# A Model for Determining Appropriate Speed Breaker Mechanism for Power Generation

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***Abstract***

*The key to sustainable economic development is having adequate electricity to power homes and industrial machines. However, electric power supply in majority of developing countries is grossly inadequate. To improve on the power generation different renewable energy sources have been explored. One of the sources of renewable energy is the application of speed breaker system to convert kinetic energy of moving vehicles into electricity using various mechanisms. The purpose of this paper is to develop a methodology for determining the most appropriate mechanism of speed breaker system for effective power generation. The proposed approach aggregated the Analytic Hierarchy Process (AHP) and the Weighted Aggregated Sum Product Assessment (WASPAS) methods. The efficacy of the methodology is illustrated with a numerical example. From the analysis, the optimum speed breaker mechanism for power generation is the roller mechanism. A sensitivity analysis was also carried out to determine the effect of one of the parameters of the proposed method on the performance of the different mechanisms. The result of the sensitivity analysis showed that the optimum solution remained unchanged.*

***Keywords:*** *Speed breaker mechanism, decision criteria, AHP, WASPAS, power generation.*

## 1. Introduction

The demand for electric power is ever increasing due to surge in industrial activities and population growth without any corresponding increase in power generation. The key to sustainable economic development is having adequate electricity to power homes and industrial machines and in order to improve on the level of power generation, most developing countries have begun to explore different renewable energy as alternative to the traditional fossil fuel. The energy derived from automobiles passing over speed breakers is one the renewable energy that is being explored in some developing countries to boost electric power supply. The speed breaker system has been modernised in these countries in a way that the kinetic energy of a vehicle passing over it, is converted in to electricity. The speed- breaker system mechanism in use for this purpose is: roller, air piston, rack and pinion and chain mechanisms.

In the literature, majority of the authors have been concerned about design of various mechanisms that will yield optimum electric power. Mishra [1] proposed the application of the rack and pinion mechanism to produce speed breaker system for effective generation of electricity to power street lights, traffic lights and rural areas. Bhagdika et al [2] promoted the use of the roller mechanism for speed breaker system design. Das [3] also proposed the application of roller mechanism for generating electric power for minor needs. Patil et al, [4] presented a speed breaker system which uses

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the spur gear and chain drive mechanism to convert kinetic energy of moving vehicles into electricity. Olugboji [5] proposed air piston mechanism for electricity generation.

A comparative analysis of some of the mechanisms to determine the most effective means for power generation have been carried out by a few authors in the literature. Jagtap et al., [6] carried out comparative analysis of three mechanisms; roller, rack and pinion and air piston using mere physical comparison of parameters of five decision criteria. However, a mere visual comparison is not an effective means to determine optimum mechanism in a decision problem involving multiple decision criteria that maybe conflicting. In order to determine optimality in a more systematic manner, [7] applied an MCDM method which combines Standard Deviation (SDV) and Complex Proportional Assessment (COPRAS) techniques to select the best speed breaker mechanism for efficient power generation.

In this paper, an integrated AHP and WASPAS methods is applied to determine most appropriate mechanism for power generation. The method proposed in this paper has the following advantages over the hybrid Multiple-Criteria Decision Making (MCDM) approach applied by [7]: (1) The AHP used to evaluate criteria weights in this paper has the capacity to involve decision makers opinions in the decision making process as opposed to the SDV method applied by [7] which utilizes only objective data in evaluating weights and (2) the WASPAS method is simpler in terms of analysis and implementation when compared to the COPRAS technique.

## 2. Speed breaker mechanisms

The speed breaker is primarily design and constructed on roads especially in area of high human and vehicular movement to eliminate or minimize risk of accidents. However, of recent the speed breaker have become a source of renewable energy in which kinetic energy of vehicles passing over it is converted into electricity. Three types of speed breaker mechanisms that are commonly used to generate electricity are described in Table 1.

**Table 1** Speed breaker mechanisms types [6]-[8]

| Mechanism | Descriptions |
|---|---|
| Roller Mechanism (A1) | In this type of mechanism an iron roller is fixed on a wooden ramp and as the roller rotates due to automobiles passing over the ramp, the generator shaft connected to the roller via chain and sprocket arrangement simultaneously rotate and electric power is generated in the process. |
| Rack and Pinion Mechanism (A2) | In this arrangement, the speed breaker at the top of the whole system is directly connected to a rack. As the rack move downward, a small pinion linked to it rotates which in turn causes the rotation of a larger pinion connected to it through a shaft. Electricity is generated due to the rotation of the generator shaft connected to the pinions |
| Air piston Mechanism(A3) | In this mechanism type, the speed breaker is made from metal sheet in the form of dome shape sustained by spring stands. The dome is connected to a piston with the aid of a connecting rod. The movement of vehicles across the dome, causes the reciprocating motion of the piston which in turn produce rotary movement of the shaft of the generator |

## 3. Methodology

Two methods have been chosen for selecting the most appropriate mechanism for speed breaker system in order to harness kinetic energy of moving vehicles. The two MCDM approaches are: AHP and WASPAS. The AHP is applied to determine decision criteria weights whilst applying the WASPAS in the ranking of alternative speed breaker mechanisms. Three speed breaker mechanisms: roller, rack and pinion and air piston are ranked using five decisions: cost, mechanism set up, maintenance, efficiency and design. The first step in the analysis is to obtain pairwise comparison judgement from expert with regard to decision criteria. The pairwise judgement is then analysed with AHP methodology to estimate weights of decision criteria. Parameters are also obtained for the three mechanisms with regards to the decision criteria, the data together with the weights of decision criteria are analysed with the WASPAS method to produce performance score for each mechanism.

### 3.1 Analytic Hierarchy Process (AHP) method

AHP technique was proposed by T. Saaty [9]. In utilising the approach, a decision problem is structured in a hierarchical form which is then decomposed into several sub-tasks that are analysed individually and then aggregated to obtain an optimum solution, thus the overall problem is more easily solved [10]. The steps involved in the AHP technique are as follows [9]:

Step 1: The first stage in resolving a decision problem with AHP is to obtain pairwise comparison judgement from experts based on Saaty ratio scale. The comparison judgements is then use to form comparison matrix, *F*, as follows:

$$F = [f_{ij}]_{nxn} = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ f_{n1} & f_{n2} & \cdots & f_{nn} \end{bmatrix} \quad (1)$$

Where

$f_{ij} > 0, f_{ij} = 1/ f_{ji}, \quad f_{ii} = 1$

The relative significance of criterion *i* over that of criterion *j* is signified by $f_{ij}$. For example if criteria *i* and *j* are of the same significance $f_{ij} = f_{ji} = 1$. The Saaty AHP scale use by expert in pairwise assessment of decision criteria can be found in [9].

Step 2. The individual criterion weight are then estimated as follows:

$$w_i = \frac{1}{n}\sum_{j} \frac{f_{ij}}{\sum_i f_{ij}} \quad (2)$$

Where $w_i$ is the weight of *i*th criterion.

Step 3. For the expert judgement to be acceptable the consistency ratio calculated must be less than 10% [10]. However, the consistency ratio $I_r$ is determined as follows:

$$I_{r,} = \frac{GI}{RI} \quad (3)$$

Where RI denotes an average random value of $GI$ and the value for different sizes of matrix can be found in [9] while $GI$ is the consistency index which is calculated as

$$GI = \frac{\lambda_{\max} - n}{n - 1} \quad (4)$$

Where $\lambda_{\max}$ is the maximum eigenvalue and is estimated as

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Fw)_i}{w_i} \quad (5)$$

The application of the method in resolving decision problem and evaluating weights of decision criteria have been reported in literature. Examples of the application of the techniques in weights evaluation for decision problems are the work of [11]-[13]. There are AHP software available for easy analysis and implementation of the method and one of such is the AHP online calculator developed by Goepel [14].

### 3.2 WASPAS approach

WASPAS is a hybrid of the Weighted Sum Model (WSM) and the Weighted Product Model (WPM). The two approaches were combine in a systematic manner to avoid limitations of the WSM and WPM methods. Chakraborty and Zavadskas [15] used the method to solve eight diverse industrial decision problems.

The performance index score of alternatives is evaluated as follows [16]-[17]:

$$SP = \lambda\, cQ_i + (1-\lambda)\, dQ_i = \lambda \sum_{j=1}^{n} y_{ij}.w_j + (1-\lambda)\prod_{j=1}^{n}(y_{ij})^{w_j} \quad (6)$$

Where SP is performance index, cQi and dQi are the performance of alternative i with respect to decision criteria j for WSM and WPM methods respectively, λ are values taken from 0 to 1,$w_j$ is the weights of criterion j and *y*ij is the normalised matrix which is evaluated depending on whether the decision criteria is beneficial or non-beneficial.

Decision criteria such as efficiency that requires maximisation in the decision making process are beneficial criteria while the decision criteria such as cost that requires minimisation are non-beneficial. The beneficial and non-beneficial are normalised using Eq. 7 and 8 respectively as follows:

$$y_{ij} = \frac{x_{ij}}{\max_i x_{ij}}, \quad j = 1,2,\dots n, \quad i = 1,2,\dots m \quad (7)$$

$$y_{ij} = \frac{\min_i x_{ij}}{x_{ij}}, \quad j = 1,2,\dots n, \quad i = 1,2,\dots m \quad (8)$$

The ranking of the alternatives are carried out based on performance index, SP, and the alternative with the highest value of SP is the optimum solution.

## 4. Case study

In order to establish the appropriateness of the integrated AHP and WASPAS methods for the prioritisation of speed-breaker mechanisms for power generation, data were obtained from the work of [6]-[7]. Jagtap et al.[6] presented a data for three different speed-breaker mechanisms with respect to five decision criteria and the information are shown in Table 2. However, to make the information suitable for use in the MCDM tool, [7] transformed it to Table 3 using a 3 point Likert scale.

Table 2. Comparison of mechanisms

| Mechanisms | Decision criteria | | | | |
|---|---|---|---|---|---|
| | Cost | Mechanism Set up | Maintenance | Efficiency | Design |
| A1 | Cheap | Very Easy | Less Required | ~50% | Easy to design |
| A2 | Moderate | Difficult | Weekly Basis | ~70% | Depends upon weight sustaining capacity |
| A3 | Costly | Very Difficult | Daily Basis | ~85% | Depends upon compressing power of air pistons |

Table 3. Decision criteria

| Mechanisms | Decision criteria | | | | |
|---|---|---|---|---|---|
| | Cost (C1) | Mechanism Set up (C2) | Maintenance (C3) | Efficiency (C4) (%) | Design (C5) |
| A1 | 1 | 1 | 1 | 50 | 1 |
| A2 | 2 | 2 | 2 | 70 | 3 |
| A3 | 3 | 3 | 3 | 85 | 3 |
| Criteria type | Min | Min | Min | Max | Min |

The data in Table 3 was solved by [7] using an integrated SDV and COPRAS. However, in this paper a combined AHP and WASPAS methods is applied in finding optimum alternative.

# 5. Results and discussion

## 5.1 AHP analysis

The first step in the AHP analysis in determining decision criteria weights is to obtain comparison judgement of the decision criteria from expert. To achieve this aim, an AHP questionnaire was produced and sent to an expert to perform pairwise comparison of decision criteria using Saaty ratio scale. The pairwise comparison judgment obtained was transformed into a pairwise comparison matrix indicated in Table 4. Applying Eq. 2 to the comparison matrix in Table 4, weights for the five decision criteria; C1, C2, C3, C4 and C5 are obtained and the results are shown in Table 5. The consistency of expert's judgement was calculated using Eq. 3-5 and from the analysis a consistency ratio within the range of acceptable value was obtained.

Table 4. Comparison matrix

| | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| C1 | 1 | 1 | 1 | 1/3 | 3 |
| C2 | 1 | 1 | 1 | 1/3 | 1 |
| C3 | 1 | 1 | 1 | 1/3 | 3 |
| C4 | 3 | 3 | 3 | 1 | 3 |
| C5 | 1/3 | 1 | 1/3 | 1/3 | 1 |

Table 5. Decision criteria weights

| **Decision criteria** | **Weights** | **Rank** |
|---|---|---|
| C1 | 17.50% | 2 |
| C2 | 13.90% | 4 |
| C3 | 17.50% | 2 |
| C4 | 41.70% | 1 |
| C5 | 9.40% | 5 |

### 5.2 WASPAS analysis

Having determined the criteria weights which is needed in the analysis of the WASPAS method, the decision matrix in Table 3 is normalised using Eq. 7 for criterion C4 and Eq. 8 for criteria C1, C2, C3 and C5 and the result is shown in Table 6. It is worth noting that, Eq. 7 was applied in normalising C4 because it is a beneficial criterion while Eq. 8 was used in normalising criteria; C1, C2, C3 and C5 because they are non-beneficial criteria. Eq. 6 is then applied to the normalised matrix together with the evaluated criteria weights and for $\lambda$ equal to 0.5 in order to obtained performance score for each mechanism. The performance scores and corresponding ranks of mechanisms are presented in Table 7 and Figure 1.

Table 6. Normalised decision matrix

| Mechanism | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| A1 | 1.0000 | 1.0000 | 1.0000 | 0.5882 | 1.0000 |
| A2 | 0.5000 | 0.5000 | 0.5000 | 0.8235 | 0.3333 |
| A3 | 0.3333 | 0.3333 | 0.3333 | 1.0000 | 0.3333 |

Table 7. Mechanisms performance scores and ranks

| Mechanism | SP | RANK |
|---|---|---|
| A1 | 0.8149 | 1 |
| A2 | 0.6059 | 2 |
| A3 | 0.5692 | 3 |

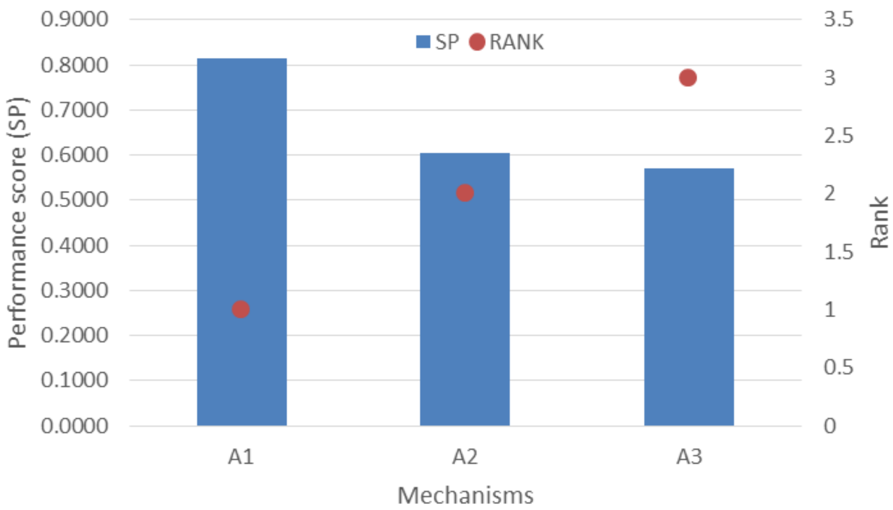


Figure 1. Mechanisms performance scores and ranks.

From Table 7 and Figure 1, the optimum mechanism is A1 having the highest SP value of 0.8189 while the worst solution is A3 having the lowest SP value of 0.5692. The whole mechanisms ranking is in the order of A1-A2-A3. Utilising SDV-COPRA method, Emovon and Okaro [7] obtained a ranking order of A1-A2-A3 for the three mechanisms. In both scenario the optimum solution is the same. However, the approach used in this paper overcome the limitations of the methods used by [7]. The AHP applied in this paper to determine criteria weights has the capacity to include the decision makers opinions in the decision making process as opposed to the SDV method used by previous author which utilizes only objective data. Furthermore, in terms of application, the WASPAS method is simpler than the COPRAS method because WASPAS can be applied in the form of the simplest MCDM approaches; WSM and WPM when value of $\lambda$ is set at 1 and 0. In addition WASPAS has lesser mathematical steps than the COPRAS method. On this basis, the AHP-WASPAS approach was chosen and with the intension that it will be more attractive to decision makers and power generation industries in addressing multi-criteria decision problems than SDV-COPRAS method.

### 5.2.1 Sensitivity analysis

The effect of λ on performance score of the different mechanism was performed. The values of λ was set from 0 to 1 and the performance score obtained together with the corresponding ranking of the three mechanisms are indicated in Table 8 and Figure 2.

Table 8. Effect of λ on ranking performance

| λ | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.8015 | 0.8042 | 0.8069 | 0.8095 | 0.8122 | 0.8149 | 0.8176 | 0.8203 | 0.8229 | 0.8256 | 0.8283 |
| A1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 0.5926 | 0.5953 | 0.5980 | 0.6006 | 0.6033 | 0.6059 | 0.6086 | 0.6113 | 0.6139 | 0.6166 | 0.6192 |
| A2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | 0.5270 | 0.5355 | 0.5439 | 0.5523 | 0.5608 | 0.5692 | 0.5776 | 0.5860 | 0.5945 | 0.6029 | 0.6113 |
| A3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |

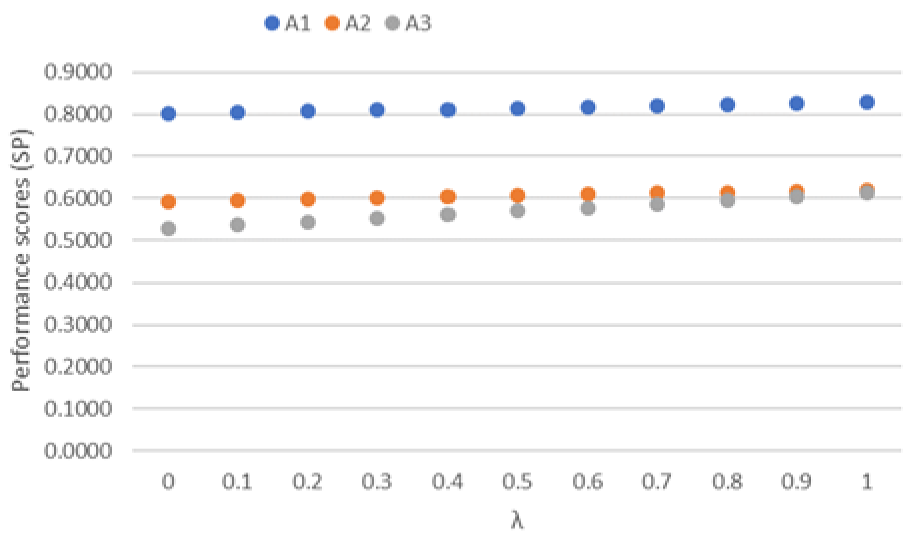


Figure 2. Performance index of mechanisms for varying value of λ

From Table 8 and Figure 1, it is obvious that for every value of λ applied for the WASPAS analysis, the optimum alternative; A1 remained unchanged. Although, the optimum alternative remained unchanged, however, the performance scores of A1 for every value of λ are not the same. For example, when λ was set at 0.1 and 0.5, the performance score obtained for A1 were 0.8042 and 0.8149 respectively. When λ is set at 0 the WASPAS method acts as WPM and when set at 1 it behaves as WSM. From Figure 1 it is also glaring, that the individual mechanisms performance score improves as the value of λ increases and the best values were obtained when WASPAS behave like WSM.

## 6. Conclusion

The paper presented an integrated AHP and WASPAS method for the ranking of speed breaker mechanisms in order to determine the optimum mechanism for effective power generation. Three different speed-breaker mechanisms; A1, A2 and A3 were ranked with respect to five decision criteria: C1, C2, C3, C4 and C5. A numerical example was applied to demonstrate the effectiveness of the methodology. The optimum mechanism obtained from the analysis of the case study was A1 which denotes roller mechanism when the value of $\lambda$ was set at 0.5. A sensitivity analysis was also conducted to observe the effect of $\lambda$ on the performance of the three mechanisms by setting $\lambda$ at values from 0 to 1. From the result of the sensitivity analysis, the optimum mechanism remained unchanged for the different values of $\lambda$. The proposed approach was validated by comparing it with an integrated SDV and COPRAS methods in the literature. From the comparative analysis, both approaches yielded the same ranking for the three mechanisms. However, the proposed approach has the capability to involve decision makers' opinions into the decision-making process which the SDV-COPRAS method is incapable of doing. Furthermore, the WASPAS method when compared to COPRAS method is simpler in terms of analysis and implementation due to WASPAS approach having lesser mathematical steps and the ability to behave as WSM and WPM.

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