data Envelopment Analysis, Quality Health Model, Performance Evaluation, Efficiency, Network Data Envelopment Analysis.*

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* Corresponding Author.
[1] Department of industrial management, Firoozkooh branch, Islamic azad university, Firoozkooh, Iran, Email: komijani.mehdi@yahoo.com.
[2] Department of mathematics, Science and research branch, Islamic azad university, Tehran, Iran, Email: farhad@hosseinzadeh.ir.
[3] Department of mathematics, Firoozkooh branch, Islamic azad university, Firoozkooh, Iran, Email: amirgholamabri@gmail.com.
[4] Department of mathematics, Firoozkooh branch, Islamic azad university, Firoozkooh, Iran, Email: nashoja@yahoo.com.
[5] Department of industrial management, Firoozkooh branch, Islamic azad university, Firoozkooh, Iran, Email: sheibat@yahoo.com.

1. Introduction

Performance evaluation system is a process in measuring and comparing the amount and manner of achieving the situation desired by certain criteria and attitudes in a certain scope and area through certain indicators and in a certain period of time by the aim of continuous review, improvement, and modification [1]. Performance evaluation, as a tool to control the organization, is the process of ensuring the implementation of strategies leading to the achievement of quantitative and qualitative goals [2]. In recent years, knowledge of organizational performance is very important for managers to achieve their organizational goals, because they operate in a competitive environment and must use appropriate performance evaluation model of their organization [3]. Productivity and evaluation are the main and important demands of organizations, companies and institutions. Data envelopment analysis (DEA) is a useful method for measuring the efficiency and performance of organizations.

The advantage of using DEA models is that, in addition to determining the relative efficiency, it can determines the weaknesses of organizations by various indicators and providing the desired amount of them, determines the organization's policy to improve efficiency and productivity [4]. Network DEA models make it possible to examine the internal processes and work processes of decision-making units (DMUs) besides overall efficiency of each DMU. Therefore, the results of performance evaluation by conventional methods may prevent accessing to valuable DEA management information [5]. In this paper, the indicators such as capital utilization, total number of employees, number of defects detected in production processes, total turnover time, performance of QRQC meetings, etc. are considered to evaluate the company's performance. As can be seen, desirable and undesirable outputs are presented side by side.

What makes the need to develop a comprehensive model for evaluating the quality health performance in the automotive industry important, is the lack of a proper performance evaluation system to control the system in terms of achieving the set goals (following the goals of the strategy), improving current procedures, achieving the situation desired, further improving the quality of products, increasing customer satisfaction, and providing feedback for continuous improvement, review, and modification. This requires that such a quality health performance evaluation system be provided in accordance with what has been mentioned, and more importantly, that quality health performance evaluation based on reliable data. By the above requirements, an attempt is made to provide a model suitable for the production unit in automotive industry, so that it covers the key indicators of this industry. In this model, the production organization should be evaluated based on KPIs, or the factory quality health evaluation model (in the automotive industry) should be presented and all deficiencies should be covered and fixed by combining two qualitative and quantitative approaches in the evaluation.

As well as the need for research and development, design and development of new products, the automotive industry needs to maintain the current situation, especially in terms of cost, quality and sustainable manpower. In this paper, it is tried to provide a model to improve the quality level of the product and process by evaluating the quality health performance of production lines by providing desirable and undesirable indicators related to the quality health of the lines (compliance of the results of KPIs evaluation with predetermined goals). The model should be able to rank the quality health of the lines. This is because determining the direction of efficiency and KPIs of the organization and measuring them to increase efficiency and effectiveness of its health requires an efficient and integrated system. By providing a mathematical model of performance evaluation system with the help of network DEA, relative efficiency and weaknesses of the organization can be identified in various indicators and by presenting their desired amount, the policy of the organization to improve efficiency and productivity can be determined. On the other hand, creating a homogeneous and regular development process between the elements of the organization is proposed as a common language for solving quality problems to promote customer satisfaction, sustainable production, cost management, and achieve the highest level of performance. In this regard, it should be possible to take advantage of the analysis of the results of KPIs and their corresponding impact on the health of the organization based on the organizational vision and missions of automakers. However, evaluation systems used currently in automotive industry are not suitable for these organizations.

The problem considered in the present study is the network system by favorable and unfavorable outputs in the field of process health and the model and network considered are multiplicative model and hybrid network, respectively. Innovation and the main purpose of this paper is to model the factory health performance evaluation system based on key indicators of the automotive industry using network DEA and empowerment of the automotive industry to make inefficient lines more efficient. The findings of this research can be exploited in all independent lines of the automotive industry and help to optimize the production lines of the automotive industry through the performance system and ranking of production lines to increase the quality of process and product and consequently the factory health system.

In the following, the second part examines the theoretical literature and research background, the third part presents the model, the fourth part is the research findings, and the fifth part comes as the results.

2. Review of Literature

Performance indicators or Key Performance Indicator (KPIs) are modern tools helping maintain high levels of performance in production [6]. In addition, performance indicators only describe what has happened; they represent what will happen, because they provide information to the decision maker, which may affect the future competitive position of the company [7]. The role of production performance indicators reflects the current state of production by monitoring and controlling operational efficiency, implementing improvement programs, and measuring the effectiveness of strategic decisions [8]. Common indicators for evaluating the performance of production systems are quality, cost, delivery time and flexibility [9]. A KPI helps the organization define and measure the process of moving toward goals. These indicators are measurable values representing the rate of progress in performing activities that affect the success of the organization [١٠].

DEA, as a non-parametric method, plays an important role in measuring relative efficiency and is used as a mathematical planning method to evaluate DMUs by initial assumption that DMUs use similar inputs to generate similar inputs. DEA models are used in a comparative space based on the ability of each DMU to convert inputs to outputs. The study of [١١] can be considered as the first experimental study in performance evaluation, where the number of outputs is limited to one and it is assumed that the return to scale is constant. They were then modified and developed by [١٢]. In contrast, [١٣] employed a Cobb-Douglas production function and used mathematical programming methods to estimate industry parameters for primary metals in the United States, and the number of outputs was limited to one. Also, [١٤] proposed a fractional programming method for adding outputs to a virtual output and inputs to a virtual input, and used their ratios to represent the relative efficiency of a DMU. In [١٥], it was assumed that the return to scale is constant. In a subsequent study by [١٦], this assumption was considered to present variables for the return to scale. In the same year, [١٧] obtained the same performance measurement based on the concept of distance functions. Moreover, [١٨] classified performance evaluation methods into six categories, although they originally belonged to two parametric and non-parametric methods.

After the work of [١٤], numerous studies have been reported on the methodologies and applications of DEA. The term network DEA first appeared in 2000 [١٩]. Evaluating the performance of the whole unit or black box is relatively simple, as only the inputs supplied and the outputs generated by the DMU must be considered, which allows systematic expression of the model. In contrast, measuring network system performance using a general model is difficult to express because different structures of the network generation system are involved. The simplest structure of network systems is a two-stage backup system in which externally supplied inputs are all used in the first stage to produce a set of intermediate products, which are used in the second stage to produce the final output of the system [۲۰]. The review presented in [۲۱] respected to network DEA provides the details of many related models and applications and provides an overview of the issue.

If X_{ij} and Y_{rj} define the i input (i = 1,…, m) and the r output $(r = 1, \dots, s)$ from the j DMU, the DEA model developed by [15] to measure the relative efficiency of DMU with the assumption of a constant return to scale in multiplier form is as follows:

$E_0 = max \sum_{r=1}^{s} u_r Y_{r0}$	(1)
s.t.	
$\sum_{i=1}^{m} v_i X_{i0} = 1$	
$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, j = 1, \dots, n$	
$u_r, v_i \geq \varepsilon, r = 1, \dots, s, i = 1, \dots, m$	

Where, u_r and v_i are virtual coefficients and ε is a small non-Archimedean number used to avoid ignoring any factor in the calculation of return [22], this model is commonly referred to as CCR model. If the return to the permissible scale is variable, the infinite variable u_0 is deduced from $\sum_{r=1}^{s} u_r Y_{r0}$ in the objective function and $\sum_{r=1}^{s} u_r Y_{rj}$ in the constraint set [16]. Model (1) is the input. The DEA model can also be set as an extra-organizational model. In this case, the model under constant returns to scale is the same as model (1), while one of the variables returned to scale adds an infinite variable v_0 to $\sum_{i=1}^{m} v_i X_{i0}$ and $\sum_{i=1}^{m} v_i X_{ij}$ in the constraint set [16]. This model, which allows the return to scale to be variable, is commonly referred to as the BCC model.

Model (1) has a dual that can be adjusted as follows:

$E_0 = min\theta - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$	(2)
s.t.	
$\sum_{j=1}^{n} \lambda_j X_{ij} + s_i^- = \theta X_{i0}, i = 1, \dots, m$	
$\sum_{j=1}^{n} \lambda_j Y_{rj} - s_i^+ = Y_{r0}, r = 1, \dots, s$	
$\lambda_j, s_i^-, s_r^+ \geq 0, j = 1, \dots, n, i = 1, \dots, m, r = 1, \dots, s$	
θ Unlimited	

This model is input-oriented and of envelope type. If an output-oriented model is desired, the performance of the function changes to $max\,\theta + \varepsilon(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+)$ and the variable θ connected to X_{i0} is passed to Y_{r0}. In addition, when the assumption of constant returns to scale changes to variable returns to scale, the convexity limit of $\sum_{j=1}^{n} \lambda_j = 1$ is added.

Model (1) or its equivalent model (2) does not consider the internal structure of the system in measuring productivity and is, therefore, commonly referred to as the black box model. The black box model considers only the consumed X_i inputs and the Y_r outputs generated by the system. Compared to the black box model, a network model considers the performance of component processes in measuring the performance. When considering internal structure of a system, externally supplied inputs can be directly used by all processes, and the outputs of each process can be either the final output of the system or intermediate products used by other processes for production.

Recent studies such as [23] have provided an overview of the literature and classification of DEA applications in transportation systems (TS). By classifying the papers, the origin of DEA in transportation problems is examined and then the development and overview of DEA provided at TS. Article [24] examines various mathematical and statistical approaches to predict the events by the aim of designing and constructing a combined forecasting method to predict the events based on logistic regression (LR) and DEA techniques. [25] Using Data Envelopment Coefficient Analysis (DEA-R) models, examines the allocation of centralized resources by centralized structures and proposes a method to determine the resource allocation of centralized structures minimizing the input-to-output ratio. [26] Provides a cut-off measurement (SBM) model in DEA that controls negative data. In this paper [27], two non-linear technologies are proposed based on the definitions of weak disposable in Spanish airport systems, which include weak disposable by non-uniform reduction factors and new weak disposable. Linearization methods are also proposed and for evaluating the efficiency of decision units (DMUs), a directional distance function (DDF) is applied to linear technologies and the analysis of the results is presented. [28] Provides a method for comparative and relative analysis of building sites in terms of their safety performance. The method proposed uses DEA to identify the efficiency of building sites known also as decision units. In [29], the fuzzy data envelopment analysis (fuzzy DEA) method is used to study the cost efficiency of DMUs and the proposed method is used to evaluate the fuzzy cost efficiency according to the α -level approach. In [30], sustainability means the flexibility of jobs during the time through economic, economic, social and environmental systems. [31] Increasing productivity and efficiency in industries with custom engineering production systems (ETOs) increases the interest of universities and businesses. The paper [32] proposes a method for finding non- dominated points of the Production Possibility Set (PPS) by Variable Returns to Scale (VRS) technology in DEA. It presents a multi-objective linear programming (MOLP) problem whose potential region is PPS, undergoing variable-scale returns to produce non-dominant points, and shows that Pareto-MOLP solutions produce efficient units in DEA, and vice versa. It also solves the MOLP problem by using a limited number of heavy cone beams produced by efficient solutions. By changing the weight, it gains new efficient points and thus produces a set of efficient solutions.

Successful implementation of quality manufacturing systems has been a common problem for automotive companies all over the world since the early 1900s [33-35]. Poor quality production systems negatively affect the indicators of production efficiency performance, lean processes, time cycle changes, power consumption, time change, failure, waiting time, revision, and time cycle [36]. Manufacturers should focus on increasing the quality health of production lines and reducing the time cycle. As product demand continues to increase, so does the need to focus on time cycle and productivity [37].

In Iran, DEA had began by the thesis of Alirezaei under the supervision of Jahanshahloo [٣٨]. After that, it was used in the evaluation of the performance of electricity distribution companies ,٣٩] [٤٠, power plants [٤١], banks [٤٢], insurance companies, general departments of roads and transportation, and etc. One of the latest works done in Iran in this field is to evaluate the performance of the manager by the help of DEA.

As can be seen, in most cases, KPIs have been evaluated by using DEA. In relation to applications, banks and financial institutions have the highest number, followed by farms, transportation, and electricity services. The focal issues are mainly related to supply and value chains. Other entities, such as universities, high-tech companies, retail stores, waste categories, and manufacturing companies, also appear in this literature.

3. Modeling

In network DEA models, each DMU consists of several components. The structure used in the model is hybrid and the indices, decision variables and model parameters are given below:

i input index of each unit

j index of the examined unit

r output index of each unit

U_r weighted variable given to the r output

V_i weighted variable given to the i input

X_{ij} input value of i from the j unit

Y_{rj} output value of r from the j unit

Z_g median value produced by the g unit

Taking into account the above indices, variables and parameters, the problem will be in Figure 1, where each DMU_i has m input variables of X_{ij}, $X_{ij} = X_{ij}^{(1)} + X_{ij}^{(2)}$, h median variable of Z_g, which are the output of the previous unit and the input of the next unit, and s is the input variable of Y_{rj}. The middle and final outputs of the system include two types of desirable and undesirable output variables.

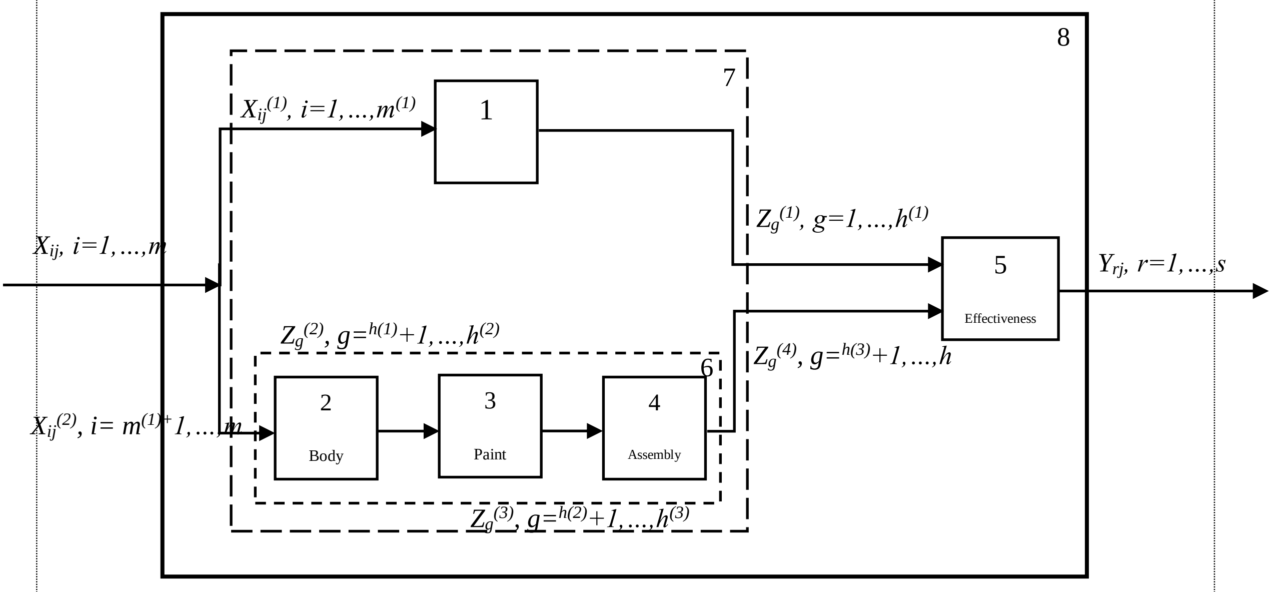


Figure 1. Network process of evaluating the performance of an automotive company

The efficiency of black boxes 1 to 5 separately, 6 by the product of the efficiency of boxes 2, 3 and 4, 7 by the convex combination of the efficiency of boxes 1 and 6, and finally 8 by the efficiency of all DMUs multiplied by the efficiency of boxes 5 and 7 are equal to the following equations, which are efficient when equal to 1 and inefficient when not equal to 1.

$$\theta_j^{(1)} = \frac{\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)}}{\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)}} \tag{3}$$

$$\theta_j^{(2)} = \frac{\sum_{g=h^{(1)}+1}^{h^{(2)}} w_g Z_{gj}^{(2)}}{\sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}} \tag{4}$$

$\theta_j^{(3)} = \dfrac{\sum_{g=h^{(2)}+1}^{h^{(3)}} w_g Z_{gj}^{(3)}}{\sum_{g=h^{(1)}+1}^{h^{(2)}} w_g Z_{gj}^{(2)}}$	(5)
$\theta_j^{(4)} = \dfrac{\sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}}{\sum_{g=h^{(2)}+1}^{h^{(3)}} w_g Z_{gj}^{(3)}}$	(6)
$\theta_j^{(5)} = \dfrac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)} + \sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}}$	(7)
$\theta_j^{(6)} = \dfrac{\sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}}{\sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}}$	(8)
$\theta_j^{(7)} = \dfrac{\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)} + \sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}}{\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}}$	(9)
$\theta_j^{(8)} = \dfrac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}}$	(10)

According to the definition of efficiency and input-oriented model, the modeling of the above problem is as following:

$\theta = max \dfrac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{i=1}^{m^{(1)}} v_i X_{i0}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{i0}^{(2)}}$	(11)
s.t.	
$\dfrac{\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)}}{\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)}} \leq 1, j = 1, \dots, n$	
$\dfrac{\sum_{g=h^{(1)}+1}^{h^{(2)}} w_g Z_{gj}^{(2)}}{\sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}} \leq 1, j = 1, \dots, n$	
$\dfrac{\sum_{g=h^{(2)}+1}^{h^{(3)}} w_g Z_{gj}^{(3)}}{\sum_{g=h^{(1)}+1}^{h^{(2)}} w_g Z_{gj}^{(2)}} \leq 1, j = 1, \dots, n$	
$\dfrac{\sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}}{\sum_{g=h^{(2)}+1}^{h^{(3)}} w_g Z_{gj}^{(3)}} \leq 1, j = 1, \dots, n$	
$\dfrac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)} + \sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}} \leq 1 , j = 1, \dots, n$	
$\dfrac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}} \leq 1, j = 1, \dots, n$	
$\dfrac{\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)} + \sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}}{\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}} \leq 1, r = 1, \dots, s, j = 1, \dots, n$	
$\dfrac{\sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)}}{\sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)}} \leq 1, r = 1, \dots, s, j = 1, \dots, n$	
$u_r \geq \varepsilon, r = 1, \dots, s$	
$v_i \geq \varepsilon, i = 1, \dots, m$	
$w_g \geq \varepsilon, g = 1, \dots, h$	

In general, DEA models are divided into input-oriented and output-oriented groups. In this method of linearization of the Charnes and Cooper model, it is argued that to maximize the value of a fractional expression, the denominator of the fraction should be considered equal to a constant number and the numerator is maximized. Accordingly, the denominator of the fraction is set to one, and this model is called the multiplicative form [22], which is given below.

$$
\begin{array}{l}
\theta = max \sum_{r=1}^{s} u_r Y_{r0} \\
s.t. \\
\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)} - \sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} \leq 0, j = 1, \dots, n \\
\sum_{g=h^{(1)}+1}^{h^{(2)}} w_g Z_{gj}^{(2)} - \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)} \leq 0, j = 1, \dots, n \\
\sum_{g=h^{(2)}+1}^{h^{(3)}} w_g Z_{gj}^{(3)} - \sum_{g=h^{(1)}+1}^{h^{(2)}} w_g Z_{gj}^{(2)} \leq 0, j = 1, \dots, n \\
\sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)} - \sum_{g=h^{(2)}+1}^{h^{(3)}} w_g Z_{gj}^{(3)} \leq 0, j = 1, \dots, n \\
\sum_{r=1}^{s} u_r Y_{rj} - \sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)} - \sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)} \leq 0, j = 1, \dots, n \\
\sum_{r=1}^{s} u_r Y_{rj} - \left(\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)} \right) \leq 0, j = 1, \dots, n \\
\sum_{g=1}^{h^{(1)}} w_g Z_{gj}^{(1)} + \sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)} - \left(\sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)} \right) \leq 0, r = 1, \dots, s, \\
j = 1, \dots, n \\
\sum_{g=h^{(3)}+1}^{h} w_g Z_{gj}^{(4)} - \sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)} \leq 0, r = 1, \dots, s, j = 1, \dots, n \\
\sum_{i=1}^{m^{(1)}} v_i X_{i0}^{(1)} + \sum_{i=m^{(1)}+1}^{m} v_i X_{i0}^{(2)} = 1 \\
u_r \geq \varepsilon, r = 1, \dots, s \\
v_i \geq \varepsilon, i = 1, \dots, m \\
w_g \geq \varepsilon, g = 1, \dots, h
\end{array}
\quad (12)
$$

By solving above model, the efficiency of $DMU\ 0$ is obtained. By placing the optimal coefficients obtained in the performance relationships of other black boxes, the efficiency of the components can also be obtained.

4. Case Study

The relationship between the indicators of performance evaluation considered for this issue is shown in Table 2, which is normalized.

The data required and the inputs and outputs of each of the five production lines have been collected by following up Pars Khodro Company in 2019. Also, the data collected was reviewed under the supervision of the company's experts and the inputs and outputs of each station were determined via the opinion of the company's experts, presented in Tables 3, 4 and 5.

Table 2. Performance evaluation indicators

<table>
<tr><th>Indicator number</th><th>Group</th><th>Indicator title</th><th>Calculation method</th><th>Scoring scale (value normalized by data ranking method)</th></tr>
<tr><td>1</td><td>Product</td><td>Defect rate reported to after-sales service network during the first 3 months after car delivery (3MIS[1] achievement ratio)</td><td>(Monthly committed amount of 3MIS / current amount of declared defects in the after-sales service network during the first 3 months after car delivery) × 100</td><td><table><tr><td rowspan="2">Scoring scale</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr><tr><td>120%</td><td>110%</td><td>100%</td><td>75%</td><td><75%</td></tr></table></td></tr>
<tr><td>2</td><td>Product</td><td>Rate of warranty number of defects declared in after-sales service network during the first 3 months after delivery of the car under customer protection in the last two months to the number of warranty of defects declared in after-sales service network during the first 3 months after delivery of car covered by customer protection received in the last three months 3MIS Q3 / Customer protection ratio</td><td>Number of 3MIS guarantees in the last two months that have CP[2] / Number of 3MIS guarantees received during the last three months) × 100

Point deduction in CP control process is checked based on standard file tables</td><td><table><tr><td></td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr><tr><td>Scoring scale</td><td>90%</td><td>75%</td><td>60%</td><td>50%</td><td><50%</td></tr></table></td></tr>
<tr><td>3</td><td>Product</td><td>The number of V1 and V2 defects of the product, which are evaluated by the auditor in the form of audits in static and dynamic modes (at least 10 vehicles of each model randomly within 2 hours). Short-AVES</td><td>(Number of V1 and V2 defects (taking into account the date of calculation) / Monthly factory target (according to S-AVES criteria) × 100</td><td><table><tr><td></td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr><tr><td>Scoring scale</td><td>Target 60%</td><td>Target 80%</td><td>Target 100%</td><td>Target *200%</td><td>>Target *200%</td></tr></table></td></tr>
</table>

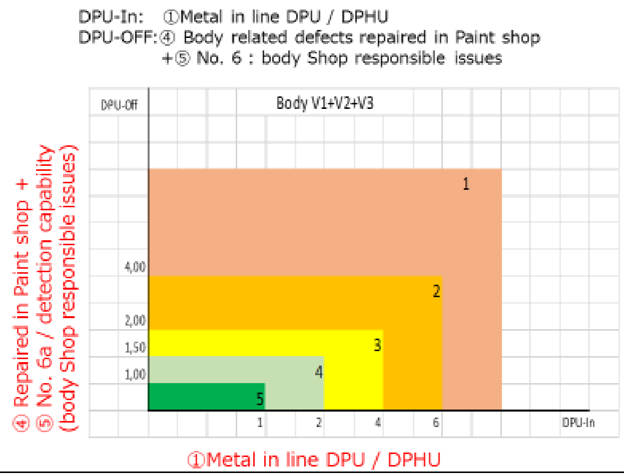
[1] Three Month In Service
[2] Customer Protection

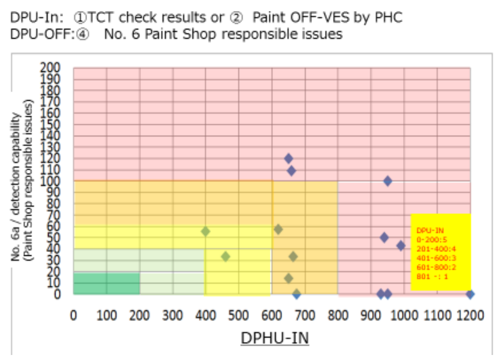
<table>
<tr>
<td>4</td>
<td>Product</td>
<td>Comparison of PHC[1] results with factory evaluation results (Index 3: At least 10 vehicles of each model at random)
S-AVES convergence V1, V2 (GAP ratio)</td>
<td>PHC results (DPHU) / last reported value (DPHU) of plant (TCS) × 100</td>
<td>
<table>
<tr><td>Scoring scale</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Ratio</td><td>1</td><td>1,2</td><td>1,75</td><td>2</td><td>>2</td></tr>
<tr><td></td><td>0,75</td><td>0</td><td></td><td></td><td></td></tr>
</table>
</td>
</tr>
<tr>
<td>5</td>
<td>Product</td>
<td>S-AVES V1</td>
<td>(Number of V1 defects / Volume Number of products calculated) × 100</td>
<td>
<table>
<tr><td></td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Scoring scale</td><td><1.5 DPHU</td><td>3DPHU</td><td>6 DPHU</td><td>9 DPHU</td><td>>9 DPHU</td></tr>
</table>
</td>
</tr>
<tr>
<td>6</td>
<td>Process</td>
<td>Ability to detect the defects by inspectors at the final stations and focus on calculating the ability of inspectors to detect defects from the CSC station to the final Sign Off station separately for each inspector
Inspection Capability of Final area</td>
<td>Numerator:
Number of defects detected in the inspection card (after the end of the T&C process and after the completion of the line work)
Denominator:
Number of defects detected in the inspection card (after the end of the T&C process) + Number of external current defects (number detected by S-AVES) - Bad defects (not repaired)
Identify bad repairs (unrepaired items), calculate and report defects that can be repaired</td>
<td>
<table>
<tr><td>Scoring scale</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>DPHU-OFF (No6 & No3) 0-100 DPHU</td><td>80%</td><td>75%</td><td>65%</td><td>55%</td><td><55%</td></tr>
<tr><td>101-200 DPHU</td><td>90%</td><td>80%</td><td>70%</td><td>60%</td><td><60%</td></tr>
<tr><td>>200 DPHU</td><td>92%</td><td>85%</td><td>80%</td><td>70%</td><td><70%</td></tr>
</table>
</td>
</tr>
<tr>
<td>7</td>
<td>Process</td>
<td>Repair capability</td>
<td>Number of V1/V2 defects detected and properly repaired before SAVES evaluation / Number of V1/V2 defects detected (if there is no information about V1/V2/V3, all defects should be</td>
<td>
<table>
<tr><td rowspan="2">Scoring scale</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>100%</td><td>98%</td><td>95%</td><td>90%</td><td><80%</td></tr>
</table>
</td>
</tr>
</table>

[1] Plant Health Check

<table>
<tr><td></td><td></td><td></td><td>considered)</td><td></td></tr>
<tr><td>8</td><td>Process</td><td>Straight passage or ratio of vehicles according to the cartography (straight flow diagram) that pass through the final process route without being delivered to repair stations outside the line for repair/ the total number of vehicle production
F-STR[1]</td><td>(Number of vehicles produced without repair / Total number of vehicles ready for delivery) × 100</td><td><table><tr><td rowspan="2">Scoring scale</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr><tr><td>98%</td><td>95%</td><td>80%</td><td>65%</td><td><65%</td></tr></table></td></tr>
<tr><td>9</td><td>Process</td><td>All defects repaired after the production line process is completed
DPU[2]-OFF / DPHU-OFF</td><td>(Number of defects / volume number of calculated products) × 100
(Calculation period: daily / weekly / monthly)
DPU IN report: monitoring case + management of the results of defects detected and repaired in the production line</td><td><table><tr><td rowspan="2">Scoring scale DPHU</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr><tr><td><50</td><td><100</td><td><400</td><td><600</td><td>Over 600</td></tr></table></td></tr>
</table>

[1] Final-Straight Run Ratio
[2] Defect Per Unit

<table>
<tr><td>10</td><td>Process</td><td>Body DPU/ DPHU</td><td>DPU IN:
Number of defects observed in the production process (TCT) of the body salon (related to the activities of the body salon)
DPU Off:
Total number of observed defects of A6 and 8 indicators related to the body salon</td><td>
</td></tr>
<tr><td>11</td><td>Process</td><td>Painting DPU / DPHU</td><td>DPU IN: Number of defects observed in the production process of the painting salon (related to the activities of the painting salon)

DPU Off: Total number of observed defects of index a6 related to the painting salon</td><td>
</td></tr>
<tr><td>12</td><td>Process</td><td>Self-declaration based on the completion of submitted files
APW[1]
Proper employee ratio
L or U level employee ratio</td><td></td><td><table>
<tr><td></td><td colspan="5">1 job 2operator ratio

1 operator 2 job ratio (over 2 position L/U level)</td></tr>
<tr><td>Proper</td><td>95%</td><td>94%-90%</td><td>89%-80%</td><td>79%-70%</td><td>-70%</td></tr>
<tr><td>Over 81%</td><td>5</td><td>4</td><td>4</td><td>3</td><td>2</td></tr>
<tr><td>80-61%</td><td>5</td><td>4</td><td>3</td><td>3</td><td>2</td></tr>
</table></td></tr>
</table>

[1] Alliance Production Way

<table>
<tr><td></td><td></td><td></td><td></td><td>
<table>
<tr><td>60-41%</td><td>4</td><td>4</td><td>3</td><td>3</td><td>2</td></tr>
<tr><td>40-21%</td><td>4</td><td>3</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>20-0%</td><td>3</td><td>3</td><td>2</td><td>1</td><td>1</td></tr>
</table>
</td></tr>
<tr><td>13</td><td>Process</td><td>Rate of operators' achievement of L-level based on APW control checklist and company production way evaluation results
L Level operator (Job observation)
Standard and training</td><td>(Number of L-level operators / total number of operators sampling) × 100</td><td>
11 a : L Level score based on Job Observation
<table>
<tr><td rowspan="2">11-a (Job Ob)</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>100%</td><td>80%</td><td>60%</td><td>40%</td><td><40%</td></tr>
</table>
11 b : Standards and training : Coherence between GOS – SOS – ORT
<table>
<tr><td rowspan="2">11-b (Document)</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>100%</td><td>80%</td><td>60%</td><td>40%</td><td><40%</td></tr>
</table>
KPI 11 = 11a × 70% + 11b × 30%
</td></tr>
<tr><td>14</td><td>Process</td><td>Calculating the performance of QRQC[1] based on evaluation checklist on the basis of effectiveness and responsiveness indicators.
Performance of QRQC sessions</td><td></td><td>
<table>
<tr><td rowspan="2">Score scale

*Use liner score

1-2,
2-3,
3-4,
4-5</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>QRQC APW standard is respected (All criteria are higher than Level4 and all MUST criteria are Level5 or higher)</td><td>QRQC APW standard is respected (All criteria are level 3 or higher and all HOW TO ACT criteria are 4 or higher)</td><td>QRQC APW standard is respected (all criteria of "QRQC Evaluation Grid" >= score 2)</td><td>QRQC APW standard is not fully respected (criteria of "QRQC Evaluation Grid" = All criteria are Level1 or higher and all HOW TO ACT criteria are Level2 or higher)</td><td>QRQC APW standard is not respected (all criteria of "QRQC Evaluation Grid" = score 1)</td></tr>
</table>
</td></tr>
<tr><td>15</td><td>Process</td><td>Number of vehicles in the</td><td>Inventory of repair stations</td><td>
<table>
<tr><td>Scoring scale</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
</table>
</td></tr>
</table>

[1] QRQC : Quick Response Quality Control

<table>
<tr>
<td></td>
<td></td>
<td>range of repair stations from the beginning of offline to the time of delivery to the customer and its inventory management in repair stations (body, painting, mechanics, electricity)
Repair inventory number</td>
<td>according to cartography</td>
<td>
<table>
<tr><td>60 JPH</td><td>5</td><td>15</td><td>40</td><td>80</td><td>120</td></tr>
<tr><td>45 JPH</td><td>4</td><td>12</td><td>30</td><td>60</td><td>90</td></tr>
<tr><td>30 JPH</td><td>3</td><td>9</td><td>20</td><td>40</td><td>60</td></tr>
</table>
</td>
</tr>
<tr>
<td>16</td>
<td>Process</td>
<td>Defects detected in S-AVES[1] with the origin of parts
Average V1+V2 supplier
Supplier SAVES</td>
<td>(Number of defects identified in Short-AVES with origin of parts / number of vehicles evaluated) × 100</td>
<td>
<table>
<tr><td colspan="2">Scoring scale</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td rowspan="4">No.3a

plant SAVES Target

(V1,V2)</td><td>80 DPHU</td><td><2.00</td><td>2.00-4.00</td><td>4.01-6.00</td><td>6.01-10.00</td><td>>10.00</td></tr>
<tr><td>100 DPHU</td><td><2.50</td><td>2.50-5.00</td><td>5.01-7.50</td><td>7.51-12.50</td><td>>12.50</td></tr>
<tr><td>150 DPHU</td><td><3.80</td><td>3.81-9.50</td><td>9.51-11.00</td><td>11.01-18.70</td><td>>18.70</td></tr>
<tr><td>200 DPHU</td><td><5.00</td><td>5.00-10.00</td><td>10.01-15.00</td><td>15.01-25.00</td><td>> 25.00</td></tr>
</table>
</td>
</tr>
</table>

[1] S-AVES : Short – Alliance Vehicle Evaluation Standard

Table 3. Values related to input indicators

	x(i,j)	Utilization of capital	Total number of employees	Order purchase cycle time	Total turnover time	Total inventory cost	Cost per hour of operation
A	DMU1	2.4	2.2	2.8	2.8	3.6	2.4
	DMU2	2.4	3.2	2.2	2.2	2.2	2.4
	DMU3	3.6	4	2.8	2.8	3.6	3.6
	DMU4	2.2	2.6	3	3	3	2.2
	DMU5	4	2.6	3.4	3.4	3.4	4
B	DMU1	1.2	5	5	2.4	2.6	1.2
	DMU2	1.8	4.6	4.5	3.5	1.3	1.8
	DMU3	2.4	4.7	2.3	5	5	2.4
	DMU4	1.4	3.6	3.2	4	4.2	1.4
	DMU5	3.2	3.6	2.1	4.1	2.2	3.2
C	DMU1	4.2	1.5	2.6	2.9	3.8	4.2
	DMU2	5	4.1	1.3	5	3.6	5
	DMU3	3.3	3.7	2.9	5	2	3.3
	DMU4	1.5	4	1.4	2.5	1.2	1.5
	DMU5	3.4	4.8	3.9	1.3	2.3	3.4
D	DMU1	1.3	5	3	4.5	3.6	1.3
	DMU2	1.6	2.9	2.2	1.7	5	1.6
	DMU3	2	2.9	5	5	2.3	2
	DMU4	4.3	4	2.2	2.5	5	4.3
	DMU5	2.1	2.1	1.7	5	2	2.1
E	DMU1	1.3	1	1.5	1	1.4	1.3
	DMU2	2	2.8	1	1.7	1.2	2
	DMU3	2.5	1.9	4.9	3.7	2	2.5
	DMU4	3.4	3.1	2.5	1.9	1.6	3.4
	DMU5	1.3	5	2.7	5.6	1.8	1.3

Table 4. Values related to median indicators

	z(d,j)	capital Utilization	Order purchase cycle time	Total turnover time	Cost per hour of operation	Short-AVES	S-AVES convergence V1, V2 (GAP ratio)	S-AVES V1	DPU-OFF / DPHU-OFF	Proper employee ratio L or U level employee ratio	L Level operator (Job observation) Standard and training
A	DMU1	5	4	3.2	1.7	2.1	4.3	1.6	4.5	2	3.3
	DMU2	4.9	1.2	5	3	2	1.7	2	4	2.5	2

	DMU3	1.8	2.4	5	1.1	4	3.8	1	5	4	2.5
	DMU4	3.8	5	1.9	2.5	5	4.4	3	4.7	1.5	4.5
	DMU5	2.2	1.5	3	4	2.1	2	4.9	1.4	5	3.4
B	DMU1	3.8	1.1	1.4	4.8	1.8	1.4	2.2	4	1.6	2.9
	DMU2	1.2	3	1.8	3.5	4.4	5	1.5	3.1	1.4	5
	DMU3	5	3.3	2.6	2	2.8	1	3.2	1.6	5	1.4
	DMU4	2.1	1.5	3.1	3.9	3.1	2.9	3.7	2.7	3.7	5
	DMU5	4.4	1.1	4.6	5	3.6	4.9	5	2.3	3.1	3
C	DMU1	1.2	5	2.6	5	3.5	4.4	1.9	5	1.2	1.6
	DMU2	5	3.5	3.5	1	5	5	5	5	3.6	4.7
	DMU3	1.8	4.3	3.5	4.2	5	2	5	3.7	1.4	2.8
	DMU4	5	5	5	1.8	4	4.5	5	2.4	5	1.8
	DMU5	1.4	4.8	3	5	5	5	4.6	5	5	5
D	DMU1	5	5	5	1.2	4.5	3.6	3.1	2.1	1.6	5
	DMU2	4.2	4.7	3.3	3.8	3.7	4.6	4.3	5	2.7	4.7
	DMU3	1.9	1.4	1.1	3.8	4.7	4	3.3	4.6	1.3	5
	DMU4	5	4	3.3	5	2.9	2.3	1.4	5	4	2
	DMU5	3.7	3.6	1.4	2.7	4.5	4.4	5	3.7	5	1.8
E	DMU1	1.5	2.2	3	1.7	2.3	3.9	1.7	2.9	1.9	2
	DMU2	1.3	1.3	2.4	5	2.1	1.9	3.5	1.8	4.9	1.7
	DMU3	1.6	2	3.5	4.8	1.8	2.3	5	1.6	1.7	5
	DMU4	2.2	3.5	1.6	3.1	1.6	2.7	1	1.8	4.6	1
	DMU5	2.5	1.6	2.6	2.2	2.9	1.8	1	5	4.7	1.1

Table 5. Values related to output indicators

		Output (Product)					**Output (Process)**										
	y(r,j)	**3MIS achievement ratio**	**3MIS Q3 / Customer protection ratio**	**Short-AVES**	**S-AVES convergence V1, V2 (GAP ratio)**	**S-AVES V1**	**Inspection Capability of Final area**	**Repair ability**	**F-STR**	**DPU-OFF / DPHU-OFF**	**DPU/ DPHU of body**	**DPU / DPHU of painting**	**Proper employee ratio L or U level employee ratio**	**L Level operator (Job observation) Standard and training**	**Performance of QRQC sessions**	**Repair station inventory**	**Average V1+V2 supplier**
A	DMU 1						3.5	2.5	3.5	1.5	2.5	2	4.5	4	2	3.5	2.5
	DMU 2	3.5	3	3.5	4.2	3.2											

	DMU 3	3.2	4.2	3.5	2.7	3.2											
	DMU 4	2	3	3.5	3.2	2.2											
	DMU 5	4	4.2	4.5	2.7	3.2	2	2.5	5	4	2.5	3	3.5	2.5	3.5	4.5	4
B	DMU 1						5.1	1.7	4.7	5.1	4.5	5.1	2.6	4	1.8	4.6	5.8
	DMU 2	1.9	1.4	5.2	1.6	5.1											
	DMU 3	4.8	5.5	4.3	4.8	2.6											
	DMU 4	3.9	3.3	2.2	3.8	3											
	DMU 5	1.3	1.2	3.1	2.8	3.4	2.5	4.2	3.7	1.5	4.6	2.6	1.1	5.9	4.7	4	2.5
C	DMU 1						2	5.5	3.7	2.5	3.3	3.3	3.4	3.1	2.6	2	4.2
	DMU 2	5	2	3.7	3.9	1.4											
	DMU 3	3.4	4.4	2.8	5.5	1.7											
	DMU 4	1.3	2.8	3.8	4.3	4.5											
	DMU 5	3.5	2.7	1.9	3.3	2.3	5.8	2.9	5.9	3.3	5.7	2.7	1.7	4.2	4.1	1.2	5.4
D	DMU 1						3.8	1.8	5.7	3.3	1.1	2.7	1	3	1.2	5.9	1.7
	DMU 2	5.7	4.6	4.2	2.7	2.7											
	DMU 3	3.9	3.6	5.9	1.7	1.5											
	DMU 4	4.3	5.3	5.3	3.7	1.2											
	DMU 5	5.4	4.1	3.3	5.4	5.9	2.3	2.1	4.1	4.2	4.2	4.1	1.6	4.2	1.6	3.6	1.3
E	DMU 1						2.9	1.5	2.3	4.6	4.8	5.3	2	1.8	4.8	3	2.1
	DMU 2	5.6	1.6	4.8	5.5	2.5											
	DMU 3	6	2.5	4.6	1.5	2.8											
	DMU 4	1.3	2.7	1.4	5	3.9											
	DMU 5	5.6	3.8	3.9	2.1	2.6	4.2	5.7	5.8	1.4	3.9	5.6	2.9	1.5	4.9	3.6	1.4

One way to model undesirable output is to reverse any undesirable output existed. Because the lower the number, the better, and the higher the inverse, the better, and thus the behavior transforms from undesirable to desirable. Using *GAMS win64 25.1.2* software, the total performance of all five production lines is calculated and given in Table 6. As can be seen, line E is more efficient than the other lines.

Table 6. Production line efficiency

		Black-Box 1	Black-Box 2	Black-Box 3	Black-Box 4	Black-Box 5	Black-Box 6	Black-Box 7	Black-Box 8
A	DMU1	0.72	1.00	0.64	0.87	0.34	0.55	0.71	0.24
	DMU2	1.00	0.87	1.00	0.99	0.95	0.86	0.99	0.56
	DMU3	0.68	0.80	1.00	0.79	1.00	0.63	0.71	0.68
	DMU4	0.99	0.46	0.84	1.00	1.00	0.39	0.71	0.95
	DMU5	1.00	0.69	1.00	0.64	1.00	0.44	0.71	0.96
B	DMU1	0.63	1.00	0.64	1.00	0.47	0.64	0.63	0.30
	DMU2	0.08	0.41	1.00	0.76	0.26	0.31	0.08	0.06
	DMU3	0.33	1.00	1.00	1.00	0.63	1.00	0.63	0.21
	DMU4	0.18	0.48	0.77	0.62	1.00	0.23	0.63	0.18
	DMU5	1.00	0.45	0.90	1.00	1.00	0.41	0.63	0.96
C	DMU1	0.67	1.00	1.00	1.00	0.13	1.00	0.68	0.09
	DMU2	1.00	0.94	0.48	0.59	0.51	0.26	0.92	0.63
	DMU3	1.00	0.66	1.00	0.78	1.00	0.52	0.68	0.95
	DMU4	0.46	1.00	0.77	1.00	1.00	0.77	0.68	0.48
	DMU5	0.69	0.81	0.80	0.53	1.00	0.34	0.68	0.67
D	DMU1	1.00	0.62	1.00	0.22	1.00	0.13	0.15	0.15
	DMU2	0.32	0.35	0.79	0.50	1.04	0.14	0.15	0.15
	DMU3	1.00	0.40	1.00	0.43	0.72	0.17	0.15	0.15
	DMU4	0.40	0.52	0.86	1.00	0.40	0.45	0.15	0.18
	DMU5	0.67	1.00	0.98	1.00	1.00	0.98	0.15	0.94
E	DMU1	0.60	0.71	0.81	0.60	0.44	0.35	0.59	0.26
	DMU2	0.70	0.70	1.00	0.50	0.48	0.35	0.69	0.23
	DMU3	0.82	0.77	0.91	0.22	1.00	0.15	0.59	0.77
	DMU4	1.00	0.83	0.96	0.66	1.00	0.52	0.59	0.97
	DMU5	1.00	1.00	1.00	1.00	1.00	1.00	0.59	1.00

Given that in the past it was very difficult to see the movement of the organization, the companies could not provide activities tailored to the circumstances. Therefore, there is a need for the system representing the way to define the correct and timely actions to put the whole organization in the right direction. Here, by putting the more efficient line at the forefront, the rest of the lines can be compared with and the necessary actions can be formulated. Due to the importance of the appropriateness of the production process and product quality, PHC model is presented.

PHC examines the quality health system of the factory by focusing on two factors of the processes and product of the organization. Processes and products each contain a number of indicators. The intersection between the product and the process falls at a point indicating that if there is a product that has the score of 3.5 in both the product and process. The point indicates how healthy is the plant in terms of quality. Otherwise, for example, if it falls in the yellow point, it means that the plant does not have quality health. These two processes and products' figures must be balanced and grow together, that is, the process must do its job properly and provide a good product, or vice versa, we have a good product and should make sure that the process does properly its job. We cannot have a product by high quality but not good process, and vice versa.we cannot have a good process,but a bad the output. In our organizations, the product may be good but the process is bad, and this will happen when the product is brought to an acceptable point with additional costs,

Table 7. Coefficients obtained from model solving and PHC inspection results

				A					B					C					D					E				
	No.	**Category**	**KPI**	**Coefficient**	**Last Score**	**Last Coefficiential Score**	**Last p.k Score**	**Last Audit Score**	**Coefficient**	**Last Score**	**Last Coefficiential Score**	**Last p.k Score**	**Last Audit Score**	**Coefficient**	**Last Score**	**Last Coefficiential Score**	**Last p.k Score**	**Last Audit Score**	**Coefficient**	**Last Score**	**Last Coefficiential Score**	**Last p.k Score**	**Last Audit Score**	**Coefficient**	**Last Score**	**Last Coefficiential Score**	**Last p.k Score**	**Last Audit Score**
Product	1	Field Quality	3MIS achievem	0.005	3.175	0.0159	3.4	3.17	0.005	4.475	0.022	2.8	3.17	0.005	2.3	0.012	2.9	3.52	0.069	4.55	0.313	4.5	4.18	0.005	1.825	0.009	2.0	1.95
	2		3MIS Q37 Customer	0.005	3.6	0.018			0.133	2.725	0.362			0.092	2.975	0.275			0.005	4.325	0.313			0.005	2.15	0.012		
	3	Shipping Quality	S-AVES V1 + V2	0.005	3.75	0.0188	3.0		0.005	3.65	0.018	3.6		0.005	3.05	0.01525	4.1		0.005	4.375	0.022	3.8		0.005	1.675	0.008	1.9	
	4		convergence (GAP ratio)	0.005	3.2	0.016			0.005	3.25	0.016			0.832	4.125	3.431			0.005	4.475	0.022			1.0862	1.9	2.064		

Process						
11	10	9	8	7	6	5
Built in Quality				Detection capability		
Painting DPU /	Body DPU /	Real DPU-OFF / DPHU-OFF (	F-STR	Repaire Capabilit	n Capabilit	S-AVES V1
0.005	0.005	0.005	0.005	0.005	0.591	1.841
2.5	2.5	2.75	4.25	2.5	2.75	2.95
0.013	0.0125	0.014	0.021	0.013	1.624	5.43
3.0				2.7		
3.12						
0.005	0.005	0.005	0.005	0.005	1.825	0.005
3.8	4.55	4.75	4.2	3.95	3.75	3.75
0.019	0.023	0.024	0.021	0.02	6.845	0.019
4.3				3.8		
3.83						
0.005	0.005	0.005	0.005	0.005	0.005	0.005
3	4.15	2.9	4.35	3.95	3.5	2.475
0.015	0.021	0.015	0.022	0.02	0.018	0.012
3.6				3.7		
3.41						
0.005	0.005	0.005	0.005	0.005	1.245	0.005
3.4	1.15	3.75	4.55	1.95	3.05	2.6
0.017	0.006	0.019	0.023	0.01	3.797	0.013
3.2				3.0		
2.60						
0.005	0.005	0.005	0.005	0.005	0.869	0.005
1.2	3.35	1.5	3.65	1.25	2.55	2.95
0.006	0.017	0.0075	0.018	0.006	2.21	0.015
2.4				2.5		
2.36						

16	15	14	13	12
Supplier Quality	Basic Strength			
Supplier SAVES	hand(Repair inventory	QRQC activity	BODY / TRIM L Level operator	employee ratio / 2 L level worker at 1 WS
0.005	0.005	0.005	0.005	0.005
3.25	4	2.75	3.25	4
0.016	0.02	0.014	0.016	0.02
3.3	3.5			
0.005	0.005	0.005	0.005	0.005
3.75	4.3	3.25	4.5	1.85
0.018	0.022	0.0163	0.023	0.009
3.8	3.5			
0.005	0.139	0.005	0.005	0.005
4.6	1.6	2.35	3.65	2.05
0.023	0.223	0.012	0.018	0.01
4.6	1.7			
0.005	0.005	0.005	0.005	0.005
1.5	4.3	1.4	3.6	1.3
0.008	0.022	0.007	0.018	0.007
1.5	2.7			
0.005	0.005	0.005	0.005	0.005
1.75	1.95	4.85	1.65	2.45
0.009	0.01	0.024	0.008	0.012
1.8	2.7			

such as manpower costs and high reprocessing. The opposite may also happen, when the process is very good but the product is bad. So, we can say that the organization has quality health, when a process does the job properly and this process leads to the right product. The number in the hatched area 5 in Figure 2 indicates that the organization is in good quality health, and in order to reach the excellent level, corrective measures must be defined to improve and grow the organization. The hatched areas 1 and 2 are not good and balanced. As can be seen in the hatched area 2, either the process is good and the product is bad, or vice versa, the product is good and the process is bad and the organization is not in good quality health status.

By drawing the points of the last inspection scores of Table 7 in Figure 2, the points obtained represent the quality health of production lines.

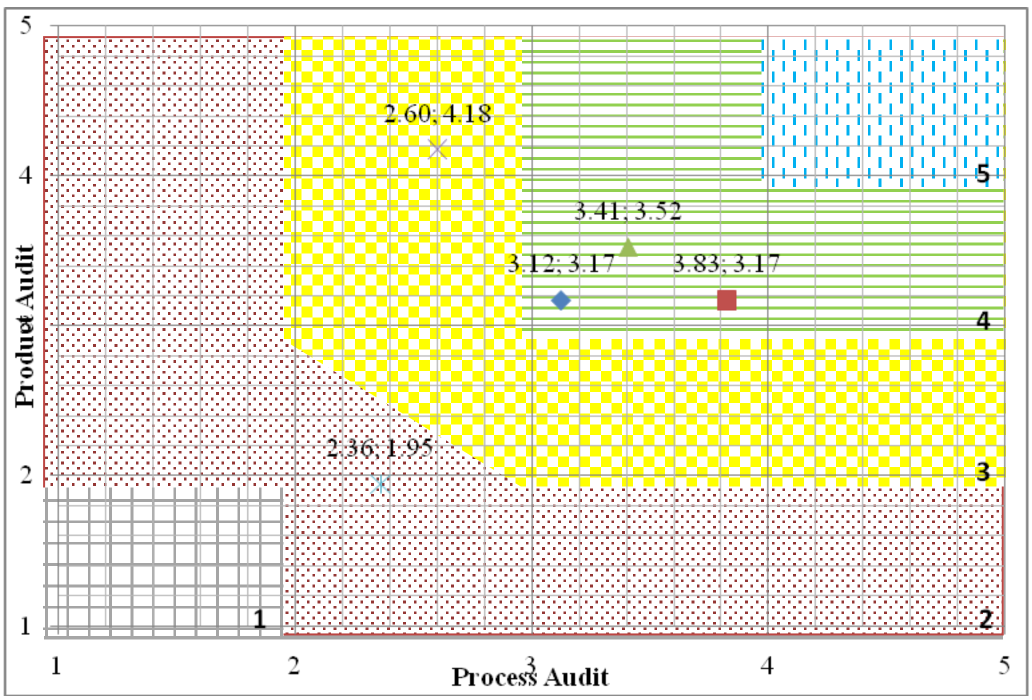


Figure 2. PHC diagram of the 5 production lines under study

In Figure 2, hatched area 1 is not defined, because the minimum score given to them in each process and product is one. The hatched area 2 along the axis X indicates the further we move forward, the better the process, and the further forward along the axis Y, the better the product. In fact, this area has no balance and the organization has a bad process for a good product and a bad product for a good process. The hatched area 3 is similar to area 2, but there is a reduction in its imbalance and it is in the middle zone indicating that the organization is neither good nor bad. The hatched area 4 is acceptable indicating acceptable quality of the product and process, balanced, but not reached to the ideal area. The hatched area 5 is an area where both the product and process are good, i.e. the organization is in perfect health.

5. Conclusion

Performance evaluation is important to enable the management to have a better understanding of the past achievements in production units and planning for future development. The goal is to understand how much one can expect the unit to increase the output by its own current input value, or how much of its current output can be saved by increasing the efficiency. The final interpretation of KPIs results in the organization act like the results of periodic tests for human body, meaning that each member/element does its job properly, can overshadow the entire human body/organization.Accurate assessment of vital factors in every person/organization plays a key role in diagnosing the current situation and improvement measures and thus, the health of the individual/organization.

The model developed is closer to the real world due to the consideration of desirable and undesirable outputs, in which the efficiency of five production lines in Iran Automotive Company is in 2019 using the network DEA model. Using the coefficients calculated for the identified desirable and undesirable input and output indicators related to the quality health of the lines, a model for evaluating the quality health of car production lines is presented. The most important operational feature of the model proposed is identifying and formulating temporary corrective works and achieving permanent corrective results along with the person in charge of problem solving and operational schedule according to the most efficient organization/production line finding the origin of the problem and thus, prevents problems. Therefore, by providing appropriate feedback to develop corrective activities for the source of the problem, it reduces the costs of quality loss, rework, improving the quality of products and increasing the level of process capability. This model can be generalized to other light and heavy automotive companies in Iran.

In order to find inefficient areas in an optimal conditions and make them efficient, the following measures can be done: establishing control processes, convening and holding committee meetings to resolve issues, performing CP audits and reviewing submitted documents, assessing the effectiveness of corrective activities and reporting to related units, correct action Non-compliant product reprocessing process, correct completion of CP protection section, Job rotation according to standards, increase of direct passage rate (STR) of production halls, improvement of reprocessing the status of quality defects, improvement of periodic compliance in each production EWT , Sampling more than 40 vehicles, making appropriate arrangements for recording quality defects, preventing Difficult to Check, preparing and compiling repair sauces, inspecting and checking, training people to detect and fix defects and standard retraining, performing GK audits, process audits Analysis of industrial safety and health risks, formation of specialized committees to follow up to eliminate quality defects, reducing output defects from the assembly line, eliminating the defects related to design and parts, establish a precise control mechanism for protection of production line tools, performing particle measurement by PM unit according to the control plan and maintenance plan, in color halls, ergonomics improvement for the end of stations, use of green card to determine the location of defects, daily production according to the production plan to prevent fluctuations and movement of forces, proper timing using APW system, Provide appropriate job allocation for each workstation, detailed planning for each operator to achieve skill level L, implementation of standard operating time cycle, GK audit and process audit and factory management audit, effectiveness of levels 0, 1 and 2 analyzes the presence of the members of the responsible units in the meetings, the cartography of the repair area and the waiting areas (outside the repair line), performed the analysis of the improvement of the SAVES index related to the input materials and parts.

Future studies are suggested to consider the desired criteria in the uncertain mode or consider the levels of supplier and distributor in the model. Other DEA models or other methods can be used also used to rank the indicators.

References

[1]	Kaplan, R.S. and D.P. Norton, The balanced scorecard: measures that drive performance. 1992.
[2]	Amaratunga, D., D. Baldry, and M. Sarshar, Process improvement through performance measurement: the balanced scorecard methodology. Work study, 2001. 50(5): p. 179-189.
[3]	Zhang, J. and W. Tan, Research on the performance evaluation of logistics enterprise based on the analytic hierarchy process. Energy Procedia, 2012. 14: p. 1618-1623.
[4]	Kazan, H., Performance evaluation in research and development, intellectual capital, and firm infrastructure projects as intangible assets. African Journal of Business Management, 2012. 6(5): p. 1872-1882.
[5]	Chen, C. and H. Yan, Network DEA model for supply chain performance evaluation. European journal of operational research, 2011. 213(1): p. 147-155.
[6]	Kaganski, S., et al., Implementation of key performance indicators selection model as part of the Enterprise Analysis Model. Procedia CIRP, 2017. 63: p. 283-288.
[7]	Amrina, E. and S.M. Yusof. Key performance indicators for sustainable manufacturing evaluation in automotive companies. in 2011 IEEE international conference on industrial engineering and engineering management. 2011. IEEE.
[8]	Hon, K., Performance and evaluation of manufacturing systems. CIRP annals, 2005. 54(2): p. 139-154.
[9]	Hudson, M., A. Smart, and M. Bourne, Theory and practice in SME performance measurement systems. International journal of operations & production management, 2001. 21(8): p. 1096-1115.
[10]	Renault PHC Standard. Master Document, Renault Company, 2017.
[11]	Farrell, M.J., The measurement of productive efficiency. Journal of the Royal Statistical Society: Series A (General), 1957. 120(3): p. 253-281.
[12]	Farrell, M.J. and M. Fieldhouse, Estimating efficient production functions under increasing returns to scale. Journal of the Royal Statistical Society: Series A (General), 1962. 125(2): p. 252-267.
[13]	Aigner, D.J. and S.-F. Chu, On estimating the industry production function. The American Economic Review, 1968. 58(4): p. 826-839.
[14]	Charnes, A., W.W. Cooper, and E. Rhodes, A Data Envelopment Analysis Approach to Evaluation of the Program Follow through Experiment in US Public School Education. 1978, Carnegie-Mellon Univ Pittsburgh Pa Management Sciences Research Group.
[15]	Charnes, A., W.W. Cooper, and E. Rhodes, Measuring the efficiency of decision making units. European journal of operational research, 1978. 2(6): p. 429-444.
[16]	Banker, R.D., A. Charnes, and W.W. Cooper, Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science, 1984. 30(9): p. 1078-1092.
[17]	Byrnes, P., R. Färe, and S. Grosskopf, Measuring productive efficiency: an application to Illinois strip mines. Management Science, 1984. 30(6): p. 671-681.
[18]	Førsund, F.R., C.K. Lovell, and P. Schmidt, A survey of frontier production functions and of their relationship to efficiency measurement. Journal of econometrics, 1980. 13(1): p. 5-25.
[19]	Färe, R. and S. Grosskopf, Network DEA. Socio Econ Plan Sci 34:35–49, 2000.
[20]	Cook, W.D., L. Liang, and J. Zhu, Measuring performance of two-stage network structures by DEA: a review and future perspective. Omega, 2010. 38(6): p. 423-430.
[21]	Kao, C., Network data envelopment analysis. International Series in Operations Research & Management Science. DOI, 2017. 10: p. 978-3.
[22]	Charnes, A. and W.W. Cooper, The non-Archimedean CCR ratio for efficiency analysis: a rejoinder to Boyd and Fare. European Journal of Operational Research, 1984. 15(3): p. 333-334.
[23]	Mahmoudi, R., et al., The origins, development and future directions of data envelopment analysis approach in transportation systems. Socio-Economic Planning Sciences, 2020. 69: p. 100672.

[24]	Pourmahmoud, J. and M. Gholam Azad, Hybrid Method of Logistic Regression and Data Envelopment Analysis for Event Prediction: A Case Study (Stroke Disease). Iranian Journal of Operations Research, 2020. 11(1): p. 43-58.
[25]	Razavyan, S., Efficiency of Centralized Structures in Data Envelopment Analysis Ratio Models. International Journal of Mathematical Modelling & Computations, 2019. 9(3 (SUMMER)): p. 197-199.
[26]	Tone, K., T.-S. Chang, and C.-H. Wu, Handling negative data in slacks-based measure data envelopment analysis models. European Journal of Operational Research, 2020. 282(3): p. 926-935.
[27]	Seihani Parashkouh, F., et al., Two-Stage Network DEA with Undesirable Outputs: An Application in the Air Transportation in the Spain. Iranian Journal of Operations Research, 2020. 11(1): p. 1-24.
[28]	Nahangi, M., Y. Chen, and B. McCabe, Safety-based efficiency evaluation of construction sites using data envelopment analysis (DEA). Safety science, 2019. 113: p. 382-388.
[29]	Pourmahmoud, J. and N.B. Sharak, Evaluating Cost Efficiency Using Fuzzy Data Envelopment Analysis method. Iranian Journal of Operations Research, 2020. 11(1): p. 25-42.
[30]	Farzipoor Saen, R., M. Song, and R. Fisher, New data envelopment analysis models for assessing sustainability Part 2: A static data envelopment analysis approach. 2020.
[31]	Telles, E.S., et al., Drum-buffer-rope in an engineering-to-order system: An analysis of an aerospace manufacturer using data envelopment analysis (DEA). International Journal of Production Economics, 2019: p. 107500.
[32]	Lotfi, H., Characterization of efficient points of the production possibility set under variable returns to scale in DEA. Iranian Journal of Operations Research, 2010. 2(1): p. 50-61.
[33]	Gijo, E. and J. Scaria, Process improvement through Six Sigma with Beta correction: a case study of manufacturing company. The International Journal of Advanced Manufacturing Technology, 2014. 71(1-4): p. 717-730.
[34]	Miina, A., M. Saat, and E. Kolbre, Critical success factors of lean thinking implementation in Estonian manufacturing companies. 2012: TUT Press.
[35]	Kumar, N., et al., Implementing lean manufacturing system: ISM approach. Journal of Industrial Engineering and Management (JIEM), 2013. 6(4): p. 996-1012.
[36]	Bagozzi, R.P., Performance and satisfaction in an industrial sales force: An examination of their antecedents and simultaneity. Journal of Marketing, 1980. 44(2): p. 65-77.
[37]	Kumar, S.S. and M.P. Kumar, Cycle time reduction of a truck body assembly in an automobile industry by lean principles. Procedia Materials Science, 2014. 5: p. 1853-1862.
[38]	Gholamreza, J. et al., Measuring the efficiency in DEA by fuzzy input an output: A method for assessing, ranking and applying weight restrictions.
[39]	Mohamadhoseyn, p. and H.Kiyoumars, Using DEA in assessing the efficiency of Thermal power plants of electricity generation in Iran.
[40]	Ismaiel,A.and L. Hasan, The effect of forming electricity market on the efficiency of power plants in Iran.
[41]	Mohamadreza, A.and A. N. Allah, Evaluating the performance of steam, gas and water power plants and determining their technical efficiency by using DEA.
[42]	Hadi,M.and S. B. Gh. Bahram, Evaluating the efficiency and sensitivity analysis of banking system by using DEA.