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Hybrid SWOC-AHP Analysis of Two-Stroke Twin Spark Engine

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Abstract

A two-stroke engine is a promising device that provides a high power-to-weight ratio in automobiles. In recent times, the twin-spark configuration has shown advantages over the single-spark configuration. However, the rapid combustion associated with the twin-spark configuration leads to a higher NO_x emission. Therefore, it is important to determine its strength-weakness-opportunity-challenges (SWOC). It is also important to prioritize the SWOC factors and sub-factors connected with the twin spark two-stroke engine. Thus, the primary aim of the current investigation is to perform the hybrid SWOC-analytical hierarchy process (AHP) analysis for producing the quantifiable priorities for the factors of the two-stroke twin spark configuration. Additionally, the rank-stability of SWOC factors is investigated using sensitivity analysis. From the results, challenge factors emerged to be the most significant, and to counter the challenges, the deployment of opportunity factors showed an improvement in the performance of the twin spark configuration. Moreover, weaknesses attained the least position, which shows a positive perception for developing the future emissions-compliant engine designs. Finally, implementing a twin spark configuration in a two-stroke engine can play a significant role in enhancing its additional benefits.

Keywords: *Analytical hierarchy process, Strength-weakness-opportunity-challenge, Sensitivity, Twin Spark, Two-Stroke.*

1.0 Introduction

A two-stroke engine delivers a power stroke for each revolution of the crankshaft, and this advantage provides a notable power-to-weight ratio. Also, it produces less frictional losses than a four-stroke engine for the same power output. However, the two-stroke engine has received much criticism for its drawbacks of high specific fuel consumption and unburned hydrocarbon (UBHC) emission because of the short-circuiting of the fresh air-fuel mixture through the scavenging process as explained by Heywood[1]. Through the short-circuiting, 30% to 40% of the fresh air-fuel mixture will be lost by the exhaust[2]. To overcome the drawbacks of the two-stroke, many authors have proposed new technologies like exhaust control and butterfly control valves[3,4]. Later a new design of transfer ports was established by Onishi et al[5] for better improvement in the scavenging process. Subsequently, some investigations were carried out to find a new scavenging concept by Saxena et al.[6] and Magee et al.[7] to reduce short-circuiting of the fresh charge. All these concepts proposed by different authors made the mechanical system of the two-stroke engine more complex, and thus, most of the proposed concepts are not practically implemented. However, considering the advantage of the two-stroke engine's power-to-weight ratio, it is still preferred in many vital applications[1]. Therefore, designing a two-stroke engine that complies with the future emission regulations is a challenge for the engine manufacturers. To achieve the objective of stringent emission regulations, there is a need to provide

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complete combustion inside the cylinder. To achieve this phenomenon, one of the solutions is to ignite the fuel as fast as possible or to operate with a lean air-fuel mixture[8]. This can be achieved by providing twin spark plugs in the engine so that fuel can burn faster[9]. It will decrease the combustion duration and UBHC. Further, it will enhance the drivability while keeping up high specific power output and low engine-out emission[10]. According to Altin & Bilgin[11], the twin-spark configuration showed improvement in performance and reduction in fuel consumption over the single-spark two-stroke engine. However, rapid combustion with twin spark plugs leads to a higher temperature rise, which will eventually result in higher NO_X emission and a reduction in trapping efficiency[1,12]. In this direction, using the twin spark two-stroke engine can play a significant role in enhancing its additional benefits than any other engine. Looking at the twin spark two-stroke engine's pros and cons, it is vital to determine the Strength-Weakness-Opportunity-Challenges (SWOC) associated with it. Further, it will help the manufacturers understand the strength of the twin spark two-stroke engine so that it will not become abandoned in the future. Also, weaknesses can be addressed by the new creative and innovative approach. In addition, opportunities will help in motivating and producing new engine designs in the field of the twin spark two-stroke engine. Finally, competing with challenges will help in making improved plans and policies to remove the obstacles in this segment.

The decision-making process is complex in nature, though approaches based on multi-criteria decision-making methods (MCDM) are helpful tools for solving complex problems. In regard to the present study, it is important to prioritize the SWOC factors and their sub-factors associated with the twin spark two-stroke engine. For this purpose, different MCDM methods like AHP, Vikor, ANP, Topsis, Electre, Promethee, etc., can be utilized. Amongst these, the analytical hierarchy process (AHP) is an instinctive method for analyzing decisions intently. This method is helpful in solving specific and alternative decisions of complex issues using a multiple-level ranking. Further, it can be used to combine both qualitative and quantitative factors[13] by converting the SWOC elements (qualitative) to the quantifiable elements[14]. AHP is a transparent, simple, and capable theory of measurement. It focuses on the application of pair-wise comparison of alternatives with the help of assigned weights based on the priorities that enable the judgments of experts [15]. It provides the facility to validate the reliability and cross verifying the elements within the pair-wise comparisons. The results of AHP are delivered on a quantitative basis so that these can be further extended to use in the sensitivity analysis. In addition, the quantified results can be easily conveyed to the persons who are involved in the decision-making process[16]. Due to the mentioned advantages of AHP, SWOC-AHP has been employed for decision and strategic decision making in multiple fields for quantity and qualitative analytical process[17,18].

In brief, a two-stroke engine using twin sparks can play a major role in providing additional benefits compared to a single spark configuration. Thus, to find more motives or difficulties that impede its developmental path, it is vital to carry out an investigation through the SWOC-AHP perspectives. The hybrid SWOC-AHP analysis for a two-stroke twin spark engine is yet to be reported. Therefore, it is felt necessary to add to the existing literature by furnishing the current hybrid SWOC-AHP analysis. For this purpose, the laid-out objectives are: to find out the strength, weakness, opportunity, and challenge (SWOC) associated with the twin spark two-stroke engine and to arrange them in the hierarchy; to find out the priorities of the SWOC elements and rank the elements by applying the AHP technique; and to validate the AHP results through the sensitivity analysis in order to find the stability of the ranks of the SWOC elements.

2.0 Methodology

In this study, a hybrid methodology (SWOC-AHP analysis) is adopted to analyze the twin spark two-stroke engine technology aspects. Initially, a SWOC analysis was conducted to find the strengths, weaknesses, opportunities, and challenges of the twin spark two-stroke technology. Further, the AHP methodology has been implemented to rank the SWOC elements (locally and globally) and build the prioritization model. Finally, a sensitivity analysis has been extended to examine the rank-wise stability of SWOC elements. The step-wise methodology implemented in this paper is as shown in Figure 1.

2.1 SWOC Analysis Method

SWOC analysis is a tool that can evaluate the strengths, weaknesses, opportunities, and challenges of any technology. In general, the terms strength and weakness are considered internal factors, while opportunity and challenge are considered external factors related to any technology. This will give reasonable ground for formulating strategies to counter challenges and weaknesses linked with the technology. Moreover, the term challenge attains the objective with a motivational mindset[19]. SWOC analysis will be very much useful whenever a decision is to be made in a constrained environment. Thus, in this study, the SWOC analysis is applied to the two-stroke twin spark engine technology to support its strengths, eradicate weaknesses, exploit opportunities, and overcome challenges or constraints.

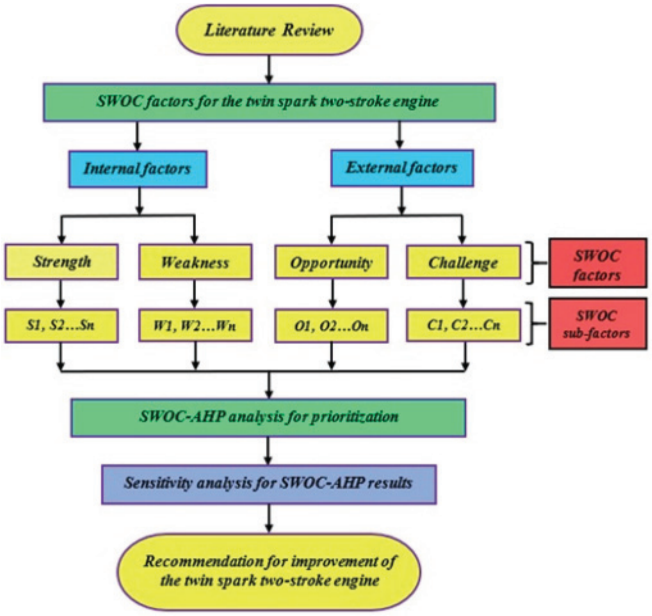

Figure 1: Hybrid methodology flow chart used in this study

2.2 Hybrid SWOC-AHP Method

Analytic Hierarchy Process (AHP) is the most extensively applied multi-criteria analysis. This method offers the opportunity to frame the problem hierarchically, and it can take into account numerous qualitative and quantitative factors in the problem. Moreover, it has been formed based on pair-wise comparison, which enables estimations and judgments. Additionally, it illustrates the incompatibility and compatibility of the decision, which is an advantage of this method in MCDM. In this study, AHP is connected with the SWOC framework to systematically evaluate the SWOC factors and sub-factors associated with the twin spark two-stroke engine so that a quantifiable degree of significance for all the factors can be presented to the decision-makers[15]. Step-by-step procedure of the AHP method are given below[20,21]:

Step-1: It includes formulating the hierarchical structure of the SWOC framework. It comprises dividing the problem into three levels: (a) achieving the goal (In this study, a recommendation of suitable factors to overwhelm the challenges and weakness of twin spark two-stroke technology) (b) the SWOC factor (i.e., strengths, weaknesses, opportunities, and threats) and (c) the SWOC sub-factors connected with each SWOC factor.

Step-2: A pair-wise comparison has been made for the SWOC factors and their sub-factors based on their relative importance. The pair-wise comparison matrix construction between the SWOC factors is evaluated by using Saaty's 1 to 9 point scale of relative importance is shown in Table 1.

Step-3: After framing the comparison matrix, the priority weights of the SWOC factors and the local priority weights of the SWOC sub-factors are calculated using the eigenvectors and eigenvalues, as shown in Eq. (1)[17].

Table 1: Scale of relative importance[22]

Interpretation	Scale of importance A_{ij}
Both i and j elements are assumed to be equally important	1
Element i is assumed to be moderately important than element j	3
Element i is assumed to be strongly important than element j	5
Element i is assumed to be very strongly important than element j	7
Element i is Absolutely important than element j	9
Intermediate scales between the two adjacent judgemental.	2,4,6,8
If element i has lower value than j $A_{ji} = 1/A_{ij}$	Reciprocal

$$(Z - \lambda_{max} I)\, v = 0 \qquad \text{... (1)}$$

Where Z is comparison matrix; λ_{max} is the highest eigenvalue of a comparative matrix; v is eigenvector corresponding to λ_{max}; is an identity matrix.

Further, the local priority weight of SWOC factors and SWOC sub-factors can be determined by Eq. (2); as shown below:

$$w_i = \frac{v_i}{\sum_{i=1}^{N} v_i} \qquad \text{... (2)}$$

Where i is 1, 2, 3, ..., n; $i \neq k$; w_i, local priority weight of SWOC factors and SWOC sub-factor.

Step-4: The consistency of the comparison matrix is determined using the Consistency Ratio, which is characterized as Eq. (3).

$$CR = \frac{CI}{RI} \qquad \text{... (3)}$$

Where CI is consistency index = $\left(\frac{\lambda_{max}-N}{N-1}\right)$; IR random index; N is order of the comparison matrix.

Random Index (RI) is the arbitrarily produced value for the reciprocal matrix on the 9-point scale. The 'value of the RI will be varied for the different orders of the comparison matrix, which is shown in Table 2. For the consistency, the ratio of a and comparison matrix should not exceed 0.05 and 0.08, respectively.

Step-5: Finally, the global priority weights of a SWOC sub-factors will be calculated by multiplying the normalized priority weight of the SWOC factor and the local priority weights of SWOC sub-factors as shown in Eq. (4)[18].

Table 2: Values of Random Index[20]

n	1	2	3	4	5	6	7	8	9	10
Value of RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$$w_{global} = w_i(SWOC\ factor) \times w_i\ (SWOC\ sub\text{-}factor) \quad \ldots (4)$$

Where w_{global} is the global priority weight of a SWOC sub-factors.

2.3 Sensitivity analysis

For single-dimensional additive non-proportional weight sensitivity analysis, the SWOC factor having maximum priority is considered to be the utmost vital factor. This utmost vital SWOC factor is changed from 0.1 to 0.9 in a step size of 0.1 and the priorities of the other SWOC factors are varied accordingly. Due to non-proportionality, the SWOC factors' priorities are changed without maintaining the fixed ratio of it. The steps of the sensitivity analysis are given below[23].

Step-1: The utmost significant of SWOC factor is changed from to by by following expression Eq.(5).

$$w_k' = w_k + \Delta_k \quad \ldots (5)$$

Where w_k', is changed utmost significant factor; w_k is selected utmost significant factor; Δ_k is discrete amount of change in the original weight.

Step-2: The normalized priorities of the other SWOC factors are changed by Δ_i from their initial normalized priority of w_i, which can be calculated using the Eq. (6) as shown below:

$$\Delta_i = \left(\frac{\Delta_k \times w_j}{w_k - 1}\right) \quad \ldots (6)$$

Step-3: The changed normalized priority of a SWOC factor is obtained by Eq. (7) as shown below:

$$w'_{i\ (\text{SWOC factor})} = (w_{i(\text{SWOC factor})} + \Delta_i) \quad (7)$$

Where $w'_{i\ (\text{SWOC factor})}$ is changed normalized priority of a SWOC factors.

Step-4: The changed global priority of a SWOC sub-factor is finally obtained by multiplication of the normalized local priority of that SWOC sub-factor with a SWOC factor and the changed normalized priority (w'_i) of that particular SWOC factor, as shown in Eq. (8):

$$w'_{g\ (\text{SWOC sub-factor})} = w'_i \times w_{i\ (\text{SWOC sub-factor})} \quad \ldots (8)$$

Where, $w'_{g\ (\text{SWOC sub-factor})}$ is changed global priority of a SWOC sub-factors.

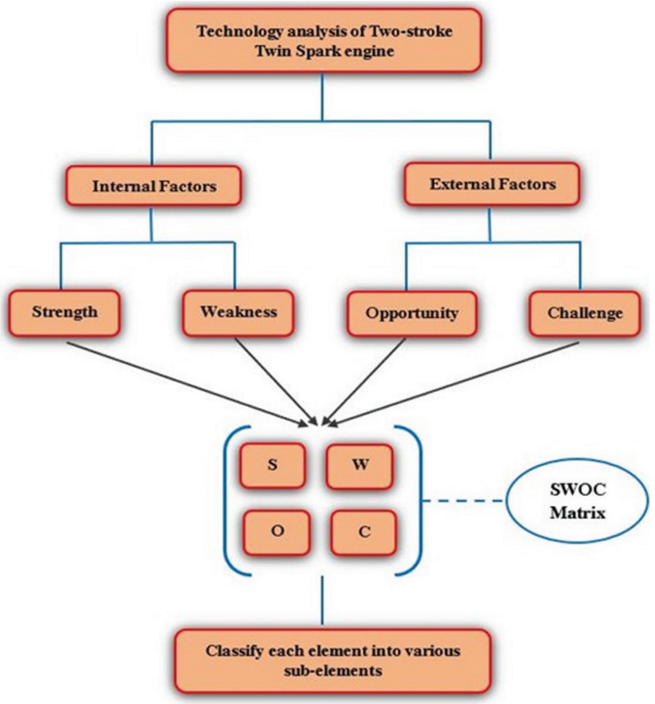

Figure 2. The layout of SWOC analysis

3.0 Results and Discussion

3.1 SWOC Analysis for the Twin Spark Two-Stroke Engine

Based on the available literature, fourteen important SWOC sub-factors are identified in which four strengths, three weaknesses, four opportunities, and three challenges are identified. The identified SWOC sub-factors are presented below using the SWOC analysis. The layout of the SWOC methodology adopted in this paper is shown in Figure 2.

3.1.1 Strengths of two-stroke twin spark engine

Higher power to weight ratio (S_1): On employing a dual spark plug in the two-stroke engine, more power can be generated without changing fuel input[24]. The simultaneous use of spark plugs at two distinct points results in a decreased flame propagation distance, ascertaining quicker and more comprehensive combustion[25]. Thus, it reduces combustion time loss and leads to an improvement in performance. Experimental studies of twin spark four-stroke engines have proven to be more efficient than single spark plug engines[26].

Reduction in specific fuel consumption (S_2): Use of twin spark plugs in a two-stroke engine improves in-cylinder combustion in the engine, resulting in decreased specific fuel consumption and increased thermal efficiency[12]. The experimental investigation by Ramtilak et al.[27] has shown improvement in the four-stroke engine's specific fuel consumption by adapting the twin spark plug.

Low UBHC and CO emission (S_3): In a conventional single spark two-stroke engine, UBHC and CO emissions are produced due to the incomplete combustion and misfire cycles, mainly at low speed and high load [28]. Khan & Shaikh[12] have highlighted that on using twin spark plugs in the two-stroke engine, a reduction in UBHC and CO emissions occurs compared with a single spark plug two-stroke engine. This is due to the probability of a rise in successful combustion, which leads to accelerating the flame propagation using two combustion sources[26].

Reduction in cycle-by-cycle variation (S_4): On using multi-spark plugs, reduction in Cycle-by-Cycle Variation (CCV) is achieved in a four-stroke engine[29]. Hence, a similar effect will be attained using twin spark plugs in the two-stroke engine.

3.1.2 Weaknesses of two-stroke twin spark engine

Rise in NO_X emissions (W_1): Faster combustion is achieved using twin spark plugs in the two-stroke engines[9]. This increases the pressure and temperature inside the cylinder compared with a single spark engine[1], which eventually leads to NO_x formation in the burned gas region behind the flame front [28] for the twin spark two-stroke engine.

Rise in knocking tendency (W_2): Using the twin spark in a two-stroke engine leads to an increase in in-cylinder temperature and pressure, ultimately increasing the knocking tendency[30]. Due to the higher knocking tendency, mass burned in the auto-ignition condition may increase the risk of damage to the engine parts[31]. A similar phenomenon is also reported by Forte et al[32].

High cost and difficulty in maintenance (W_3): In the two-stroke twin spark engine, the manufacturing cost is higher than a single spark engine. Also, when a single spark plug is damaged, replacement of both the spark plug is needed[33]. Moreover, the maintenance cost of the twin spark plug engine is higher because of its complexity in design[33].

3.1.3 Opportunities of two-stroke twin spark engine

Integrating GDI with twin spark technology (O_1): The development of Gasoline Direct Injection (GDI) in the two-stroke engine has extensively proved its ability to reduce the scavenging losses and emissions[34], and to improve the fuel consumption[35]. Thus, combining twin spark with GDI will give the best results for further reducing the emissions and improving the performance to comply with emission regulations[36].

Integrating after-treatment devices (O_2): The use of a twin spark in a two-stroke engine results in higher NO_x emission. One effective solution for reducing emissions in an engine is through the utilization of after-treatment devices[28] like the catalytic converter, exhaust gas recirculation (EGR), etc. So, integrating such after-treatment devices with the twin spark two-stroke engine will reduce the NO_x emission significantly[37].

Combining with turbocharger (O_3): A turbocharger in a two-stroke engine provides more power and better thermal efficiency[38] by improving the trapping efficiency over a naturally aspirated engine[39]. Uguru-Okorie et al.[40] achieved a reduction in cycle-by-cycle variation by combining the turbocharger in a two-stroke engine. Hence, using a turbocharger in the twin spark two-stroke engine will further increase its power and thermal efficiency.

Using the structural flow of large scale (O_4): Large scale structural flow such as swirl and tumble in the engine enhance air-fuel mixing[28] and reduce specific fuel consumption[41]. Therefore, such structural flow, along with a dual spark plug, is highly beneficial for the two-stroke engine.

3.1.4 Challenges of two-stroke twin spark engine

Challenge from four-stroke engines (C_1): Due to the advantage of lower fuel consumption[42] and high volumetric efficiency[43], the four-stroke engines are the most popular and widely used than the two-stroke engine in the present generation. In this regard, a four-stroke engine will provide a considerable challenge in using a twin spark two-stroke engine for the general-purpose[44].

Future emission regulations (C_2): It has been observed across the globe that emission standards in the automobile sector are becoming more and more stringent[8]. Therefore, implementing new emission standards made a significant impact on manufacturers of the two-stroke engine. Thus, meeting such stringent emission standards in a two-stroke engine is a great challenge[45].

Optimum location of spark plugs (C_3): Research regarding the optimum location of twin spark plugs in the two-stroke engine has not been reported yet. Hence, finding the optimum location of the twin spark plugs in the two-stroke engine is a challenge.

A summary of the SWOC analysis of the two-stroke twin spark engine in the SWOC matrix form is as shown in Table 3.

3.2 Hybrid SWOC-AHP analysis

In the present study, SWOC-AHP analysis is performed on a two-stroke twin spark technology. This is carried out by Saaty's 9-point comparison scale[20] as described in the methodology section. The results obtained by the pair-wise comparison and the normalized priority are illustrated in Table 4. As per the results illustrated in Table 4, the challenges connected with the twin spark two-stroke engine show the highest global priority of 0.576 followed by the opportunities of 0.216 associated with it. Here, external factors are given the

Table 3: SWOC matrix of two-stroke twin spark engine

Strengths	**Weakness**
• Higher power to weight ratio (S_1) • Reduction in specific fuel consumption (S_2) • Low UBHC and CO emission (S_3) • Reduction in cycle-by-cycle variation (S_4)	• Rise in NOX emissions (W_1) • Rise in knocking tendency (W_2) • High cost and difficulty in maintenance (W_3)
Opportunities	**Challenge**
• Integrating GDI with twin spark technology (O_1) • Integrating after-treatment devices (O_2) • Combining with turbocharger (O_3) • Using the structural flow of large scale (O_4)	• Challenge from four-stroke engines (C_1) • Future emission regulations (C_2) • Optimum location of spark plugs (C_3)

Table 4: Pair-wise comparison matrix of SWOC factors

SWOC factor	Strength (S)	Weakness (W)	Opportunity (O)	Challenges (C)	Group priority	Group position
Strength	1	3	0.5	0.167	0.134	3
Weakness	0.333	1	0.333	0.2	0.073	4
Opportunity	2	3	1	0.333	0.216	2
Challenge	6	5	3	1	0.576	1
λ_{max} = 4.158; CR= 0.059; RI= 0.89						

highest priority so that we can easily overcome the indirect technology aspects of the twin spark technology. Further, it can be seen that the strengths and the weaknesses accompanying the twin spark two-stroke engine attended less global priority of 0.134 and 0.073 respectively. The consistency of the comparison matrix of the comparison matrix of the SWOC factors is ensured by calculating the value of 0.059 of the matrix, which is within the limit. Thus, it can be seen that the external factors such as challenges and opportunities show a more significant function than the internal factors like strengths and weaknesses for the twin spark two-stroke engine. Table 5 shows the local and global preferences of the SWOC sub-factors.

Amongst the challenge sub-factors, C_2 has attained the highest global priority of 0.317 by occupying the 1st position in local and global priority, followed by C_1 and C_3 occupying 2nd and 3rd global positions. This highlights the challenges associated with the twin spark two-stroke engine playing a crucial role in developing the new two-stroke engine, competing with future emission regulations. Amongst opportunity sub-factors, O_1 has obtained the highest local priority and 4th position in the global priority, followed by O_2 and O_3 as successive local preferences in the global priority. This indicates that most of the opportunity sub-factors are the second most preferred in developing the twin spark two-stroke technology. The strength sub-factor S_3 is also one of the important sub-factors, obtaining the highest local priority and 6th global position among the strength sub-factors. Decreasing the emission levels is one of the important criteria to clear future emission regulations. S_3 is followed by sub-factors S_4, S_2 and S_1 as subsequent positions in the local priority and 8th, 10th and 13th positions in the global priority. In case of the weakness sub-factors, W_1 has achieved the highest local priority weight and 9th position in the global priority. Followed by W_2 and W_3 attaining the least local position and 12th, 14th position in the global priority. Thus, it can be realized that taking care of the challenges and harvesting the opportunity sub-factors O_1 and O_2 will lead to further improvement in the twin spark two-stroke engine

3.3 Sensitivity analysis

In this study, sensitivity analysis was carried out to examine the effect of twin spark two-stroke technology on varying the utmost factors. From the hybrid SWOC-AHP results, it can be seen that the challenge factor has come out as the utmost vital factor. The challenge criteria show the highest weight in the range 0.4-0.9 and retain the first rank,

Table 5: Pair-wise comparison matrix of SWOC sub-factors for local and global priority and position

S-Sub-factor	S_1	S_2	S_3	S_4	λ_{max}	CR	Local Priority	Local Position	Global Priority	Global Position
S_1	1	3	1	0.5	4.186	0.069	0.248	3	0.0334	10
S_2	0.333	1	0.333	0.333			0.095	4	0.0127	13
S_3	1	3	1	2			0.356	1	0.0478	6
S_4	2	3	0.5	1			0.301	2	0.0404	8
W-Sub-factor	W_1	W_2	W_3	λ_{max}	CR	Local Priority	Local Position	Global Priority	Global Position	
W_1	1	2	3	3.009	0.009	0.540	1	0.0396	9	
W_2	0.5	1	2			0.297	2	0.0218	12	
W_3	0.333	0.5	1			0.163	3	0.0120	14	
O-Sub-factor	O_1	O_2	O_3	O_4	λ_{max}	CR	Local Priority	Local Position	Global Priority	Global Position
O_1	1	2	2	2	4.143	0.054	0.389	1	0.0839	4
O_2	0.5	1	2	3			0.299	2	0.0646	5
O_3	0.5	0.5	1	2			0.188	3	0.0406	7
O_4	0.5	0.333	0.5	1			0.124	4	0.0267	11
C-Sub-factor	C_1	C_2	C_3	λ_{max}	CR	Local Priority	Local Position	Global Priority	Global Position	
C_1	1	0.5	1	3.018	0.018	0.240	2	0.1385	2	
C_2	2	1	3			0.550	1	0.3170	1	
C_3	1	0.333	1			0.210	3	0.1210	3	

whereas the weakness criteria have the least weight and hold the last rank. It depicts less fluctuation and monotonicity in the global priority of the SWOC sub-factors. Thus, it can be specified that AHP results are validated by the sensitivity analysis. Furthermore, new overall priority weights are achieved by multiplying the local priority weights by the new global priority weights. Variation in global priority changes the overall priority of all criteria, the results of which are shown in Table 6. The normal weight (in Table 7) indicates the original priority weight taken from Table 6. After changing the priority factor, a graphical representation of the results is shown in Figure 3. It can be seen that the results of the sensitivity analysis are robust.

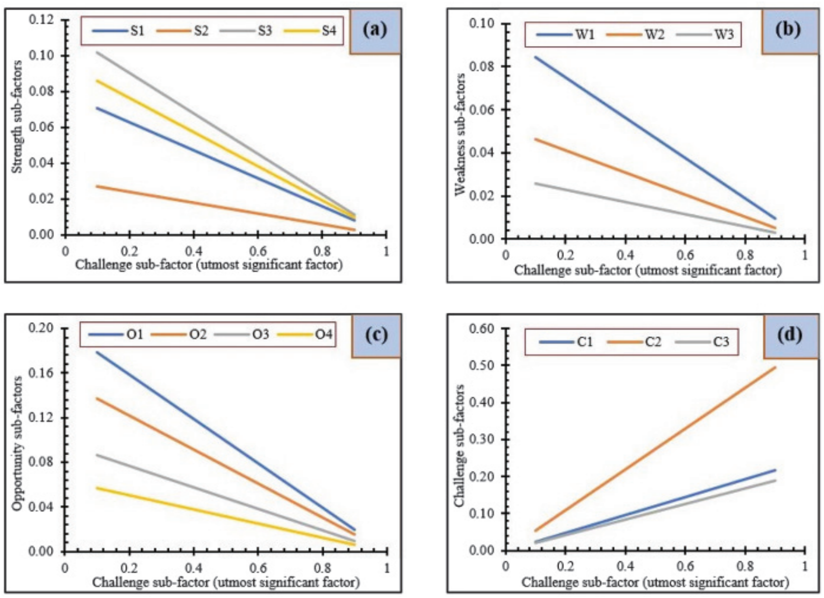

Figure 3. Change in global priority of (a) Strength sub-factors (b) Weakness sub-factors (c) Opportunity sub-factors (d) Challenge sub-factors

Table 6: Priorities of SWOC factors on varying the utmost significant factor

SWOC	0.1	0.2	0.3	0.4	0.5	Normal	0.6	0.7	0.8	0.9
Strength-(S)	0.286	0.254	0.222	0.190	0.159	0.134	0.127	0.095	0.063	0.032
Weakness-(W)	0.156	0.139	0.121	0.104	0.087	0.073	0.069	0.052	0.035	0.017
Opportunity-(O)	0.458	0.407	0.357	0.306	0.255	0.216	0.204	0.153	0.102	0.051
Challenge- (C)	0.100	0.200	0.300	0.400	0.500	0.576	0.600	0.700	0.800	0.900

Table 7: Global priority of SWOC sub-factors on varying the utmost significant factor

Sub-factor	0.1	0.2	0.3	0.4	0.5	Normal	0.6	0.7	0.8	0.9
S_1	0.071	0.063	0.055	0.047	0.039	0.033	0.031	0.024	0.016	0.008
S_2	0.027	0.024	0.021	0.018	0.015	0.013	0.012	0.009	0.006	0.003
S_3	0.102	0.090	0.079	0.068	0.056	0.048	0.045	0.034	0.023	0.011
S_4	0.086	0.076	0.067	0.057	0.048	0.040	0.038	0.029	0.019	0.010
W_1	0.084	0.075	0.066	0.056	0.047	0.040	0.037	0.028	0.019	0.009
W_2	0.046	0.041	0.036	0.031	0.026	0.022	0.021	0.015	0.010	0.005
W_3	0.026	0.023	0.020	0.017	0.014	0.012	0.011	0.009	0.006	0.003
O_1	0.178	0.158	0.139	0.119	0.099	0.084	0.079	0.059	0.040	0.020
O_2	0.137	0.122	0.107	0.092	0.076	0.065	0.061	0.046	0.031	0.015
O_3	0.086	0.077	0.067	0.057	0.048	0.041	0.038	0.029	0.019	0.010
O_4	0.057	0.050	0.044	0.038	0.031	0.027	0.025	0.019	0.013	0.006
C_1	0.024	0.048	0.072	0.096	0.120	0.138	0.144	0.168	0.192	0.216
C_2	0.055	0.110	0.165	0.220	0.275	0.317	0.330	0.385	0.440	0.495
C_3	0.021	0.042	0.063	0.084	0.105	0.121	0.126	0.147	0.168	0.189

3.4 Recommendations for improving twin spark two-stroke engine

According to the SWOC-AHP analysis, the challenge sub-factors like C_2, C_1, and C_3 are found to be the utmost sub-factors that hinder the use/development of the twin spark two-stroke engine. Thus, to counter the challenges, the following suggestions are proposed:

1. The challenge C_2 (i.e., Future emission regulations) can be met by using after-treatment devices in the twin spark two-stroke engine. That is, by using the opportunity O_2 linked with the twin spark two-stroke engine and also by the use of biofuels [46].
2. To counter challenge C_1 (i.e., Challenge from four-stroke engines), the GDI concept in the twin spark two-stroke engine can be utilized. That is, by using the opportunity O_1 connected with the twin spark two-stroke engines, the fuel consumption in it can be made comparable with the four-stroke engine. Additionally, the twin spark two-stroke engine's volumetric efficiency can be enhanced by improved designed intake ports.
3. The challenge C_3 (i.e., Optimum location of spark plugs) can be eradicated by exhaustive investigation of the performance and the emission of the twin spark two-stroke engine with different spark plug locations so that the optimal position of the spark plug can be found.

3.4.1 Limitations of the study

A hybrid SWOC-AHP method has been used in the study to examine the twin spark two-stroke engine technology. This study depends on the SWOC factors within which fourteen numbers of sub-factors associated with the twin spark two-stroke engine are identified. Nevertheless, other sub-factors may be present, which are not considered in the study. Further, in the SWOC-AHP analysis, the pair-wise comparison is conducted based on the experts' perceptions from industrial and academic, which may be biased in nature.

4.0 Conclusion

The present study suggests the adoption of twin spark technology in the two-stroke engine for its sustainable growth. From the SWOC-AHP analysis, four strengths, three weaknesses, four opportunities, and three challenges were identified for the twin spark two-stroke engine. The results indicate that the development of twin spark technology in a two-stroke engine mainly depends on external factors, i.e., challenges and opportunities. The external factors like C_2 (Future emission regulations), C_1 (Challenge from four-stroke engines), and C_3 (Optimum location of spark plugs) are found to be the most influential for the twin spark two-stroke engine with a global position of 1st, 2nd, and 3rd. Finally, to counter the challenges like C_2 and C_1, it is recommended that the opportunity like O_2 (Integrating after-treatment devices) and O_1 (Integrating GDI with twin spark technology) can be utilized in the twin spark two-stroke engine along with the use of bio-fuels and improved intake ports design. Moreover, to counter challenge C_3, exhaustive investigations on the optimum location of the spark plug are needed for enhancing the performance and reducing the emissions of the twin spark two-stroke engine.

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