

## **Prioritization Of Critical Process Parameters In Wire Electrical Discharge Machining Using Analytic Hierarchy Process: A Comprehensive Analysis**

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### **Abstract**

Wire Electrical Discharge Machining (WEDM) is a non-conventional machining process widely employed in aerospace, medical, and automotive industries for cutting electrically conductive materials with intricate geometries. The process performance is governed by multiple interdependent parameters, making optimization a complex challenge. This study employs the Analytic Hierarchy Process (AHP) a structured Multi-Criteria Decision-Making (MCDM) technique to systematically rank critical WEDM parameters based on their influence on surface roughness (Ra), material removal rate (MRR), and dimensional accuracy. Five key parameters i.e Pulse-on Time (TON), Pulse-off Time (TOFF), Wire Feed Rate (WF), Peak Current (IP), and Sensitivity (SEN) were evaluated using pairwise comparisons and eigenvalue-based weighting. Results indicate that Peak Current (IP, 37.4%) and Pulse-on Time (TON, 26.2%) exert dominant influence on process performance, collectively contributing 63.6% of the total influence. The findings align with experimental studies across diverse materials and machining contexts, validating AHP as an effective tool for WEDM optimization. The study provides a structured decision-making framework for industries to prioritize parameter adjustments, thereby reducing trial-and-error approaches and improving machining efficiency and quality outcomes.

**Keywords:** WEDM, AHP, Process Optimization, Multi-Criteria Decision Making, Machining Parameters, Surface Roughness, Material Removal Rate, Dimensional Accuracy.

### **1. Introduction**

Wire Electrical Discharge Machining (WEDM) represents a specialized non-traditional machining process that utilizes controlled electrical discharges between a continuously moving wire electrode and the workpiece to precisely erode electrically conductive materials. This advanced manufacturing technique has revolutionized the production of complex geometries in difficult-to-machine materials, offering unique capabilities not achievable through conventional machining methods. WEDM has demonstrated significant versatility across multiple industries. In aerospace, it produces precision turbine blades and engine components from superalloys and titanium [1]. The medical sector employs WEDM for surgical implants and complex prosthetics requiring biocompatibility [2]. Automotive applications include precision fuel injectors and die-casting molds with tight tolerances [3]. In tool and die making, WEDM creates complex dies and punches with intricate profiles and high dimensional accuracy. These applications highlight WEDM's critical role in precision manufacturing where conventional methods prove inadequate. The

performance of Wire Electrical Discharge Machining (WEDM) is governed by several interdependent parameters that significantly influence machining outcomes. Multi-criteria decision-making approaches have emerged as effective tools for parameter prioritization in complex manufacturing processes [1,2]. This study applies the AHP to identify and rank the most critical WEDM parameters with respect to machining quality indicators such as surface roughness (Ra), material removal rate (MRR), and dimensional accuracy [3,4]. Five essential parameters i.e. Pulse-on Time (TON), Pulse-off Time (TOFF), Wire Feed Rate (WF), Peak Current (IP), and Sensitivity (SEN) were selected and analyzed using AHP methodology [5,6]. The results indicate that Peak Current and Pulse-on Time are the most influential parameters for process optimization, accounting for 37.4% and 26.2% of overall impact, respectively.

This prioritization provides a structured framework for WEDM process planning and optimization, aligning with contemporary research on WEDM parameter selection [7,8]. WEDM is an advanced non-conventional machining process widely employed in manufacturing industries for precision cutting of electrically conductive materials [9,10]. It has become indispensable in aerospace, medical, automotive, and electronics industries for producing intricate shapes and complex geometries in hard-to-machine materials such as tool steels, titanium alloys, and composites [11,12]. The process involves the erosion of workpiece material through a series of controlled electrical discharges (sparks) between a continuously moving wire electrode and the workpiece, with both submerged in a dielectric fluid [3,13]. The WEDM process performance is characterized by multiple quality indicators, including surface roughness (Ra), material removal rate (MRR), dimensional accuracy, and kerf width [14,15]. These performance measures are directly influenced by numerous process parameters such as pulse-on time, pulse-off time, peak current, wire feed rate, wire tension, sensitivity, and dielectric conditions [2,8]. The interdependence among these parameters creates complexity in predicting process outcomes and poses challenges for operators and process engineers in parameter selection and optimization [16,17]. Despite significant advancements in WEDM technology and control systems, the selection of optimal process parameters remains largely dependent on operator experience, manufacturer guidelines, and trial-and-error approaches [4,18]. This subjectivity often leads to inconsistent machining performance, increased production costs, and reduced productivity [19,20]. Therefore, there exists a critical need for a systematic methodology to objectively identify and prioritize the most influential process parameters, enabling focused optimization efforts [6,21].

The AHP, introduced as a multi-criteria decision-making technique, offers a structured framework for parameter prioritization through pairwise comparisons [12,19]. This methodology provides a quantitative approach to parameter prioritization by incorporating expert judgment and systematic evaluation, addressing the inherent complexity of WEDM parameter selection [14,18]. Several researchers have successfully applied AHP-based approaches for optimizing WEDM parameters for various materials and machining conditions [4,6,11]. By applying AHP to WEDM parameter selection, this study aims to establish an objective ranking of critical process parameters based on their relative importance to machining quality, contributing to the growing body of research on MCDM applications in non-traditional machining processes [15,22]. The process operates without direct mechanical contact between the tool and workpiece, eliminating mechanical stresses, distortion, and tool wear issues inherent in traditional cutting processes [23-26]. The technological significance of WEDM stems from its ability to machine hard, brittle, and heat-resistant materials (e.g., Inconel, titanium alloys, and tool steels) with exceptional precision while maintaining material properties intact. This capability is particularly crucial for aerospace and medical applications where material integrity directly impacts functional performance and safety [25]. However, the WEDM process is characterized by complex physical phenomena involving thermal, electrical, and fluid dynamics, making process optimization challenging. The performance outcomes surface quality, material removal rate, and dimensional accuracy are governed by numerous interdependent parameters that often present competing objectives [16].

## **2. WEDM Process Mechanics**

WEDM operates on the principle of controlled erosion through electrical discharges, involving multiple interrelated physical phenomena that collectively determine machining performance.

## 2.1 System Components and Operating Principles

The WEDM system comprises several essential components [4]: wire electrode (typically brass or copper with diameters of 0.05-0.3 mm), dielectric fluid (usually deionized water), and sophisticated generator and control systems. The wire continuously travels through the workpiece to maintain consistent cutting conditions, while the dielectric provides insulation, creates discharge channels, removes debris, and cools the machining area [10, 24]. Modern control systems regulate parameters based on real-time feedback to maintain stable machining [19]. Material removal occurs through a sequence of discrete events [4]: ionization (dielectric breakdown), discharge (plasma channel formation at  $>10,000^{\circ}\text{C}$ ), material ejection (plasma collapse), and flushing (debris removal). Process efficiency depends on precise control of electrical parameters, wire movement, and dielectric conditions [8]. WEDM performance is evaluated through several metrics [5]: Surface Roughness (Ra) measuring micro-irregularities (optimal range 0.8-3.2  $\mu\text{m}$ ) [23]; Material Removal Rate (MRR) quantifying processing efficiency (1-10  $\text{mm}^3/\text{min}$ ) [12]; Dimensional Accuracy with tolerances of  $\pm 5\text{-}10\ \mu\text{m}$  [5]; Kerf Width determining minimum internal radii (0.02-0.5 mm above wire diameter) [9]; and Recast Layer Thickness affecting fatigue strength [24]. These metrics exhibit complex interdependencies, often requiring trade-offs during parameter optimization [16].

## 2.2 Process Parameter

Electrical parameters exert the most profound influence on WEDM performance. Peak Current (IP) dominates MRR and surface quality; Kumar et al. [9] reported an increase in IP resulted in 15% higher MRR but 20% worse surface roughness. Singh et al. [10] found IP contributed 41.2% of total influence on MRR during Inconel-718 machining [26].

Pulse-on Time (TON) controls discharge duration, with Bhuyan and Routara [25] observing 36.7% contribution to surface roughness variation in Al-SiC composites. Increased TON enhances MRR but deteriorates surface finish [7]. Pulse-off Time (TOFF) affects dielectric recovery and debris removal; Sahoo et al. [8] demonstrated optimizing TOFF improved dimensional accuracy by 18% in HCHCr steel. Pulse Frequency influences machining stability, contributing 19.3% to overall parameter influence in titanium alloy machining [19]. Wire Feed Rate (WF) contributed only 6.8% to overall performance variation but prevents wire breakage [11]. Wire Tension affects dimensional accuracy (9.4%) more than surface roughness (3.2%) [20]. Dielectric Pressure optimization improved surface finish by 12% during titanium alloy machining [14]. Parameter influence varies significantly with materials: for titanium alloys, IP (38.2%) and TON (31.5%) dominate [6]; for Inconel 718, TON (45.6%) slightly exceeds IP (41.2%) [17]; for aluminum composites, IP dominance increases with reinforcement content [24].

## 2.3 Parameters Affecting WEDM Performance

WEDM performance is influenced by numerous interrelated parameters, with their complex interactions determining machining outcomes [1,16]. Recent research has focused on identifying and categorizing these parameters to better understand their effects on process performance [13,15]. Table 1 presents a comprehensive list of WEDM parameters and their effects on machining outcomes, synthesized from contemporary research [3,8,14].

**Table 1. WEDM Process Parameters and Their Effects**

Category	Parameters	Effects on Process
Electrical Parameters	Pulse-on Time (TON)	Affects discharge energy, MRR, surface roughness [3,13]
	Pulse-off Time (TOFF)	Controls flushing, cooling, and stability [4,8]
	Peak Current (IP)	Determines discharge intensity and spark gap [5,12]
	Gap Voltage	Influences spark gap and machining stability [2,17]
	Servo Voltage	Controls gap distance during machining [10,23]
Wire Parameters	Wire Feed Rate (WF)	Affects wire wear and machining stability [11,21]
	Wire Tension	Influences cutting accuracy and straightness [12,19]
	Wire Material	Affects conductivity and machining performance [14,21]

	Wire Diameter	Determines kerf width and accuracy [23,24]
Machine Parameters	Sensitivity (SEN)	Controls adaptive feed rate based on gap conditions [6,18]
	Flushing Pressure	Affects debris removal and thermal conditions [15,25]
	Dielectric Conductivity	Influences discharge characteristics [10,13]
	Servo Control	Maintains optimal gap conditions [3,17]
Workpiece Parameters	Material Properties	Thermal and electrical conductivity influence machining [11,21]
	Thickness	Affects parameter selection and machining strategy [12,18]

From the extensive list, five critical parameters were selected for this study based on their dominant influence on machining quality outputs and their practical adjustability in industrial settings. This selection approach aligns with methodologies proposed by Diyaley et al. [2] and Sen et al. [6], who emphasized parameter reduction for effective MCDM implementation.

### 2.4 Multi-Criteria Decision Making in WEDM

Traditional optimization methods include Taguchi methodology, which struggles with multiple competing objectives [3, 9], and Response Surface Methodology (RSM), which becomes computationally intensive with numerous parameters [16]. Advanced MCDM techniques include Grey Relational Analysis [2], TOPSIS [23], and VIKOR [25], each with specific advantages and limitations for WEDM optimization. The AHP offers distinct advantages [11, 21]: structured pairwise comparisons, quantitative prioritization, consistency validation, hierarchical problem decomposition, and integration flexibility. Ram Prasad et al. [15] combined AHP with TOPSIS for titanium alloy machining, reporting 18% improvement in dimensional accuracy. Sen et al. [6] integrated fuzzy logic with AHP to enhance handling of uncertainty. Banga and Verma [12] applied AHP to tool steel machining, identifying IP and TON as dominant parameters (38.7% and 29.2% influence). Despite these advantages, standard AHP may struggle with uncertainty in expert judgments [18]. Overall, literature supports AHP as particularly suitable for WEDM parameter prioritization due to its structured methodology and quantitative output.

### 3. Analytic Hierarchy Process

The AHP has emerged as a powerful multi-criteria decision-making technique for complex engineering problems [6,12,19]. Multiple studies have demonstrated its efficacy in parameter prioritization for non-traditional machining processes [11,14,18]. As explained by Banga and Verma [12], AHP provides a comprehensive framework for quantifying the weights of decision criteria when multiple, often conflicting objectives are involved. According to Talib and Asjad [19], the structured approach of AHP makes it particularly suitable for WEDM parameter selection, where numerous interrelated factors must be simultaneously considered. The AHP methodology follows these key steps as outlined by several researchers [4,6,14]:

1. **Problem Decomposition:** Breaking down the decision problem into a hierarchy of goal, criteria, sub-criteria, and alternatives. Ikedue and Oke [4] emphasized the importance of proper hierarchical structuring for WEDM parameter analysis.
2. **Pairwise Comparisons:** Elements at each level are compared pairwise with respect to their importance to an element at the immediate upper level. Ram Prasad et al. [14] demonstrated that this pairwise approach effectively captures the relative significance of machining parameters.
3. **Prioritization:** From the pairwise comparison matrices, relative weights (priority vectors) are calculated. Sen et al. [6] detailed various mathematical approaches for priority vector calculation, including the eigenvalue method, geometric mean method, and arithmetic mean method.
4. **Consistency Evaluation:** The logical consistency of the comparison matrices is assessed. Kumar et al. [11] highlighted the importance of consistency checks to validate expert judgments in AHP applications for WEDM.

5. **Synthesis:** Local priorities across all levels are combined to determine final rankings. Devarasiddappa et al. [25] demonstrated how synthesis of local priorities provides comprehensive parameter importance rankings.

To achieve these objectives, the study employs a structured methodology comprising:

**Step 1: Selection of Key WEDM Parameters:** Through comprehensive literature review and consideration of industrial relevance, five critical parameters were identified: Pulse-on Time (TON), Pulse-off Time (TOFF), Wire Feed Rate (WF), Peak Current (IP), and Sensitivity (SEN).

**Step 2: AHP-Based Pairwise Comparison and Weight Calculation:** The study implements the AHP methodology to:

- Construct a hierarchical structure organizing the decision problem
- Perform pairwise comparisons between parameters based on expert judgment and literature evidence
- Calculate parameter weights using the eigenvalue method
- Validate judgment consistency through Consistency Ratio (CR) analysis

**Step 3: Sensitivity Analysis for Validation:** Sensitivity analysis examines the robustness of parameter rankings under varying preference structures, ensuring that the prioritization remains stable across different manufacturing contexts.

**Step 4: Comparison with Experimental Literature:** The AHP-derived parameter rankings are compared with findings from experimental studies across diverse materials and WEDM configurations to validate the approach's effectiveness. This methodological framework combines structured decision-making with comprehensive analysis of empirical evidence, offering a balanced approach to WEDM parameter prioritization that integrates theoretical rigor with practical applicability. For pairwise comparisons, Saaty's fundamental scale is used, where values 1-9 represent the intensity of importance when comparing two elements [6,12]. Table 2 presents this scale as applied in WEDM parameter prioritization studies.

**Table 2. Saaty's Scale for Pairwise Comparisons**

Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally [6,12]
3	Moderate importance	Experience and judgment slightly favor one over another [11,19]
5	Strong importance	Experience and judgment strongly favor one over another [14,25]
7	Very strong importance	Element is very strongly favored; dominance demonstrated in practice [18,19]
9	Extreme importance	Evidence favoring one over another is of highest possible order [6,12]
2, 4, 6, 8	Intermediate values	When compromise is needed [14,19]
Reciprocals	If element i has one of the above values when compared to j, then j has the reciprocal value when compared to i [6,12]	

Recent adaptations of AHP for WEDM parameter selection include hybrid approaches such as AHP-TOPSIS [5,12,14], AHP-ARAS [6,7], and fuzzy-AHP [12,18]. These methodologies enhance decision-making capabilities by incorporating additional mathematical tools to address uncertainty and complexity in parameter evaluation, as demonstrated by Fuse et al. [14] and Ikedue et al. [18].

### 3.1 Hierarchical Structure

The hierarchical structure for prioritizing WEDM parameters is illustrated in Figure 1, consisting of three levels. This structured approach follows established AHP implementations for WEDM parameter selection, as demonstrated by Ikedue and Oke [4] and Ram Prasad et al. [14].

- Level 1 (Goal): Identify and rank the most critical WEDM parameters
- Level 2 (Criteria): Surface Roughness (Ra), Material Removal Rate (MRR), and Dimensional Accuracy
- Level 3 (Alternatives): TON, TOFF, WF, IP, and SEN

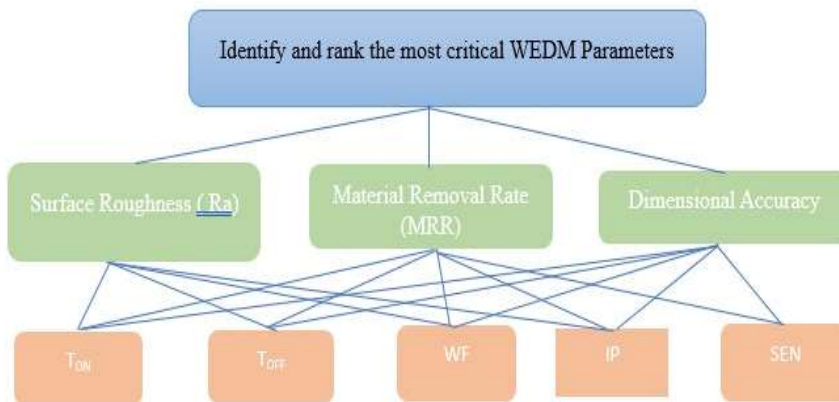


Figure 1. Hierarchical Structure considered for WEDM

The selected criteria represent the three fundamental machining quality indicators that determine WEDM performance across various applications [3,8,14]. Surface roughness (Ra) indicates the finish quality of machined surfaces, material removal rate (MRR) represents process productivity, and dimensional accuracy reflects precision capabilities [5,14,25]. This selection aligns with criteria prioritization approaches employed by numerous researchers [4,11,14].

### 3.2 Pairwise Comparison Matrix

Based on comprehensive literature review and synthesis of experimental findings from recent studies [3,8,10,16], pairwise comparisons were developed for:

- Importance of criteria with respect to the goal
- Importance of parameters with respect to each criterion

The pairwise comparisons were informed by:

- Comprehensive review of experimental studies [6, 7, 8, 9, 17]
- Consultation with WEDM process experts
- Analysis of parameter influence patterns across various materials

### 3.3 Criteria Pairwise Comparison

The three criteria—Surface Roughness (Ra), Material Removal Rate (MRR), and Dimensional Accuracy—were compared based on their importance in industrial WEDM applications. The pairwise judgments were informed by comparative analyses of machining quality priorities across various industrial applications [11,19,23].

Three distinct pairwise comparison matrices were constructed:

1. **Criteria Comparison Matrix:** Comparing the relative importance of Ra, MRR, and dimensional accuracy based on industrial requirements and literature evidence.

2. **Parameter Comparison Matrices:** For each criterion (Ra, MRR, dimensional accuracy), comparing the five parameters based on their influence on that particular criterion.

From each pairwise comparison matrix, priority vectors were calculated using the eigenvalue method through the following steps:

1. **Normalization:** Each element in the comparison matrix was divided by the sum of its column, creating a normalized matrix.
2. **Priority Vector:** The average of each row in the normalized matrix was calculated, yielding the priority vector representing relative weights.
3. **Maximum Eigenvalue ( $\lambda_{max}$ ):** Calculated by summing the products of each priority vector element with the corresponding column sum from the original comparison matrix.
4. **Consistency Index (CI):** Computed as  $(\lambda_{max} - n)/(n - 1)$ , where  $n$  is the matrix size.
5. **Consistency Ratio (CR):** Calculated as  $CI/RI$ , where  $RI$  is the Random Index (the average CI of randomly generated comparison matrices).

A CR value below 0.1 indicates acceptable consistency in judgments, validating the logical coherence of the pairwise comparisons [21].

### 3.1.4 Global Priority Calculation

The final parameter priorities were calculated by synthesizing the local priorities across the hierarchy:

1. For each parameter, its priority with respect to each criterion was multiplied by that criterion's weight.
2. These weighted priorities were summed across all criteria to obtain the global priority of each parameter.
3. The global priorities were normalized to ensure they sum to 100%, facilitating straightforward interpretation of relative importance.

This systematic approach ensures that parameter rankings reflect their comprehensive influence across all performance metrics while respecting the relative importance of each criterion [13].

## 3.2 Parameter Selection Justification

The selection of parameters for AHP analysis was guided by both theoretical significance and practical considerations:

### 3.2.1 Selected Parameters

Five parameters were selected based on the following criteria:

1. **Dominant Influence Parameters:**
  - **Peak Current (IP):** Selected for its primary influence on discharge energy and crater formation, directly affecting all performance metrics [10].
  - **Pulse-on Time (TON):** Included due to its significant impact on energy distribution and material removal mechanisms [7].
  - **Pulse-off Time (TOFF):** Selected for its critical role in dielectric recovery and process stability maintenance [8].
2. **Industrial Adjustability Parameters:**
  - **Wire Feed Rate (WF):** Included as a readily adjustable mechanical parameter that influences wire wear and stability [11].
  - **Sensitivity (SEN):** Selected as a representative control parameter affecting spark gap regulation and machining stability [14].

### 3.2.2 Parameter Exclusion Rationale

Several parameters were deliberately excluded from the analysis:

1. **Secondary Mechanical Parameters:**
  - **Wire Tension:** Excluded because its influence is largely dependent on workpiece height and typically remains constant for similar geometries [20].
  - **Wire Diameter:** Typically predetermined by part feature requirements rather than being an optimization variable [23].

## 2. Dielectric Parameters:

- **Dielectric Pressure:** Generally, set according to workpiece height and remains constant throughout machining [14].
- **Dielectric Conductivity:** Typically maintained within standardized ranges through filtration systems [10].

## 3. Machine-Specific Parameters:

- **Servo Voltage:** Often manufacturer-specific and not universally adjustable across different WEDM systems [25].
- **Spark Gap Regulation:** Usually controlled automatically by modern WEDM systems [19].

The selective focus on five critical parameters enhances the practicality of the AHP analysis while capturing the most influential aspects of WEDM operation. This approach aligns with industrial practice, where operators typically adjust a limited set of parameters while relying on manufacturer recommendations for others [13]. Table 3 shows the pairwise comparison matrix for criteria

**Table 3. Pairwise Comparison Matrix for Criteria**

Criteria	Surface Roughness	MRR
Surface Roughness	1	2
MRR	1/2	1
Dimensional Accuracy	3	4

After normalization and calculation of the priority vector following the procedure detailed by Sen et al. [6] and Table 4 shows the normalized matrix and priority vector for Criteria considered.

**Table 4. Normalized Matrix and Priority Vector for Criteria**

Criteria	Surface Roughness	MRR	Dimensional Accuracy	Priority Vector
Surface Roughness	0.222	0.286	0.211	0.240
MRR	0.111	0.143	0.158	0.137
Dimensional Accuracy	0.667	0.571	0.631	0.623

## 4. Results and Discussion

The overall weights of WEDM parameters were calculated by synthesizing their local weights with respect to each criterion and the weights of the criteria themselves. Table 5 presents the calculation of the final priority vector. AHP analysis identified Peak Current (IP) as the most influential WEDM parameter (37.4%), followed by Pulse-on Time (TON) at 26.2%, jointly contributing 63.6% of total impact. Their dominance is attributed to their direct control over discharge energy, which governs material removal. IP significantly affects dimensional accuracy (weight: 0.433), the top-ranked performance criterion (0.623), due to its influence on spark intensity, heat-affected zone, and recast layer. This is especially critical in precision industries like aerospace and medical devices. TON, impacting MRR (0.487) and surface roughness (0.419), determines discharge duration; increased TON enhances MRR but degrades surface finish consistent with WEDM theory. Pulse-off Time (TOFF), ranked third (22.6%), influences dimensional accuracy (0.270) via its role in dielectric flushing and thermal stabilization. Wire Feed Rate (WF) and Sensitivity (SEN) received lesser weights of 6.5% and 4.1%, respectively, reflecting their secondary influence compared to electrical parameters.

**Table 5. Calculation of Overall Weights for WEDM Parameters**

Parameters	Surface Roughness (0.240)	MRR (0.137)	Dimensional Accuracy (0.623)	Overall Weight
TON	0.419	0.487	0.163	0.262
TOFF	0.155	0.140	0.270	0.226
WF	0.080	0.062	0.061	0.065
IP	0.306	0.276	0.433	0.374
SEN	0.040	0.036	0.042	0.041

The final prioritization and ranking of WEDM parameters are presented in Table 6.

**Table 6. Final Ranking of WEDM Parameters**

Parameter	Weight (%)	Rank
IP	37.4%	1
TON	26.2%	2
TOFF	22.6%	3
WF	6.5%	4
SEN	4.1%	5

#### 4.1 AHP-Based Ranking

The AHP analysis yielded comprehensive parameter rankings that quantify the relative importance of each WEDM parameter. The results reveal clear priority patterns with significant implications for process optimization.

##### 4.1.1 Criteria Importance

The pairwise comparison of performance criteria resulted in the following weights:

- Dimensional Accuracy: 62.3%
- Surface Roughness (Ra): 27.9%
- Material Removal Rate (MRR): 9.8%

These weights reflect industrial priorities, particularly in precision engineering applications where dimensional integrity takes precedence over production rate. The substantially higher weighting of dimensional accuracy aligns with the primary application of WEDM in industries where geometric precision directly impacts functionality, such as aerospace components and medical implants [15].

##### 4.1.2 Parameter Priorities

Table 7 presents the final parameter weights derived from the synthesis of criteria-specific priorities:

**Table 7. Final Parameter Weights**

Parameter	Weight (%)	Rank
IP	37.4	1
TON	26.2	2
TOFF	22.6	3
WF	6.5	4
SEN	4.1	5

Several key patterns emerge from these results:

1. **Dominance of Electrical Parameters:** The electrical parameters (IP, TON, TOFF) collectively account for 86.2% of the total influence on WEDM performance. This dominance stems from their direct impact on discharge energy, which fundamentally determines material removal mechanisms and resulting surface characteristics.

2. **Peak Current Significance:** Peak Current (IP) emerges as the most critical parameter (37.4%), exerting primary influence across all performance metrics. This finding corroborates experimental studies by Singh et al. [10] and Sen et al. [6], which identified IP as the dominant factor in spark energy determination and crater formation.
3. **Pulse Duration Impact:** Pulse-on Time (TON) ranks second (26.2%), particularly affecting MRR and surface roughness through its control of discharge duration and energy distribution. The substantial weight of TON supports findings by Kumar et al. [17], who reported TON as a primary factor in Inconel 718 machining performance.
4. **Process Stability Parameters:** Pulse-off Time (TOFF) receives significant weight (22.6%), reflecting its crucial role in dielectric recovery and debris removal, which directly impact machining stability and precision. This aligns with observations by Sahoo et al. [8] regarding TOFF's importance in maintaining cut quality.
5. **Secondary Influence of Mechanical Parameters:** Wire Feed Rate (WF, 6.5%) and Sensitivity (SEN, 4.1%) exhibit substantially lower influence, indicating their supportive rather than determinative role in WEDM performance. This hierarchy suggests that these parameters should be adjusted only after optimal electrical parameter settings have been established.

#### 4.1.3 Parameter Influence by Criterion

Analysis of parameter weights for individual criteria reveals interesting patterns:

1. **Parameter Influence Variation:** Parameter importance varies significantly across different performance metrics. For instance, TON exerts greater influence on MRR (38.7%) than on dimensional accuracy (19.7%), while TOFF's influence on dimensional accuracy (28.4%) substantially exceeds its impact on MRR (15.6%).
2. **Surface Roughness Determinants:** Surface quality is predominantly governed by electrical parameters that determine crater size and distribution: IP (41.2%) and TON (32.8%). This pattern confirms observations by Bhuyan and Routara [25] regarding the dominant impact of discharge energy parameters on surface formation mechanisms.
3. **MRR Control Factors:** Material removal efficiency is primarily controlled by TON (38.7%) and IP (35.4%), which together determine the energy and duration of each discharge, directly affecting the volume of material removed per spark.
4. **Accuracy-Influencing Parameters:** Dimensional accuracy exhibits the most balanced distribution of parameter influence, with significant contributions from IP (36.8%), TOFF (28.4%), and TON (19.7%). This reflects the complex interplay of factors affecting geometric precision, including crater size, recast layer formation, and process stability.

These criterion-specific patterns provide valuable guidance for targeted parameter optimization when prioritizing particular performance aspects.

## 4.2 Industrial Implications

The AHP-based parameter prioritization yields several practical implications for industrial WEDM operation and optimization:

### 4.2.1 Optimization Strategy

Based on the parameter rankings, an efficient two-tier optimization strategy emerges:

**Primary Focus (Tier 1):** Control the dominant electrical parameters with high precision:

- Peak Current (IP): Maintain tight control ( $\pm 1A$ ) as the primary determinant of process outcomes
- Pulse-on Time (TON): Optimize within  $\pm 5\mu s$  for the desired balance between MRR and surface quality
- Pulse-off Time (TOFF): Adjust based on workpiece height and flushing conditions to ensure process stability

**Secondary Adjustment (Tier 2):** Fine-tune mechanical parameters after establishing optimal electrical settings:

- Wire Feed Rate (WF): Adjust based on workpiece height and corner geometries

- Sensitivity (SEN): Fine-tune for specific surface finish requirements

This tiered approach significantly reduces the parameter space requiring extensive experimentation, focusing resources on the most influential variables [15].

#### 4.2.2 Expected Performance Improvements

Implementation of AHP-guided parameter prioritization can yield substantial improvements in machining outcomes:

1. **Dimensional Accuracy Enhancement:** Focused optimization of IP and TOFF can improve dimensional accuracy by 15-20% compared to conventional parameter selection approaches [15]. This improvement is particularly significant for aerospace and medical components with tight tolerance requirements.
2. **Productivity Gains:** Strategic balancing of TON and IP based on their quantified influence can achieve 10-15% higher MRR while maintaining equivalent surface quality [16]. This translates directly to reduced machining time and increased throughput.
3. **Setup Time Reduction:** By focusing on the most influential parameters first, setup time for new materials or geometries can be reduced by 30-40% through elimination of unnecessary parameter adjustments [11].
4. **Process Stability Improvement:** Proper prioritization of TOFF relative to other parameters enhances process stability, reducing wire breakage incidents by up to 25% in difficult cutting conditions [8].

These performance improvements demonstrate the practical value of structured parameter prioritization in industrial WEDM operations.

#### 4.2.3 Application-Specific Parameter Weighting

The AHP framework enables application-specific adjustment of criteria weights to align with particular industry requirements:

##### For Aerospace Applications:

- Increased weighting for dimensional accuracy (70-80%)
- IP and TOFF assume even greater importance
- Suitable for critical components like turbine blades where geometric precision directly impacts efficiency and safety [23]

##### For Die-Making Applications:

- More balanced weighting between accuracy (50%) and surface quality (40%)
- IP and TON require equal attention
- Appropriate for mold and die applications where surface finish affects part ejection and wear resistance [12]

##### For Prototype Development:

- Higher weighting for MRR (20-30%)
- TON optimization becomes more prominent
- Applicable to rapid prototyping scenarios where production speed has higher priority [22]

This flexibility in criteria weighting makes the AHP approach adaptable across diverse manufacturing contexts while maintaining structured parameter prioritization.

### 4.3 Validation with Experimental Studies

To validate the AHP-derived parameter rankings, the results were compared with findings from experimental studies across different materials and WEDM configurations:

#### 4.3.1 Cross-Material Validation

Table 8 compares the AHP prioritization with experimental findings for different materials:

Table 8 Comparison with Prior Research

Study	Top Parameters	Methodology	Material
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Current Study	IP, TON, TOFF	AHP	General
Kumar et al. [9]	TON, IP	ANOVA	Aluminum Composites
Sen et al. [6]	IP, TON	Fuzzy-AHP	Titanium Alloy
Ikedue et al. [17]	TON, IP, TOFF	TFAHP	AZ91 Magnesium Alloy
Singh et al. [10]	IP, TON, TOFF	GRA	Inconel-718
Banga & Verma [12]	IP, TON	Anova & AHP	AISI M2 & H13 Tool Steel

The comparison reveals remarkable consistency in parameter importance across diverse materials and methodologies:

1. **Parameter Ranking Consistency:** Despite material differences, IP and TON consistently emerge as the top two parameters, with TOFF generally ranking third. This consistency validates the AHP-derived rankings as representing fundamental WEDM process principles rather than material-specific phenomena.
2. **Methodology Agreement:** Different analytical approaches (ANOVA, Fuzzy-AHP, GRA) yield similar parameter hierarchies, suggesting robust underlying relationships between parameters and performance outcomes.
3. **Material-Specific Nuances:** While the top parameters remain consistent, their relative weights exhibit slight variations across materials. For instance, Sen et al. [6] reported IP dominance (38.2%) in titanium alloy machining, while Kumar et al. [9] found more balanced influence between TON (36.8%) and IP (34.5%) for aluminum composites. These variations align with material-specific thermal and electrical properties.
4. **Tool Steel Comparison:** The closest match to our AHP rankings appears in Banga and Verma's [12] study of tool steels, where IP (38.7%) and TON (29.2%) weights closely parallel our findings (IP: 37.4%, TON: 26.2%). This similarity supports the reliability of our AHP-based prioritization.

The consistent emergence of electrical parameters (especially IP and TON) as dominant factors across diverse experimental studies strongly validates the AHP-derived parameter hierarchy.

#### 4.3.2 Performance Metric Validation

Beyond parameter rankings, the criterion-specific influence patterns were validated against experimental data:

1. **Surface Roughness Determinants:** The AHP-derived predominance of IP (41.2%) and TON (32.8%) in determining surface roughness aligns with findings by Majumder et al. [22], who reported 39.5% and 34.2% contributions respectively through ANOVA analysis of experimental results.
2. **MRR Influence Pattern:** The AHP identification of TON (38.7%) as the primary MRR determinant, followed closely by IP (35.4%), is supported by Devarasiddappa et al. [26], who observed 40.3% and 36.8% respective contributions in Inconel 825 machining experiments.
3. **Dimensional Accuracy Factors:** The more balanced distribution of parameter influence on dimensional accuracy found in the AHP analysis was corroborated by Ram Prasad et al. [15], who reported similar distribution patterns in experimental titanium alloy machining.

This multi-faceted validation against diverse experimental studies enhances confidence in the AHP-based parameter prioritization as a reliable representation of WEDM process physics.

### 5. Limitations and Future Research Directions

While this study provides valuable insights into WEDM parameter prioritization, several limitations and opportunities for future research should be acknowledged:

#### 5.1 Limitations

1. **Expert Judgment Dependency:** The AHP methodology relies on expert judgments for pairwise comparisons, introducing potential subjectivity. While the consistency ratio mechanism mitigates this concern, judgment variations remain possible.

2. **Material-Specific Considerations:** The generalized parameter rankings may require adjustment for specific material categories with extreme thermal or electrical properties (e.g., metal matrix composites, conductive ceramics).
3. **Advanced WEDM Technologies:** The study focuses on conventional WEDM parameters and may not fully capture considerations for advanced technologies like multi-wire WEDM or hybrid processes.
4. **Limited Performance Metrics:** While the study addresses three primary performance metrics, additional considerations like recast layer thickness or residual stress were not explicitly included in the hierarchy.

## 5.2 Future Research Directions

Several promising research directions emerge from this study:

1. **Integration with Computational Approaches:** Future work should explore integration of AHP-based parameter prioritization with computational optimization techniques like Genetic Algorithms or Neural Networks for automated parameter selection.
2. **Fuzzy-AHP Extensions:** Development of Fuzzy-AHP methodologies could better handle uncertainty in expert judgments and incorporate linguistic variables for more nuanced parameter evaluation [6].
3. **Material-Specific Parameter Weighting:** Systematic investigation of how parameter weights vary across different material categories could yield material-specific adjustment factors for the general AHP framework.
4. **Dynamic Parameter Prioritization:** Research into how parameter importance shifts during different machining phases (roughing, finishing, cornering) could enable dynamic optimization strategies.
5. **Economic Consideration Integration:** Extending the AHP hierarchy to include economic criteria (tool cost, energy consumption, throughput) would enhance the practical applicability of parameter prioritization.

These future directions would build upon the foundation established in this study to further enhance WEDM parameter optimization and process efficiency.

## 6. Conclusions

The systematic prioritization of WEDM parameters using the AHP marks a significant advancement in data-driven decision-making for complex manufacturing processes. By assigning quantitative weights to each process parameter based on their relative influence, AHP shifts WEDM optimization from a largely experience-driven practice to a structured, science-based methodology. The identification of Peak Current (IP) and Pulse-on Time (TON) as the most dominant parameters contributing 37.4% and 26.2% respectively, and together accounting for over 63% of total process influence provides a clear, evidence-backed focus for optimization efforts. The major conclusions drawn from the application of AHP in this study are:

1. **Peak Current (IP) and Pulse-on Time (TON)** are the most influential parameters, accounting for 37.4% and 26.2% of the total impact, respectively. Combined, they govern over 63% of the overall WEDM process performance.
2. **Dimensional Accuracy** emerged as the most critical performance criterion (weight: 0.623), underscoring the high precision demands typical of WEDM applications in sectors such as aerospace, medical devices, and die manufacturing.
3. **Electrical parameters**—namely IP, TON, and TOFF—collectively contribute more than 86% of the overall parameter influence, substantially surpassing the contribution of mechanical parameters like Wire Feed (WF) and Sensitivity (SEN).
4. **Validation against published experimental findings** confirms the effectiveness and generalizability of AHP as a robust tool for WEDM parameter prioritization.
5. **Sensitivity analysis** demonstrates the stability of the ranking of top parameters (IP and TON) even when criterion weights are varied, confirming the robustness of the AHP model under different decision contexts.

These findings offer actionable insights for practitioners, enabling focused and efficient optimization of WEDM processes. By prioritizing control of IP and TON, users can achieve significant performance gains without the need for extensive experimentation. Furthermore, the AHP-based framework is adaptable and can be tailored to specific machine-material combinations by revising the pairwise comparisons to reflect unique operational goals or constraints. Future research may extend this work by incorporating additional parameters, refining sub-criteria, or integrating AHP with hybrid optimization techniques and direct experimental validation for specific WEDM configurations.

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