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Optimization of Process Parameters for A Wind Turbine in A Ducting System Through The Taguchi-Pareto-DEMATEL Method

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ABSTRACT

In a heating, ventilation, and air conditioning (HVAC) unit, ducting systems with wind turbines are responses to the system's high wind energy yields. However, the efficiency of the system is a challenge. To tackle this issue, optimization of process parameters plays a central role. Unfortunately, while applying the Taguchi method as an optimization procedure for high wind energy yields, the existing procedures are not clear enough to project a deep understanding of how to establish priorities among the system's parameters and yet showcase relationships among them. Consequently, this study proposes a new approach, the Taguchi-Pareto DEMATEL (Decision making trial and evaluation laboratory), to establish priorities among the process parameters and concurrently define associations among the parameters of the wind turbine inducting system. The proposed method amalgamates the Taguchi-Pareto method, which prioritizes the process parameters and minimizes the anticipated value of the variance with DEMATEL. The DEMATEL method is infused into the structure to verify interconnection among the wind turbine process parameters and establish a map to show the comparative association within the parameters. Thus, the DEMATEL framework probes and solves the complex energy yield problem of the wind turbine. The parameters used are input air pressure, ducting height, the distance between the blower and the pipe, total effective length, and the gap between the truck and runout. The desired optimal value of parameters for the proposed method are as follows: $P_2H_2TG_2EL_1BD_1$, which is interpreted as 2.5m/s of air pressure, 0.5in of height, 1in of truck gap, 0.5in of effective length, and 0.5in of blower distance. The optimized parameters of a ducted wind turbine in an HVAC system could be of vast interest to HVAC systems to plan and monitor wind turbine performance.

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1. INTRODUCTION

The present paper tackles the ducted wind turbine optimization problem in heating, ventilation, and air conditioning (HVAC) systems built for the Malaysian environment. The problem solved is to generate wind energy for a ducted wind turbine that supports the HVAC system by optimizing the parameters such as the effective length, truck gap, pressure, blower distance, and height while establishing interactions among parameters. The problem is mixed optimization and multi-criteria one because it involves minimization/maximization of parameters while tackling the actual indicators for the process performance. As such, it could be solved using a two-stage optimization scheme with the first phase involving the Taguchi-Pareto method and the second phase involving the DEMATEL (Decision-making trial and evaluation laboratory) method. Thus, a new method is proposed, and an integrated Taguchi-Pareto DEMATEL method has been applied to calculate several ratios based on diverse, relevant parameters. In the first phase of the method, the parameters are optimized without violating the system constraints, mainly the parameters' specifications. Consequently, the optimization of the ducted wind turbine-based HVAC system was measured and monitored by the experiments conducted by Malik et al. (2019). However, the experimental data was used in the present article to prosecute the validation of the method proposed in the present article.

2. EVOLUTION OF WIND AND PREVIOUS STUDIES

At first, wind turbines had been associated with James Blyth of Scotland in 1887 when this equipment was used to produce electricity. However, concurrently, in 1888, some accounts give credit to Charles Brush for the wind turbine innovation and the idea of using the wind to power a machine as experimented in a building where it was feasible to generate electricity. Furthermore, the wind had earlier been used to propel boats for several hundreds of years. Charles Brush's invention probably afforded Pour la Cour to originate the electricity-generating wind turbine and the employment of Kratostate (a regulator) to obtain power from wind turbines. However, both at the time of Charles Brush's invention and at the later times, 1891 and 1895, when Pour la Cour developed a prototype electrical powerplant, knowledge of how to develop a clutched wind turbine wind in an HVAC system was still unknown. Though the history of wind turbines started in the USA by Charles Brush and has spread to Denmark through Pour la Cour's efforts in launching the Society of Wind Electricians, only in 1991 was the UK's premier onshore wind farm launched in Corn wall. The worldwide spread of wind turbine manufacture was experienced in India in 1995 through the efforts of Scivlon Energy. In 1998, Goldwind in China brought manufacturing to the country. Spain had experience in manufacturing wind turbines in 2000 through the efforts of Gamesa on Bolsa de Madrid. All along, modifications to existing wind turbines have been made, and wind turbines in an HVAC system were born several years ago.

Notwithstanding, in the past decades (2000 to 2020), manufacturers and their events propelled significant landmarks in wind turbine development, and the key outcomes are as follows. In 2002 GE Wind Energy, which occupied the first position in global manufacturing of wind turbines by 2012, emerged. The same year 2002 also experienced a capacity enlargement of Global wind power to 3 100 megawatts in 2005, 93,820 megawatts in 2007, and 120,291 megawatts in 2008. In 2010, China led the world as the largest cumulative country of installed wind power capacity. Lastly, in 2013, China dominated the world by having wind power as the third greatest power source.

The use of parameters as indicators of the efficiency of the wind turbine has been extensively documented in the literature. Some of these parameters are interspaces between turbines in wind forms (Timothy and Richard, 2009), yaw angle (Pre-Age and Muyiwa, 2011), power generation (Rivarolo et al., 2020; Fabio et al., 2021; Rajendra et al., 2020) other parameters are design efficiency (Tariq and Markus, 2018), duct angle (Nemat et al., 2021), turbine rotor blade tip clearance (Saleem & Man-Hoe, 2019), nozzle configuration (Ssu-Yuan and Jung-Ho, 2007), turbines position inside an enclosure (Saeed et al., 2015), blade angle of attack, number of blades and variation of blade designs (Hamid et al., 2016), opening band radius and diameter of duct (Claudio et al., 2021), fan type and quantity of blade (Ziyun et al., 2020), wind lens of varying diffuser length, diffuser angle, duct length and flange height (Abdelaziz et al., 2022). The mentioned parameters in the literature are extensive, but unfortunately, some key parameters are messing. The present authors could not find pressure, gap, and height, among others, substantially in the literature. But these parameters are fundamental to the efficiency of ducted wind turbines. The treatment of these parameters in a single source by Malik et al. (2019) motivates the authors' experimental data to validate the proposed Taguchi-Pareto-DEMATEL method in this work.

Furthermore, though there have been several reports on wind turbines, few studies have been performed on the ducted wind turbine. Akhilesh and Neel (2020) worked on the magnitude of power generation by the ducted wind turbine using numerical simulation. Mousa and Mojtaba (2020) formed the initial cost of setting up a wind turbine of the omnidirectional type to be greater than the horizontal axis type. Further, fewer reports have been made on the alternative applications of a wind turbine in the past few years. For example, Qun et al. (2021) analyzed the dynamic response of the wind turbine in a water environment. Stefania and Stefano (2019) demonstrated the application of wind turbines for a roof. Sathish et al. (2020) applied knowledge of wind turbines to rail systems. The drawback of this literature is that while manufacturing systems are increasingly important in deploying roof-mounted wind turbines for ventilation comfort, the foundation of ventilation in manufacturing systems is that the HVAC systems are often ignored in the literature on the ducted wind turbine. To the best of the authors' knowledge, Malik et al. (2019) is the only reported source for the HVAC documentation. Even the article, which applied an optimization technique (Taguchi method), has the weakness or inability of the HVAC/turbine engineer to distinguish the order of importance of the parameters in association with the interrelatedness of the parameters. Hence, the Taguchi-Pareto-DEMATEL method may be appropriate for use in this article to solve this lingering problem.

Numerical analysis has been the major method employed to enhance the efficiency of wind turbines. Tarfaoui et al. (2019) assessed the structural behavior and the most crucial failure mechanism of wind turbine blades. Harjeet and Pradeep (2020) established the power generated by the turbine increase with the increasing angle of the diffuser and quantity of blades. Abolfazl and Aidin (2021) developed a narrow aperture at the inbound area of the blade with various intake magnitudes to increase the efficiency of the wind turbine by 8.1%. Timothy and Richard (2009) established that the distance between wind turbines arranged co-axially and offset configuration was reported to influence wind turbine performance installed in a wind turbine farm. Mauro et al. (2019) established the importance of using oscillating flow studies. Moreover, some optimization methods have also been applied to the wind turbine system. In particular, Tariq and Markus (2018) developed optimal designs that significantly improved output power coefficients. The approach used was the multi-objective genetic algorithm.

However, a weakness of both numerical analysis optimization methods discussed is that by their very nature, no study could claim that the obtained results could truly concurrently optimize and prioritize the parameters. Besides, those two methods are not designed to reveal associations among the parameters. Consequently, to suppress these restrictions in the past research regarding concurrent optimization, prioritization, and association establishment, the present study has proposed the Taguchi-Pareto-DEMATEL method.

Furthermore, Table 1 summarizes the literature on the relevant aspect of the study. Table 1, which summarizes the literature on ducted wind turbines, shows the various studies with methods of evaluating the performance of different aspects of the system. It is observed that the Taguchi Pareto–DEMATEL method has not been previously reported in the ducted wind turbine area and specifically for the HVAC systems. This extensive literature classification makes the proposed method's uniqueness evident. From the literature review and Table 1, insight into the uniqueness of the Taguchi-Pareto–DEMATEL method may be explained as follows: At present, as wind turbine/ HVAC engineer runs the HVAC system, it has become common knowledge to seek optimum parameters to operate the HVAC system as powered by the ducted wind turbine. However, it is noticed the engineer is always in a dilemma about which of the parameters among the following to give the utmost attention to truck gap, pressure, and height. While experience suggests the engineer’s preference for one parameter over the other, it is acknowledged that judging based on intuition may produce suboptimal results.

The engineer also appreciates the experience gained over years that may be put to practice to choose any of the parameters as the most important one. Nonetheless, it is known that experience may fail, and wrong decisions may be made. Besides, while monitoring the wind turbine-based HVAC system, several problems may emerge, and the causes should be known. Based on these discussions, the well-known Taguchi method fails to tackle these issues, but the Taguchi Pareto–DEMATEL method demonstrates the competence to overcome these challenges. First, the Taguchi-Pareto-DEMATEL method contains the Taguchi-Pareto approach, which functionally optimizes the ducted wind turbine parameters for the HVAC to reduce variations and then optimize according to the average output targets while acting on an 80-20 rule to distinguish one parameter from the other in competition. The Taguchi method is limited to the first aspect of the proceeding description for the Taguchi-Pareto method. Second, the decision-making and evaluation laboratory (DEMATEL) adds value to the Taguchi-Pareto method. The synergy created by amalgamating DEMATEL to the Taguchi-Pareto method allows for the establishment of the cause-effect chain p of the ducted wind turbine-based HVAC system, which is complicated. The ability demonstrated by the DEMATEL method permits the assessment of the independent associations among the wind turbine parameters and seeks crucial interactions by visualizing them through a structural model. The above description gives the novelty of the Taguchi-Pareto-DEMATEL method.

3. METHODS

This article presents a new type of integrated parametric optimization and association determinant – The Taguchi-Pareto DEMATEL method. This approach combines the Taguchi method, Pareto analysis, and the DEMATEL relationship fitting approach. The Taguchi-Pareto method's processing is established using the Taguchi method's outcome. This then becomes the input to the DEMATEL method. This section describes the methodology with an example of a system.

3.1 Problem Statement

Heating, ventilation, and air condition (HVAC) refers to a technology that maintains building comfort by offering adequate indoor air quality and the necessary thermal comfort. Buildings could be residential (i.e., single-family homes, large multi-family complexes) and commercial (i.e., offices and submarines). However, the energy yields may be consistent by introducing a wind turbine in the ducting system of the HVAC system (Malik et al., 2019). But in an ideal work environment, a group building maintenance engineer is responsible for the upkeep these large complexes with HVAC systems. The engineer should be trained to establish faults within the HVAC system and particularly the wind turbine system of interest to the present researchers. The engineer should establish familiarity with the wind turbine operating parameters such that budgets on resources are judiciously expended. During shortages of funds, available resources are directed at the proper operating parameters for the wind turbine of the HVAC system. Understanding what parameters are important among the wind turbine operating parameters helps avoid resource wastage and undue distribution of resources to non-deserving parameters, maintenance centers, and operators. Unfortunately, the distribution of resources to parameters/maintenance centers or operators are present is done intuitively without regard for needs assessment and justification for resource distribution. Apart from the enormous waste that could be avoided, conflicts often occur between maintenance centers, with one center claiming the need for more resources without justification and scientific guidance. It matters to resolve this problem as organizations most desire a cooperative team for healthy working relationships. Also, waste avoidance promotes the organization’s profitability and stimulates its long-term survival. However, to resolve this problem, a method that concurrently optimizes the wind turbine operating parameters selects the best parameters and establish relationship among the parameters through mapping, exploiting the causal relationships of parameters is desired.

Table 1. Literature summary of relevant studies in ducted wind turbine

S/No.	Author(s) and year	Domain of study	Work material	Key input parameters used	Adopted method(s)	Output (responses)
1	Rajendra et al. (2020)	Wind turbine enhanced with a diffuser	Diffuser and ducted wind turbine, vortex generator, and wind lens	Type of diffuser	Computational fluid dynamics	Power generated
2	Nemat et al. (2021)	Effect of opening duct angle on shrouded wind turbines	Ducted wind turbine	Opening duct angle	Multiple regression analysis and artificial intelligence	Look up a table for optimizing turbines furnished with a shroud system.
3	Claudio et al. (2021)	Aerodynamic designs of ducted wind turbines in high-rise buildings	Ducted Wind turbine and high-rise building	Bend radius and turbine duct diameter	Computational fluid dynamics simulation	Wind power and energy speed
4	Islam et al. (2021)	Integrating a wind turbine with a desalination plant	Ducted wind turbine and desalination plant	Floating desalination plant	Experimental analysis	Plant Efficiency
5	Suthagar et al. (2021)	Invelox wind turbine	Ducted wind turbine	The angle of exit diffuser and throat section velocity	Experimental analysis	Efficiency and rotor torque
6	Abolfazl and Aidin (2021)	Effect of boundary layer suction on wind turbine performance	Ducted wind turbine	Size of blade aperture	Numerical analysis	Intake magnitude and efficiency
7	Mousa and Mojtaba (2020)	Feasibility study of Invelox	Ducted wind turbine	Set up cost, geometry complexity	Feasibility study	Energy generated
8	Akhilesh and Neel (2020)	Using Exhaust air to drive ducted wind turbine	Exhaust and ducted wind turbine	The volume of exhaust air	Numerical simulation	Power generated
9	Harjeet and Pradeep (2020)	Using flue gas to drive wind turbine	Exhaust pipe and ducted wind turbine	Quantity of blades and angle of the diffuser	Numerical simulation	Power generated
10	Qazi and Man-Hoe (2021a)	Airborne wind turbine for high altitude	Diffuser and ducted wind turbine	Height and air loads	Three-dimensional numerical simulation	Power generated
11	Qun et al. (2021)	Semi-submersible wind turbine at an intermediate water depth	Ducted wind turbine	Depth of water	Numerical Analysis	Dynamic response
12	Qazi and Man-Hoe (2021b)	Performance of airborne wind turbine under unsteady loads	Ducted wind turbine	Wind shear yawed and tilted inrush	Experimental analysis	Efficiency
13	Hung and Dirk (2021)	Wind turbine lifetime control using structural health monitoring and prognosis	Ducted wind turbine	Operating and maintenance cost	Analytical review	Power generated
14	Wai and Fanzhong (2021)	Estimator for determining the effective wind speed of the rotor	Ducted wind turbine	Type of estimator	Design and simulation	Wind speed and Torque
15	Liqun et al. (2020)	Using slippery liquid-infused porous surface for wind turbine icing mitigation	Ducted wind turbine	Type of lubricants	Experimental assessment	Durability and effectiveness of the lubricants
16	Baratchi et al. (2020)	Assessment of blade element actuator element disk method for simulation of ducted tidal turbines	Ducted wind turbine	Cost of the method adopted	Blade element actuator disk method and actuator line method	Normalized power, thrust coefficient, and power coefficients
17	Jianjun et al. (2020)	Effect of divergent angle on the flow behaviors in low-speed wind accelerating ducts	Ducted wind turbine	Duct curvature, pressure zone, and outlet angle	Experimental assessment	Power generated

Consequently, parametric optimization, prioritization, and relationship mapping of wind turbine parameters become an important topical aspect of the investigation to minimize waste in the disproportionate allocation of wind turbine system resources to underserving parameters or maintenance centers. Addressing this topic also potentially improves a healthy relationship among the operators of the wind turbine systems as a reference guideline for the distribution of wind turbine resources that will be used and respected by all operators. However, the Taguchi-Pareto-DEMATEL method becomes a relevant method to solve this problem.

Interestingly, during the past recent years, much effort has been made to optimize the process parameters of wind turbines by introducing the Taguchi method in the experimental design domain (Malik et al., 2019). But the application was focused on the ducting system with the wind turbine placed to drive an HVAC system. However, the representative components of the Taguchi method principally include a factor and level institution choice of the orthogonal array, establishment of the signal-to-noise structure, the evolution of the response table, and definition of the delta values and the optimal parametric settings. The methodological components of the Taguchi method are absent in variance analysis with the tool, such as the analysis of variance completely absent in the Taguchi method. This makes the Taguchi method incapable of solving the prioritization problem when multiple parameters important to the wind turbine air pressure maximization are analyzed. Ajibade et al. (2021) introduced the Taguchi-Pareto method to solve this problem. However, the application is in the context of composite development. Interestingly, the present authors were attracted to the advantages of the TP-DEMATEL method being brought in by the Taguchi method. A principal advantage of the Taguchi method brought into the synergy of the Taguchi method, Pareto analysis, and DEMATEL method is that it considers several factors to be simultaneously optimized, thereby providing more quantitative information from fewer experimental tests. But the introduction of the Taguchi-Pareto method by Ajibade et al. (2021) brings a principal advantage to the TP-DEMATEL approach. This advantage is that the approach assists in establishing main parameters accountable for the variations in performance. From the introduction to the present time, the Taguchi-Pareto method has been extended to the maintenance system in the context of total quality management. However, despite the method's utility, it cannot reveal the relationship among the parameters of the wind turbine system. Therefore, innovation is borrowed from Maduekwe and Oke (2021), which first introduced the TP-DEMATEL approach to maintenance systems. An additional advantage of introducing the DEMATEL method to the TP-DEMATEL framework is that its application helps declare the structure of the complicated causal associations among the analyzed parameters. The method can reveal the degree of the influence of every parameter in the analysis. Consequently, it provides hints to the system operators on how to enhance the performance of certain concerns. Thus, the enumerated advantages can be exploited in the TP-DEMATEL method explored in the present article if applied properly. Besides, this paper focuses on applying the TP-DEMATEL method in the wind turbine system as new research previously unattended.

From the foregoing, the Taguchi-Pareto DEMATEL method is a combination of the Taguchi method (for optimization), Pareto principle (for prioritization), and DEMATEL method (for causal relationship analysis), may be an important tool to solve this problem. In this article, the objective is to develop and apply a new method, earlier proposed by Maduekwe and Oke (2021), based on the Taguchi-Pareto-DEMATEL method. A novel contribution is made in the context of application to the wind turbine process parameters in an HVAC system. Such work behaviour been previously reported in the literature. With this proposed solution, it is expected that waste will be avoided as the most important parameters are known and used for resource distribution to parameters or maintenance centers. Furthermore, a healthy team is promoted, enhancing the organization's productivity.

3.2 The Taguchi-Pareto-DEMATEL method

In this article, the methodology, which was assumed in this study to reinforce the computations, is to establish the experts' opinions on the wind turbine parametric relationship using a structured questionnaire addressed to experts. Although wind turbine is a specialized area, in Nigeria, an extremely scanty number of experts is available in practice. The information available in the public domain reveals that very limited experts engage in wind turbine activities, but only the visible experts are available in higher educational institutions. However, it is known that many manufacturing plants utilize turbine ventilators that offer natural ventilation from trapped air from outside the manufacturing plant. These turbine ventilators are installed on the roof and effectively move enormous hot air from the attic. Based on this information, the target audience, based on the availability of experts, was focused on a soft drinks manufacturer with a national spread of nine plants across Nigeria. Consequently, the maintenance engineers and production engineers/managers responsible for power plant maintenance and control were asked to fill the questionnaire for the authors. The filled questionnaires became the output to be used as input to the DEMATEL method. The information was obtained from two respondents in the plant.

Furthermore, maximizing the input pressure into the ducted wind turbine while minimizing height between the compartment, pipe distance from the blower, total effective length on the center height of the compartment, and the gap between the ducting compartments. An optimization method referred to as Taguchi Pareto DEMATEL was adopted. Taguchi Pareto DEMATEL applies the Taguchi optimization strategy, which employs a measurable framework called flag to commotion proportion to assess ducted wind turbine parameter that maximizes the input weight into the turbine. The Taguchi strategy was optimized through Pareto 80-20 rule. This was done by orchestrating the flag to clamor the proportion of the factors in the slipping arrangement. The whole entirety of the variables was calculated, whereas the rate commitment of each figure level was obtained Assist, the cumulative rate commitment of each figure level is inferred from the overall whole. At an 80 % aggregate rate, the Pareto 80-20 run the show is connected. The figure levels underneath the 80 % constrain are cut off and named immaterial to optimality. The figure level over the 80 % constraint is utilized to create a changing table of variables and levels. The yield of the Taguchi Pareto was advanced and optimized utilizing a decision-making trial and evaluation laboratory (DEMATEL). DEMATEL strategy may be a graphical strategy which has been utilized to assemble information from specialists and visualize the causal relationship between complex variables by utilizing graphical representation.

The following are the Steps adopted when applying Taguchi Pareto DEMATEL (Maduekwe and Oke, 2021):

Step 1: *Identification of experts in a ducted wind turbine in the industry*: Experts knowledgeable on factors that affect the performance of ducted wind turbines were identified to dodge squandering exertion in gathering the required information.

Step 2: A survey of DEMATEL was created utilizing five components. In the numerical case illustration of Gandhi et al. (2015), three choice markers were locked in to decide the degree of coordinate impact between two components through a pair-wise comparison. This paper dispersed surveys to five experts that work in a bottling company. Each of them was provided 20 pairwise questions, which experts are required to provide their suppositions through factors extending from "no influence" to "High Influence". Their responses were converted to numbers.

Step 3: Each expert produced a five-coordinated framework. Each esteem within the lattice speaks to the measure of an intuitive impact between variables. An average matrix was obtained using Equation (1)

$$Z_{ij} = \frac{a_{ij(1)} + a_{ij(2)} + a_{ij(3)} + a_{ij(4)} + a_{ij(5)}}{m} \quad (1)$$

where m = Number of respondents

Step 4: *Obtaining the orthogonal Array*: Five parameters with five levels were considered for the wind Analysis. An L5^2 orthogonal array was obtained using Minitab 16.

Step 5: Each expert produced a five 5coordinate framework. Each esteem within the lattice speaks to the measure of an intuitive impact between variables. An average matrix was obtained using Equation (2)

$$Z_{ij} = \frac{a_{ij(1)} + a_{ij(2)} + a_{ij(3)} + a_{ij(4)} + a_{ij(5)}}{m} \quad (2)$$

where m = Number of respondents

Computation of Signal to Noise Ratio: The signal-to-noise ratio was computed for the orthogonal array obtained from Minitab using Equations (3) to (5):

Larger the better = $-10\log_{10} \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$ (3)

Smaller the better = $-10\log_{10} \frac{1}{n}\sum_{i=1}^{n} y_i^2$ (4)

Nominal the best = $10\log_{10} \frac{1}{s^2}$ (5)

where y_i is the attribute of the performance being measured for the i^{th} observed value

n is the experimental trial number

s^2 is the variance of observations

Based on expert opinion, the best nominal is selected for the analysis.

Step 6: *Applying the Pareto 80-20 Rule*: The signal-to-noise ratio (nominal the best) was arranged in descending order. The full entirety of the variables was calculated, whereas the rate commitment of each calculated level was gotten. Encourage, the total rate commitment of each calculated level is inferred from the full whole. At an 80 % aggregate rate, the Pareto 80-20 run the show is connected. The calculated levels underneath the 80 % restrain cut off and named immaterial to optimality.

Step 7: *Computation of response table*: The average of each factor at different levels was computed to obtain the response table, as shown in Table 3.

Step 8: *Computation of the Matrix for DEMATEL*: The 5 x 5 matrix, as shown in Table 2 obtained from the questionnaire analysis, was used to multiply (Matrix multiplication) the response table obtained from Taguchi Pareto. The results are shown in Table 4.

Step 9: Calculation of the normalized direct-relation matrix: the direct relation matrix is obtained by applying Equations (6) and (7)

$$X = S \text{ x } Z \quad (6)$$

$$S = \frac{1}{\max_{1\le i\le n} \sum_{j=1}^{n} Z_{ij}}; i, j = 1, 2, 3, ..., n \quad (7)$$

Step 10: *Derivation of the total Matrix* T: The total Matrix can be obtained using Equation (8). The sum of the row and the column of the total matrix are computed as a label as D and R, respectively.

$$T = X(1-X)^{-1} \quad (8)$$

Step 11: *Derivation of a casual graph*: Casual graph is obtained by plotting D+R against D-R

$$D_i = \sum_{i=1}^{n} t_{ij} \quad (i = 1, 2, 3, ..., n) \quad (9)$$

$$R_i = \sum_{i=1}^{n} t_{ij} \quad (i = 1, 2, 3, ..., n) \quad (10)$$

Besides, the procedure for the method used in the present work is summarized in Figure 1, while a comprehensive description afterward was given.

In deciding on the results of the DEMATEL method, inputs from experts are drawn, which is the first step of the TP-DEMATEL method. However, in finding experts on the ducted wind turbine-based HVAC system, the researchers decided to establish certain characteristics to look for. First, it was thought that an expert could only offer a reliable viewpoint if such an expert possessed

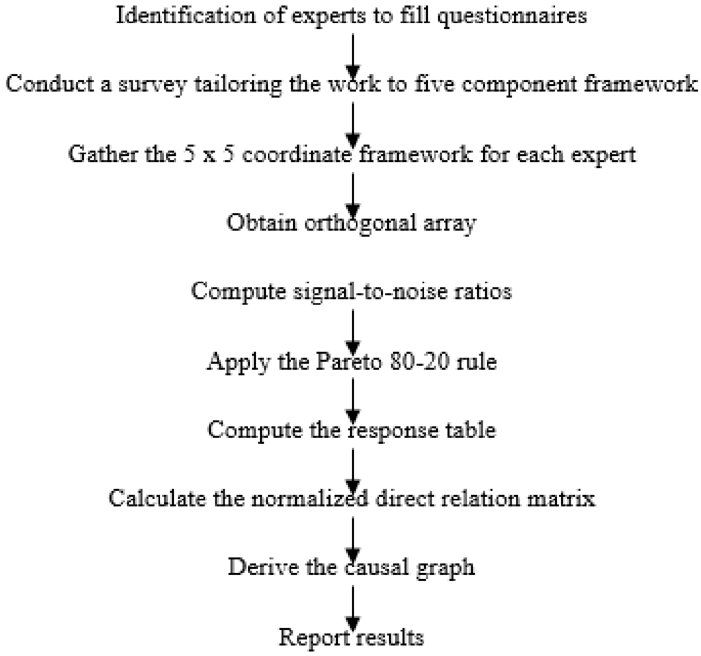

Figure 1. Methodology for the TP-DEMATEL method

enough experience in engineering and particularly in the HVAC and wind turbine domain. Thus, guided by the understanding that bottling plants have sufficient HVAC systems and wind turbines on their roofs, respondents were sought from a particular conglomerate that produces soft drinks in Nigeria but with locations spread over Nigeria. This decision was reinforced by the fact that in one of the locations and through networking, it becomes easier to monitor and collect the filled questionnaires of the administered questionnaires. Second, expertise in the respondents was considered as the respondent should be credible to offer an expert viewpoint on HVAC/ducted wind turbine issues. Finally, a respondent's qualification was considered essential to be asked to evaluate the questionnaire. However, minimum qualification of trade certificates is essential as the field of HVAC/ducted wind turbine maintenance requires some level of education for competence on the job.

Next, the survey is conducted by first recognizing all the plants whose personnel are to be visited. Then, electronic mails and telephone numbers were obtained while they were contacted for their consent and actions in filling out questionnaires. The questionnaires are then sent to them, and communication is made with them. While face-to-face communication was used for plants rear the location of one of the authors, those far among were discussed through phone and electronic mails. The third step in implementing the TP-DEMATEL method is to tailor the responses of each expert to a 5x5 coordinate structure and then link this to an average matrix single value as entries of the matrix are obtained. The fourth step of the procedure to implement the TP-DEMATEL method is to obtain an orthogonal array for the problem. Usually, the number of factors (parameters) and their levels are the main information needed to establish the orthogonal array. For such a combination, alternative orthogonal matrixes may be suggested by the software used. In this case, the Minitab is used. Thus, the simplest orthogonal array may be chosen since an illustration of a new method is made in this work.

The next implementation phase is to compute the signal-to-noise ratios based on the outcomes of the orthogonal array. Usually, one of the criteria among nominal the best, smaller the better, and larger the better is chosen. This is often decided by practically relating what is desired with each parameter and the reality. If it is desired to increase the values of certain parameters, the larger, the better criterion is a suitable choice. For a desire to reduce the value of a parameter, the smaller, the better is a good fit. However, if the HVAC engineer is indifferent to increasing or reducing the value of a parameter, then the nominal best is required as a choice.

Having obtained outcomes of the signal-to-noise ratios based on any or combinations of the three mentioned criteria, the next step in the evaluation using the TP-DEMATEL method is to apply the 80-20 rule. This is done by arranging the experimental trials with their corresponding signal-to-noise ratios in ascending order, and then an additional column is created for percentages. This extra row is noted for a cut-off of 80% or a nearby percentage. Then the remaining experimental trials above 80% are discarded and treated as irrelevant to the system's goal. The next phase of evaluation is to compute the response table. This is the average of each factor by level. To achieve this, each factor is considered, and the level is traced to the orthogonal array table. Then the appropriate signal-to-noise ratios are averaged. This is where the Taguchi-Pareto method terminates, and the DEMATEL method in the integrated method commences.

The next step is to reintroduce the 5x5 matrix earlier mentioned as the output of the questionnaire administration. Furthermore, the first phase of the DEMATEL method implementation is introduced. This is the computation of the normalized direct-relationship matrix. It consists of two matrixes, S and, which produce a matric X. besides, the next phase is conducted, which is

Table 2: Parameters considered for ducted wind analysis by Malik et al. (2019)

Sr. No.	Levels	Pressure	Height	Blower distance	Effective Length	Truck gap
1	1	0.5	0.0	0.5	0.5	0.0
2	2	2.5	0.5	1.0	1.0	1.0
3	3	5.0	1.0	1.5	1.5	2.0
4	4	10.0	1.5	2.0	2.0	3.0
5	5	15.0	2.0	2.5	2.5	4.0

to derive a total matrix T, which uses the product of the matrix X obtained previously. The reciprocal of one minus the matrix X. furthermore, a causal graph is obtained based on the relationship stated in step 11. Then, the interpretation is made. Besides, the parameters used in this work are shown in Table 2.

In Table 2, the five parameters considered for the ducted wind analysis by Malik et al. (2019) are adopted in the present study to use to process the Taguchi-Pareto-DEMATEL method proposed in this article. The reference data is suitable for use in the present article as the parameters represent the most important attributes of the ducted wind turbine in the HVAC system studied. Unfortunately, not many similar data are available in other regions of the world apart from the Malaysian experience discussed. Thus, greater insight into the ducted wind turbine installations for the HVAC system from the developing country's perspective is gained.

4. RESULTS AND DISCUSSIONS

4.1 Data analysis

The authors conducted the data analysis using Microsoft Excel 2007 software. Three principal workers of a large group of soft drinks producers, namely maintenance manager, production manager, and plant manager in three different locations of Nigeria, namely, Abuja, Kano, and Lagos, were used to obtain data for the DEMATEL method as the method relies heavily on expert's decisions. The respondents were extensively briefed on the study's intention before being given the questionnaire to study and fill. The population of respondents was mainly made, and their age is generally above 35 years old as this is roughly an age that many promising workers get to the senior management position which these respondents occupy; before asking the respondents to fill the questionnaire, the interview was conducted with them brought out facts that they have previous experience in dealing with wind turbines, ducted HVAC systems or wind turbine operated ventilated systems. Their knowledge of the devices is useful as they were asked to answer the questions based on their experience.

4.2 Evaluation based on the expert's outcomes

After the questionnaire administration, its analysis commenced with two principal activities preparing a grid and coding the data. The grid is prepared to easily interpret and store the respondents' responses. For conciseness and the limited scope of the questionnaire, a single grid is used, which was made on a sheet. To code the data, it was noted that the questions represented on the questionnaire inform of points on a scale of 0 to 3, making it easy to enter the answers directly as these numbers into the grid. Although all the answers take the same form, if the answers had taken a different form, a helpful approach to solving the problem is to translate the answers into a numerical scale. For instance, if the respondents were asked to note their preference between two parameters as higher/lower, a helpful approach is to ascribe a value of 1 to each response carrying "higher". In contrast, 0 may be ascribed to each response carrying "lower". This often leads to ease in computations of the summary statistics for the responses of the questionnaires. During the questionnaire administration, efforts were made to persuade the respondents to answer the questions as honestly as possible and to provide answers to all questions since the definition of options covered all the possible outcomes of the respondents. This information is useful for obtaining a correlational analysis of the results. The questionnaire results from the three respondents, namely the maintenance manager, production manager, and plant manager, were used to compute the means scores for the individual questions asked, notably eleven questions. However, a rounded-up average score is used for easy analysis and the input into the DEMATEL method. To explain how to results were obtained. Consider the first question in the questionnaire that asks the respondents to rate the importance of input pressure over ducting heights on a four-point scale, with 0 demoting no importance, 1 equal importance, 2 moderate importance, and strong importance. The mean score of 1 based on the rounded-up average value is then employed to indicate the overall judgment of the respondents concerning the ducting wind turbine. The highest possible score is then of strong importance, while other scores are interpreted according to the scale.

In all, a total of twenty questions were asked to the respondents, with questions 11 to 20 being complementary questions to 1 to 10 and a scale to find out if either set of questions was arbitrarily filled or consistently filled, which determines whether the respondents' opinion may be relied upon or not. In the following, the questions are discussed regarding their responses.

Question 1: How would you rate the importance of input pressure over ducting heights?

Here, the main motive is to allow the respondent to weigh the importance of the two parameters of input pressure and ducting heights, as the parameters were directly drawn from the published article by Malik et al. (2019). The scale of measurement is from 0 to 3 to ease the computation. The rounded-up average was 1.

Question 2: How would you rate the importance of input pressure over the distance between the blower and the pipe? The rounded-up average was 1. This indicates equal significance.
Question 3: How would you rate the importance of input pressure over the gap between a truck or run out? The rounded-up average was 2. This indicates moderate significance.
Question 4: How would you rate the importance of input pressure over total effective length? The rounded-up average is 2, which is of moderate importance on the rating scale.
Question 5: How would you rate the importance of ducting height over the distance between the blower and the pipe? The rounded-up average is 2, implying a moderate importance relationship between the two factors.
Question 6: How would you rate the importance of ducting heights over the gap between a truck or run out? The rounded-up average is 1. This implies equal significance on the assessment scale.
Question 7: How would you rate the importance of ducting height over total effective length? The rounded-up average is 3. This implies strong importance on the importance scale.
Question 8: How would you rate the importance of the blower and the pipe over the gap between trucks or run out? The rounded-up average is 2, implying a relationship scale of moderate importance between the assessed parameters.
Question 9: How would you rate the distance between the blower and the pipe over the total effective length? The rounded-up average is 2, implying a moderate importance association between the analyzed parameters.
Question 10: How would you rate the distance of the gap between a truck or run out over the total effective length? The rounded-up average is 2, implying moderate importance between the parameters of interest.
Question 11: How would you rate the ducting height over input pressure? The rounded-up average is 3, implying strong importance among the parameters analyzed.

Furthermore, the current study combined Taguchi Pareto with a DEMATEL model to identify the parameters that have the most effect on the power generated by a ducted wind turbine and prioritized the optimization of those parameters, using a ducted wind turbine in a bottling company in Nigeria as the research target.

4.3 Taguchi Pareto

To discover the parameter and levels that provide optimal power generation by a ducted wind turbine, Taguchi Pareto was used in Table 1. Table 4 shows the optimal parametric settings, which are 0.5 m/s input pressure, 0 inches height, 0.5-inch blower diameter, 1-inch effective length, and 1-inch truck gap.

4.4 DEMATEL

Questionnaire: In constructing the DEMATEL questionnaire, the five characteristics that determine the

Table 3: Orthogonal array

Sr. No.	Pressure	Height	Blower Distance	Effective length	Truck gap
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	1	5	5	5	5
6	2	1	2	3	4
7	2	2	3	4	5
8	2	3	4	5	1
9	2	4	5	1	2
10	2	5	1	2	3
11	3	1	3	5	2
12	3	2	4	1	3
13	3	3	5	2	4
14	3	4	1	3	5
15	3	5	2	4	1
16	4	1	4	2	5
17	4	2	5	3	1
18	4	3	1	4	2
19	4	4	2	5	3
20	4	5	3	1	4
21	5	1	5	4	3
22	5	2	1	5	4
23	5	3	2	1	5
24	5	4	3	2	1
25	5	5	4	3	2

Table 4. Matrix obtained from analysis of the questionnaire

Parameters	Pressure	Height	Blower Distance	Effective Length	Truck gap
Pressure	0	0	1	1	1
Height	3	0	1	2	1
Truck gap	2	1	1	2	0
Effective length	3	2	2	0	2
Blower distance	2	1	0	1	1

Table 5: Response Table for the Taguchi Pareto Analysis

Levels	Pressure	Height	Blower Distance	Effective length	Truck gap
I	5.249	1.373	2.454	(1.164)	1.703
II	(0.361)	1.242	(1.792)	2.854	2.208
III	(5.261)	(0.071)	(3.636)	(0.750)	(2.533)
IV	(11.515)	(3.807)	(1.716)	(2.282)	(4.172)
V	-	(4.324)	(1.799)	(4.926)	(3.269)
Delta	16.763	5.700	6.090	7.780	6.380
Highest level	5.249	1.373	2.454	2.854	2.208

Table 6: Combination of questionnaire output and Taguchi Pareto response table

Parameters	Pressure	Height	Blower Distance	Effective Length	Truck gap
Pressure	8.941	1.829	6.748	14.606	5.996
Height	13.123	6.125	4.798	0.749	8.799
Truck gap	-14.800	-7.669	-10.467	-15.207	-9.365
Effective length	-30.041	-10.451	-21.601	-26.731	-24.057
Blower distance	-37.887	-14.920	-15.976	-15.976	-17.455

performance of a ducted wind turbine were used as indices. The scoring method used a 4-point scale, with 3 representing high relevance and 0 representing negligible importance. The five specialists that took part in the analysis of the performance of ducted wind turbines were the respondents to the DEMATEL questionnaire. Before the surveys were given out, the material was conveyed to the respondents. All the questionnaires were found, resulting in a 100% retrieval rate. In Table 3, orthogonal arrays are introduced in the computation of the signal-to-noise ratios because of the important attributes of the tool, mainly in that, it allows inter-parametric interactions.

But orthogonal arrays are Dr. Genichi Taguchi's invention, rooted in a fractional factorial framework that permits the researcher to evolve a chosen subset of groups of several factors at diverse levels. In this regard, orthogonal arrays permit the researcher to abandon full factorial analysis of the parameters in support of the practical factorial examination, given that the effort in obtaining the results could be concentrated on fewer computations, thereby achieving greater efficiency. Besides, it is essential to explain how to obtain the orthogonal array values in Table 3. Table 3 contains the orthogonal arrays with the values of 1 to 5, corresponding to the labeling of levels 1 to 5. Thus, the five parameters, namely pressure, height, blower distance, effective length, and truck gap, are combined with five levels 1 to 5 and interpreted from the Taguchi menu function of the Minitab 16 software.

The software interprets it as an L25 orthogonal array indicating that there are twenty-five experimental trials. Each experimental trial has values between 1 and 5 inserted in the corresponding cells for each parameter along the row of the experimental trial. For instance, for experimental trial 1, the level 1,1,1,1, and1 are indicated that range from pressure on the second column to truck gap on the sixth column. It is noticed that for a particular experimental trial and considering all the parameters along the row; it may be feasible therein. The reason is that in the background, the Minitab 16 software has made some computations in an organized manner that gives a partial factorial analysis yet provides reliable results based on Taguchi's conception. Table 4 shows the matrix that emerged while the questionnaires were analyzed. To interpret this matrix, consider the interaction of a parameter and itself. While zero is chosen to represent each response carrying lower, it is included at the intersection of a parameter with itself. Thus, a zero value is fitted at the intersection of pressure against pressure. The same is done for all other parameters and themselves.

Now consider the first row containing the pressure parameter in its intersection with the blower distance. For all the respondents, the average observed is one and hence indicated in the appropriate cell in Table 4. The same procedure is used to fill the table. However, it should be noted that this is based on a 4-point scale where 3 represents high relevance and 0 represents negligible relevance. The intermediate values of 1 and 2 are graded in a higher order of relevance than zero. Table 4 shows the results of the expert survey.

The experts' scores were averaged and rounded to the nearest whole number to produce a five-by-five matrix. Table 5 shows the response table. The Matrix was merged with the Taguchi Pareto result to obtain a direct-relation matrix, as shown in Table 6.

The direct-relation matrix was then normalized using column vectors as the baseline and maximum values as the baseline, where S was the maximum value for each column's sum. The values in the direct-relation matrix Z were multiplied by S using Equation (6) to generate the normalized direct-relation matrix X (Table 7), Equations (6), and (7). The total-relation matrix T was calculated using Equations (6) and (8) (Table 8).

The D_i values in each column and the R_j values in each row were calculated using Equations (9) and (10), and the prominence (D + R) and relation (D – R) of the indices were determined using Equations (9) and (10).

Finally, a relationship diagram of the five indices was created using prominence as the horizontal axis and relation as the vertical axis (Figure 2). The causal link of the five indices is listed below, based on the results of Table 9 and Figure 1.

1. *High prominence and low relationship*: the indices in this quadrant include truck gap, effective length, and blower distance, all of which are effect factors influenced by the other components. These indices need to be improved but cannot be directly modified because they are effect factors.

2. *Low prominence and low relationship*: The indices in this quadrant, such as Pressure, are marginally influenced by the other indices. As a result, they are reasonably self-sufficient.

3. Low prominence and high relation: The indices in this quadrant are Height and Relationship, which have a minor influence on a few other indices. As a result, they are reasonably self-sufficient.

Table 7: Normalized direct-relation matrix

Pressure	**Height**	**Blower Distance**	**Effective Length**	**Truck gap**
0.23	0.05	0.18	0.38	0.16
0.34	0.16	0.13	0.02	0.23
(0.39)	(0.20)	(0.27)	(0.40)	(0.25)
(0.79)	(0.27)	(0.57)	(0.70)	(0.63)
(0.99)	(0.39)	(0.42)	(0.41)	(0.46)

Table 8: Total relation matrix

Pressure	**Height**	**Blower Distance**	**Effective Length**	**Truck gap**
0.019	-0.030	0.037	0.221	0.002
0.274	0.114	0.091	0.005	0.205
-0.136	-0.102	-0.116	-0.220	-0.079
-0.240	-0.048	-0.241	-0.343	-0.283
-0.676	-0.239	-0.239	-0.274	-0.271

Table 9: Summary of the prominence and relation of the five indices

Parameters	**D**	**R**	**D-R**	**D+R**
Pressure	-0.760	0.244	-1.004	-0.516
Height	-0.306	0.688	-0.994	0.382
Blower distance	-0.470	-1.699	1.229	-2.168
Effective length	-0.611	-1.156	0.546	-1.767
Truck gap	-0.430	-0.653	0.223	-1.084

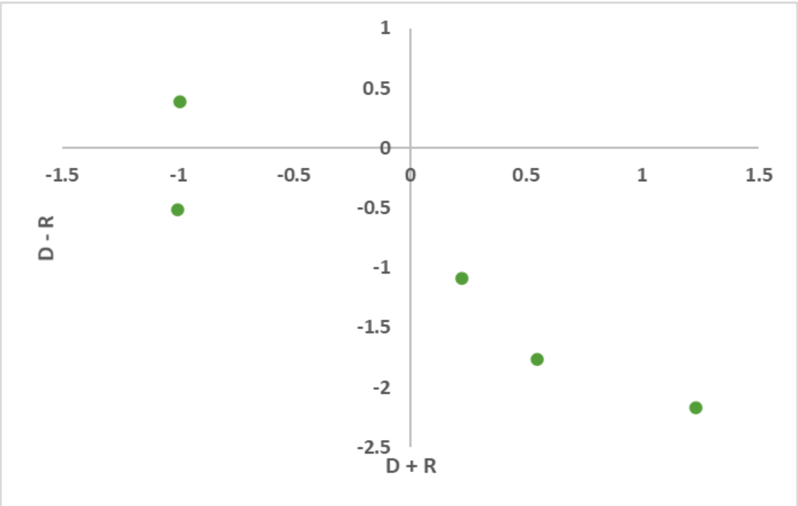

Figure 2. Relational diagram of the five indices

In conclusion, raising the input pressure by increasing the effective length, truck spacing, and blower distance can efficiently improve the power produced by a ducted wind turbine.

4.5 Taguchi Pareto and DEMATEL method

In previous parts, the sequence of improvement achieved by Taguchi Pareto and DEMATEL were explored separately. The two analysis approaches were integrated into this part to make it easier to identify essential characteristics and establish the best sequence in which to improve them. Taguchi Pareto's analysis revealed five parameters and levels that substantially impact the energy output of a ducted wind turbine. The pressure is 0.5 m/s, the blower distance is 0.5 inches, the effective length is 1 inch, and the truck gap is 1 inch. DEMATEL enables the detection and ranking of incidental factors, allowing fundamental problems to be resolved quickly and efficiently, improving the ducted wind turbines' performance. We discovered that effective length, truck gap, and blower distance were the true causal indicators, i.e., they were the key items that influenced other indicators and were the driving elements to improve the performance of a ducted wind turbine, using Taguchi Pareto and DEMATEL method.

4.6 Taguchi-Pareto-DEMATEL method versus Taguchi and DEMATEL methods

The Taguchi-Pareto-DEMATEL method was chosen as a method in this article for its advantages; it has inherent disadvantages, which could be overcome in subsequent studies. These are mentioned in Table 10 as follows:

Table 10. Advantages of the TP-DEMATEL method

Sr. No.	Advantages of the TP-DEMATEL method
1.	The TP-DEMATEL can distinguish between the individual parameters of the wind turbine system concerning which parameter is more important than the other. However, knowing how much this difference is challenging using only the Taguchi method is challenging.
2.	The TP-DEMATEL method could assist in concurrently optimizing and determining the cause-effect chain of the process. The disadvantage of the TP-DEMATEL method.
3.	The comparative weights of experts are ignored when using the questionnaire for the DEMATEL aspect of the TP-DEMATEL method. Indeed, experts may not have the same years of experience and skill to permit them to evaluate the questionnaire. Hence, grading these experts may be important in the real sense, but the present method does not cater to this.

5. CONCLUSION

Taguchi Pareto is a preventive analytic tool for increasing product and process quality while keeping mean time costs and resources to a bare minimum. As a result, problems are less likely to arise, consequences are reduced, product quality and reliability are improved, costs are reduced, and competitiveness is improved. Taguchi Pareto handles problems by focusing on individual elements and prioritizing those that can be used to achieve the best results. DEMATEL was applied to the previous approach’s outcomes to improve the Taguchi Pareto findings. After determining the values of the elements that will produce optimal output using Taguchi Pareto, DEMATEL was used to analyze the causal relationships and extent of influence of the items found. Finally, it was advised that enhancing the power generated by the ducted wind turbine should be prioritized. The current study integrated Taguchi Pareto with DEMATEL to find essential characteristics that boost the output of a ducted wind turbine, with the ducted wind turbine in a Nigerian bottling company as the research goal. Results indicated that the results of the Taguchi-Pareto method are considered to generate optimal energy from the case study, which gives an effective indication of clean power delivery. Thus, the optimal value of parameters for the ducted wind turbine is $P_2H_2TG_2EL_1BD_1$, which may be interpreted as 2.5m/s of pressure, 0.5in height, 1in the truck gap, 0.5in effective length, and 0.5in of blower distance. The method proposed in this study can be used in industry practice and contributing to academia. Researchers can also use Taguchi Pareto PROMETHEE and Taguchi Pareto Data Envelopment Analysis to explore the problem being solved.

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