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APPLICATION OF INTEGRATED TAGUCHI METHOD AND PRESENT-WORTH METHOD TO OPTIMIZE THE TURNING PARAMETERS OF INCONEL X750 ALLOY WITH AL_2O_3 NANOFLUID IN COCONUT OIL

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ABSTRACT

The present article introduces a techno-economic dimension to the turning process using literature data to correct a deficiency. This paper is about combining three variants of the Taguchi methods in five distinct formulations. The Taguchi, Taguchi-Pareto, and Taguchi-ABC methods are combined with the present worth method by introducing the interest and inflationary rates at different points in the S/N ratio (SNR) calculations. Aspect ratios and direct parameter combinations replace the traditional direct parameter analysis in the factor-level framework. A key result of this study is as follows: For the present worth evaluation of inflationary factors and considering the ranking order of parameters, namely C, F, C/V, F/V, C/F, V/C, F/C, 1/F, and 1/C, for all the twelve alternative combinations, the parameters C, F, F/V, V/C, 1/F, and 1/C performed better. The parameter V had the 5th position equivalent to 17% for V, 85% for C/V, 17% for 1/V, 8% for F/C, and 8% for C/F. Results for other formulations show promising attributes for the methods. The work could be useful for planning purposes in turning operations.

KEYWORDS: Interest rate, inflation factor, turning operations, optimization, economic factors.

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1. INTRODUCTION

The Inconel X750 alloy is described as a precipitation-hardenable material, a nickel-chromium alloy containing added aluminum and titanium (Adegoke and Oke, 2021; Adegoke et al., 2022; Şirin et al., 2021). It applies to the thrust chambers of rocket engines, forming tools, test machine grips, and extrusion dies. The alloy is attractive because of its high creep-rupture strength during high-temperature applications (i.e. 700^{o}C) and displays outstanding characteristics till cryogenic temperatures are achieved. Unfortunately, it is extremely difficult to machine Inconel X750 alloy, and the use of nanofluids during its machining to enhance the turning efficiency of the system is widespread (Tebaldo et al., 2017; Fernandes et al., 2020; Kim et al., 2021; Şirin et al., 2021; Adegoke and Oke, 2021; Adegoke et al., 2022). In previous studies, Adegoke and Oke (2021) as well as Adegoke et al. (2022) optimized the characteristics of the Inconel X750 alloy while conducting a turning operation. But the situation surrounding the turning operation is a complication and exceeds the technical parameters considered in their studies (Sristi et al., 2022). This may require a bi-disciplinary mathematical method of the turning operation in the context of relating the parameters and outcomes of the turning operation to economic parameters (Tebaldo et al., 2017; Kim et al., 2021; Cesén et al., 2022; Bohidar et al., 2022). This linkage guarantees a balanced assessment of the health of the turning operation since the information used on the operations floor also reflects the sustainability of the plant regarding the machining economics of the process (Tebaldo et al., 2017; Fernandes et al., 2020; Şirin et al., 2021; Cesén M., et al., 2022).

Consequently, this article reexamines the measures in the earlier documentation to amalgamate the Taguchi method with the present worth economic factor. The signal-to-noise ratios are included for an economic view of the turning performance using the Inconel X750. However, beyond the discussion in Oke and Fagbolagun (2020), the present article extends knowledge by introducing two additional Taguchi methods, namely Taguchi-Pareto and Taguchi-ABC to prove the uniqueness of introducing priority in concurrence with optimization using the Pareto analysis and ABC analysis as a tool to enhance the performance of the Taguchi method while also considering the present worth method that includes both the inflation rate and interest rate.

Optimization has been declared important in the turning process to monitor the progress of machining alloys (Adegoke and Oke, 2021; Adegoke et al., 2022). To optimize, the Taguchi method has been extensively used by Akıncıoğlu et al. (2016), Moganapriya et al. (2022), and Costa et al. (2016). To demonstrate what the articles offer and the gap that the present research fills, the current authors distilled out the parameters analyzed in these studies, the response variables mentioned, and the significant results declared by those authors. In Akıncıoğlu et al. (2016), the factors studied are the cutting speed, cryogenic treatment, and feed rate. While working on the Johnfond T35 CNC lathe machine, the cutting speeds were scaled into three, namely 30, 60, and 90m/min. The cryogenic treatments were limited to two categories: shallow occurring at -80°C and deep, which took place at -145°C. Besides, the feed rates were graduated at 0.1, 0.2, and 0.3mm/rev. For the study, surface roughness was the chief response, conducted in three series, while the mean of the values was adopted for the experiments. The significant results are first that the importance ratings of the parameters are feed rate, cryogenic treatment, and cutting speed as first to the last positions. Next, surface roughness enhancement on the cementite carbide tool took 28.3% by shallow cryogenic treatment, while 72.3% enhancement was experienced by deep cryogenic treatment. It was also declared that the tungsten carbide insert showed a surge in its wear resistance, considering shallow and deep treatments in cryogenic substances. Although the study is relevant since the concept of the Taguchi method with fewer experimental trials is advanced, the issue of present worth was omitted, leaving the inflation rate and interest rate unattended.

This study aimed to analyze the twin ideas of the economics and optimization of the cutting parameters while turning Inconel X750 alloy. The results can be applied by machining engineers for turning purposes, particularly in wet machining where lubricants of Al_2O_3 substance are suspended in coconut oil. Based on the experimental data by Venkatesan et al. (2019), the results were analyzed, and conclusions were offered. It was argued that working at a sub-optimal performance threshold directly affects the economics of the machining shop and the profitability obtained in any financial year. In this article, the effective criteria were defined as direct and aspect ratios. They were analyzed with the inflationary present with factors and Taguchi's signal to noise, the ratio with each of these criteria tested in single or joint forms. The Taguchi method aided the evaluation of the optimal parametric generation pattern, while the inflationary and present criteria displayed the economic strength of the scenario analyzed. The Taguchi method provides quantitative and qualitative dimensions and interpretation of results with fewer experimental runs and costs. With the evaluation of the optimal parameters from the signal-to-noise ratios, the best possible value is defined for each parameter in the analysis. With the elimination of several experimental trials in providing an economic member of experiments, the Taguchi method prides itself on simplicity. This is why the Taguchi method is preferred to alternative approaches in the evaluation scheme. This article's novelty lies in applying the Taguchi method to build up optimized values of cutting parameters, localize the machining planning scheme, improve material deployment, reduce unnecessary tasks leading to operators' fatigue and enhance operational efficiency and capacity to process more jobs. This study aimed at analyzing and gaining insights into how the limitation of the paucity of data could be addressed in the machining decision-making process. It describes a straightforward algorithm to write machining datasets, leading to a validation of operational effectiveness in the machining shop while running the data evaluation framework using machining data methods.

2. LITERATURE REVIEW

2.1. General

As a critical pillar for the sustenance of organizations, machining economics has rapidly developed over the world in machining literature (Tebaldo et al., 2017; Fernandes et al., 2020; Kim et al., 2021; Cesén et al., 2022). Scholars and experts globally have proposed many methods for monitoring and reducing the cost of machining, among which engineering economics tools and techniques are recognized as effective (Cesén et al., 2022). In turning the X750 alloy, the applied lubricant, the Al_2O_3 nanofluid-coconut oil lubricant, aims to reduce the heat generated, but what quantity and the cost of the lubricant required are unknown (Adegoke and Oke, 2021; Adegoke et al., 2022). Given the unstable interest rate (interest on capital borrowed in banks to run the machining process), the economic dimension of the system is uncertain. Therefore, to exploit the lubricants, machine hours, labor hours, cost of building and other costs in a sustainable, assuring, and stable manner, a deep study of the economic dimensions of the machining scheduling and production plan of critical machining resources and sustainable machining, the use of economic parameters coupled with optimization procedures is a compelling need.

Present worth is a mechanical industry technique, a performance flow tool where the Taguchi performance scheme with parametric values at each level is reduced to time zero through the assumption of an interest rate (Oke and Fagbolagun, 2020). In the context of the present article, it takes into account the idea that the parametric level, is worth less since time passage from the present to the future is considered. There are several studies on machining economics in the machining literature, from cutting operations to cutting materials and tools used in the machining process, but fewer research results on the concurrent optimization using the Taguchi technique and the economic tool of present worth. Iakovou et al. (1996) proposed an optimization procedure based on the parameters of the tool life equation that coupled the tool life and cutting speed parameters. Optimal cutting speed and tool replacement policies for an adaptive control situation were developed from the perspective of the economics of machining. The results revealed that the procedure provided a straightforward tool to implement and supported the continuous improvement of machining decisions. In a study conducted by Pantoja et al. (2018), a cost optimization procedure that accounts for the machine parameters in the phases of operational, machining, ordering, holding, shortage, and material costs. Anand et al.'s (2019) study shows that hard turning and grinding are affected by the process' economic efficiency. The results revealed that the anticipated low status of tool holding and storage costs were attained at optimal stock levels. While the cutting feed rate and tool life were established as dominant cutting variables on the tool cost, the significance of the effect of machining up time on total cost was emphasized.

Zhang and Lu (1990) used the expert system to study the economic concerns in an operation plan by analyzing the cost of machining from the viewpoints of the total cost and fixed and variable costs in a program that specifies the machining sequence and optimal plan. Lee et al. (1999) studied the economic machining process phenomenon, and the results demonstrated the effectiveness of the suggested methods. It was further stated that the methods are suitable to include the decision maker's perception and the method functions well to analyze uncertain, ill-defined, and vague machining problems. Kopac (2002) presented a discussion to analyze the effect of machining material, technological parameters, and machining processes on the economics of machining and cutting forces (see also Zhijun et al., 2015; Marek et al., 2016). In a study by Zuperl and Cus (2004), a non-deterministic optimization method was introduced to model the complicated cutting parameters while machining materials. The framework of the method is built on artificial neural networks, and the problem solved is referred to as the cutting-conditions optimization problem. The results showed low machining costs and high productivity using experimental data.

Madic et al. (2014) established the best and worst machining processes based on multi-criteria economic analysis and using the weighted aggregated sum product assessment approach. The results showed that the eight different machining procedures and the five economic criteria proved the method's effectiveness with practical literature data. Zhijun et al. (2015) studied the techno-economic optimization–oriented analysis to determine the optimal parametric setting and ash of coal flotation concentrate while maximizing the economic advantages. Many flotation tests were conducted with kerosene and fuel oil introduced as flotation agents. Regression models were established through the orthogonal array to determine the yield and ash of clean coal using Matlab software. Lingo software was used to find the yield and 79.91%, respectively, by which maximum income per 100t of fine raw coal resulted in 106,221 RMB. Marek et al. (2016) explored energy in recycling technology. A techno-economic process of energy utilization using combustion, anaerobic fermentation, and pyrolysis was conducted on a scale. The response has shown that, if this trend continues, it is likely to be more expedient to diversify waste paper from returning to production (recycling) and prefer economic pyrolysis.

It can be observed that several researchers have conducted a lot of research on machining economics during the turning process, but the approach mainly focused on production cost minimization, while the concurrent optimization and the economic perspective using the present worth analysis were not considered (see also Table 1). Therefore, in this article, the current worth method was studied and integrated with the Taguchi method to monitor the economic dimension of the turning operation while processing the X750 alloy under the lubricated environment.

2.2. Research gap and contribution

Considering works on economic-based machining analysis and comparing them with other aspects of the literature, such as multi-criteria analysis of machining studies and thermal-associated research on machining processes, studies on the economic aspect have a long history but scattered reports over the years. In search for articles on machining economics, it was interesting finding an article as early as 1990, coauthored by Zhang and Lu, focusing on expert systems- economic concern integration in machining analysis. However, disappointed by subsequent articles found in 1996 (Iakovou et al., 1996) and 1999 (Lee et al., 1999). See also the scanty growth of the area as evidenced in Zuperl and Cus' (2008) publication. There is a slow movement in publications on machining economics, and documented research is few that address an economic–oriented aspect of machining.

Table 1. Summary of literature concerning the study.

Sr. No.	Authors	Methods	Parameters	Contribution	Gap
1	Tebaldo et al. (2016)	Schmal 7 formula, total cost curve, productivity, economic life, maximum time of production, and the radius of the insert.	Material removal rate, cut-off length, cutting forces, index of workability, area of measurement, skewness, kurtosis, cutting parameters, tool life, cost of labour, machine amortization, cost of lubrication, general expenses, tool charging time, cost of the tool holder, tool usage, number of cutting edges.	Highlights a unique eco-friendly maximum quantity cooling scheme as a tool to mimic the tool life obtainable in a wet condition.	Even though the eco-friendly maximum quantity cooling scheme was able to mimic the tool life in a wet condition, it is more expensive. Therefore, research opportunities abound in making the system more efficient and cost-effective. Further research should aim at these objectives.
2	Kumar et al. (2019):	Regression genetic algorithm, Taguchi, ANOVA	Feed, cutting velocity, depth of cut, material removal rate, surface roughness, temperature, strain equivalent to cutting force and feed force.	Established crucial parameters of the hard turning operation by the Taguchi and ANOVA methods. They further optimized parameters using ANOVA, regression and genetic algorithm methods.	In this work, a crossover probability of 0.2 was chosen for the genetic algorithm method. However, it is at variance with the popular practice in the literature where 0.5 and above are common values to encourage intensive search within the solution search space. Thus, it is unclear why the value of 0.2 was chosen. A further experimental study by varying this value of the crossover parameter may provide greater insight into the study. This is a gap to be bridged in the future. Besides, it is suggested that an experimental study of the crossover parameter can be conducted to determine the optimal probability of crossover.
3.	Cesen et al (2019)	Cost model*	Cost of the cycle, cost of handling the workpiece, cost of handling the turned workpiece, unit cost, time required both to clamp the workpiece and to remove the turned part, tool cost, machining time cost, tool replacement cost.	Highlighting a model that indicates the manufacturing optimization cost of AISI 10/8 steel for the turning process.	There is a need to integrate optimization methods such as the Taguchi method for economic impacts.
4.	Kumari (2021)	Cost model	Feed rate, depth of cut, spindle speed, surface roughness, material removal rate	Introduction of the utility concept from a linguistic perspective to determine to most influential parameters among the depth of cut, feed rate and spindle speed while monitoring the responses using the material removal rate and surface roughness.	There is an opportunity to amalgamate evolutionary algorithms such as the firefly algorithm to the present structure to improve the computational outcomes5.

6.	Karthikeyan et al. (2020)	Taguchi-based grey relational analysis.	Cutting speed, feed rate, depth of cut.	Established optimal process parameters while processing subzero-treated EN24 alloy steel. The process tool for analysis is the Taguchi-oriented grey relational analysis.	Potential exists to extend the amalgamation to include multicriteria methods such as VIKOR, EDAS and DEMATEL.
7.	Akinclpoglu et al. (2015)	Taguchi method; ANOVA	Cryo-treated tools, feed rate, cutting speed, hardness, density, tensile strength, thermal conductivity.	Analyzed the influence of both deep and shallow cryogenic treatment used on Hastelloy C22 super alloy while turning the material for surface roughness evaluation.	There is a need for a possible integration of the evolutionary method with Taguchi to enhance the surface roughness evaluation.
8	Moganapriya et al. (2021)	Taguchi-DEAR approach	Cutting speed, feed rate, depth of cut, base pressure, pulse width, frequency, bias voltage, supply voltage, and pressure.	Evaluation of the performance of AISI 420 martensitic stainless steel using the Taguchi-DEAR method with a unique CNC turning insert coated with TiAlSiN material.	Possible combination of another optimization method with the Taguchi-DEAR method will enhance the outcome. Some of the optimization methods are genetic algorithmic, and differential evolution.
9	Adegoke et al. (2022)	Taguchi, Taguchi-Pareto and Taguchi-ABC method.	Percentage concentration, cutting speed, feed rate.	Highlighting new methods of Taguchi and Taguchi-based frameworks previously unknown for the machining process for X750 Inconel alloy. This enlarges the understanding of researchers on how to optimize materials during the machining process more effectively.	There is a need to introduce evolutionary approaches such as genetic algorithm and particle swarm optimization jointly with the presented method in future studies.
10	Adegoke and Oke (2021)	Direct and aspect ratio-based Taguchi methods.	Percentage concentration, cutting speed and feed rate.	Established flaws in the machining process concerning the X750 Inconel alloy and proposed new methods, namely the direct and aspect ratio-based Taguchi methods.	It may be useful to add some evolving optimization methods such as evolution strategies and genetic algorithms.
11	Fernandes et al (2020)	Cost model	Cutting speed, production cost, machining cost, cutting tool cost, cooling lubrication fluid cost, cleaning cost, part cleaning, swarf preparation cost, and workpiece initial diameter.	Highlighting the experimental conditions and parameters to ascertain the economic feasibility of turning AISID6 tool steel in its tempered and quenched conditions. The unique tool of solid PCBN insert was used and helped by liquid nitrogen, which enhanced the cutting tool life.	Future studies may centre on how to further enhance the tool's life by introducing optimization tools such as genetic algorithms. At present, the obtained results may be sub-optimal although economic. Furthermore, nonprofit production costs considering the dry machining condition and the introduction of liquid nitrogen may be investigated.
12	Pantoja et al. (2018)	Cost optimisation model	Total cost, production rate, tool cost, non-reproductive cost, machining cost	They developed an optimum cost model to be used as a tool management policy for manufacturing companies. The model is parameterized along with some cutting tool characteristics, machining conditions inventory and some other constraints.	In the future, it is possible to investigate and present details of power consumption, downtime and maintenance cost.
13	Zuperl and Cus (2004)	Non-deterministic optimisation approach	Production rate, metal removal rate, cutting speed, feeding rate, cutting depth, tool set-up time, tool change time, tool downtime, the volume of removed metal, tool life, and surface quality indicator.	Establishing a neural optimisation method to evaluate the properties of optimal cutting parameters while turning. Furthermore, given the machining turning objectives namely production rate, cutting quality and operation cost, the work developed a neural network that generated the optimized turning parameters where the neural network is used as a regressor.	In the future, researchers can consider alternative machine learning methods such as support vector machines for higher predictive accuracy.

As the present authors compared the few publishing, some interesting gaps in the literature were revealed. For instance, a vast majority of economic-based machining studies disregard aspect ratios and their conclusion in evaluating the machining process. Moreover, most of the methods were analyzed without due consideration for the energy consumption in the system. The authors of these studies assumed that capturing time and machining costs is enough to reflect the energy usage control. However, this is not a realistic assumption because, in reality, energy consumption is greatly reduced by the lubrication application, and the use of nano-lubricants to eliminate the heat generated and prevent huge energy expenditure has significant relevance in energy control. Even when optimization, such as geometric programming methods deployed by Alahmadi (2016), is used, it is not straightforward. The operator and decision maker struggles to acknowledge and understand its application mechanism in reality and hence is disappointed and abandons it. But the Taguchi method, which is easy to understand and apply, with both qualitative and quantitative interpretation potentials in decision making, is more suited than the geometric programming method in this economic machining modeling. Finally, no earlier study has studied the combined optimization using the Taguchi method and the present north method to analyze the cutting operations of X750 alloys using lubrication with nano-Al_2O_3 particles in coconut oil.

Thus, to advance knowledge of machining economics, this article aims at bridging the gaps identified in the literature from the above arguments. Consequently, the article proposes a coupled method of Taguchi and present worth for the cutting activities while processing the x 750 alloys on the turning machine, using the nano-Al_2O_3 coconut lubricant. Specifically stated, the important attributes of the present article may be summarized as follows;

- Incorporating and optimizing energy consumption via the Taguchi methodical analysis that developed an optimal parametric setting for the percentage concentration of the nano-Al_2O_3 coconut-based lubricant.
- Coupled optimization of the most influential parameters of the lubricated turning process of concentration of the nano-based fluid lubricant, the velocity of turning, feed rate of materials, levels at which each parameter is specified, expected rate of return (interest rate), and the size of the projected optimal value.
- Introduction of aspect ratios of factors and integrating them with direct factors for optimization and coupling efforts with economic factors

- Quantifying economic factors from the present value perspective, thus displacing the emphasis on time, production cost, and productivity of machining operations.
- Reawakening the impact of interest rate, inflationary rate, and inflationary rate on machining activities, creating awareness of the time value of money and economic consciousness.
- Combination of Taguchi method with the present worth method.

3. METHODOLOGY

3.1. Chemical composition of the X750 Inconel alloy

For the Inconel X750 alloy, its chemical composition establishes the physical and chemical characteristics of the alloy such as the density, strength and colour among others. Therefore, it is important to understand the chemical composition of the X750 alloy, which is stated as follows: Silicon: 0.50 max, Sulphur: 0.01max, copper: 0.50max, carbon: 0.08max.

3.2. Research flow

As this research aims to enhance the present machining operations patterns and frameworks by introducing documented research outcomes, it falls conventionally under the classification of applied research. The flow is shown in Fig. 1.

3.3. Parameters of the method and formulations

The present worth expression for interest rate and inflationary factor is expressed in Equations (1a) and 1(b):

Interest rate formula: $PW_{C}/_{CV}/_{FR}/_{C/V}/_{F/V} = L(1+i)^{-n}$ (1a)

Inflationary factor formula: $PW_{C}/_{CV}/_{FR}/_{C/V}/_{F/V} = L(1+\beta)^{-n}$ (1b)

Where L is each averaged signal-to-noise ratio, i represents the interest rate, β is the inflationary factor, and n is the number of levels.

The present worth method incorporating response value at each level and inflationary factor is shown in Equation (2):

$$PW = L(1+\beta)^{n} \quad (2)$$

Where l represents the response value of each level obtained from Taguchi response analysis, β represents the value of the current inflationary factor in Nigeria, and n represents the number of levels.

Furthermore, the present worth method incorporating response value at each level, interest rate, and inflationary factor are shown in Equation (3):

$$PW = (L(1+i)^{-n}(1+\beta)^{n}) \quad (3)$$

Where l represents the response value of each level obtained from Taguchi response analysis, i represent the current interest rate in Nigeria, β represents the value of the present inflationary factor in Nigeria and n represents the number of levels.

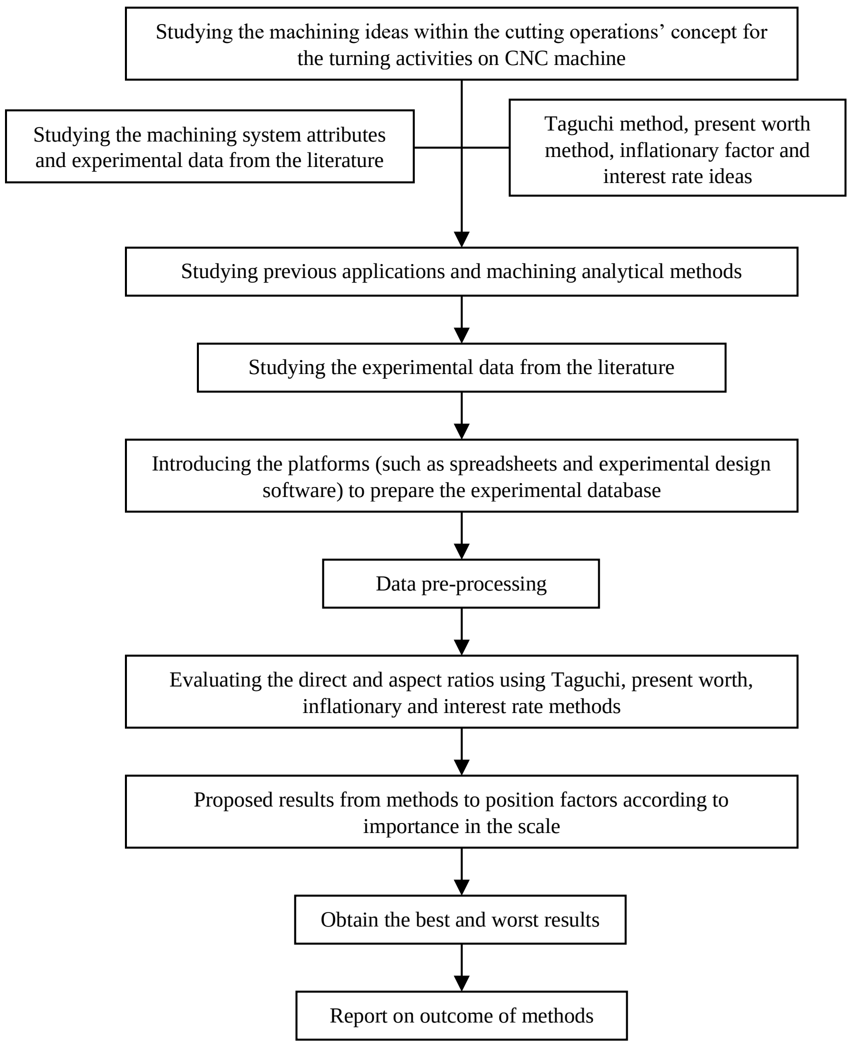

Fig. 1. Research flow for the cutting force integrated economic and optimization problem.

4. RESULTS AD DISCUSSION

Research reveals that the turning activities using the conventional CNC turning Centre are less expensive and affordable to many organizations, according to a worldwide opinion. With the relatively lower investment costs compared to non-conventional machines like electrical discharge machining, it is expected that the overhead involved from the CNC turning activities should be substantially lower than that obtained from the alternative non-conventional machining systems. However, should any unexpected excessive cost occurs, it could be handled with economic methods to minimize the overall consequence on the profit margin of the machining shop. Consequently, this machining option could maintain its attractive low-cost position from investors' and users' perspectives. Although the overhead cost of the turning operation of superalloys such as the X750 alloy during machining, the cost could be comparatively low. In general, two crucial criteria of inflationary factor and interest rate define the cost of cutting operations for the turning activities of a superalloy such as the X750 alloy. Thus, understanding how these criteria influence the cutting activities when incorporated into economic models with all measures brought to the present worth of activities plays a critical role in defining a machining model as economical. As computations are made, there is the possibility of obtaining sub-optimal measures. Thus, the analysis should be done where all the component parameters and responses are optimized; it is known that the system will benefit greatly from the analysis only when the optimal points are determined. Consequently, according to the issues discussed above and monitoring the economic health of the machining system, it felt necessary to show interest in the institution of a detailed and practical approach in the cutting operations regarding the processing of X750 alloy in economics and optimization aspects to attain the present research objective. For this particular case, the machining systems framework and experimental data, as defined by Venkatesan et al. (2019) and further analyzed by Adegoke and Oke (2021) as well as Adegoke et al. (2022) are established. Then the operating parameters for the machining shop and the financial/economic parameters prevailing in the business environment are established. For the next step, the forms of the parameters regarding being in the direct and aspect ratios are defined. Finally, the combined economic and optimization tasks are completed.

In this work, an optimization-economic (optim-eco) method called the present worth optimization has been introduced. From the parameters taken by Venkatesan et al. (2019), Table 2 emerged.

Table 2. Standard turning parameters (Venkatesan et al., 2019)

Level	C%	V m/mm	F mm/rev
1	0.25	40	0.14
2	0.5	60	0.17
3	1	100	0.2

In Table 2, it is seen that the readings are taken in three levels as well as three parameters. In addition, the aspect ratios become five parameters, all together as shown in Adegoke and Oke

(2021), Table 3. These aspect ratios mentioned keep alternating between obtaining up to twelve alternatives. The main purpose of the aspect ratio introduction is to create a broad channel for obtaining mostly correct comparable results for the optimization processes.

Table 3. Aspect ratios formulation charts (Adegoke and Oke, 2021).

Factors → Alternatives ↓	1	2	3	4	5	Factors → Alternatives ↓	1	2	3	4	5
1	C	V	F	C/V	F/V	7	1/C	1/V	1/F	C/V	F/V
2	C	V	F	C/F	V/F	8	1/C	1/V	1/F	C/F	V/F
3	C	V	F	V/C	F/C	9	1/C	1/V	1/F	V/C	F/C
4	C	V	F	V/C	F/V	10	1/C	1/V	1/F	V/C	F/V
5	C	V	F	F/C	F/V	11	1/C	1/V	1/F	F/C	F/V
6	C	V	F	C/V	C/F	12	1/C	1/V	1/F	C/V	C/F

This work considered several cases to achieve desired results, as discussed below.

4.1. Case 1 - Determination of present worth optimization for ordinary Taguchi signal-to-noise ratio averages of all the aspect ratio alternatives

In this case, the response table obtained from Taguchi's experimental run of standard and aspect ratio parameters extracted from Adegoke et al. (2022) and used to calculate the present worth of the economic parameters presented in Table 2, while considering the alternative one of standard and aspect ratios as first then followed by the other alternatives. The averaged signal-to-noise ratio of the said alternative 1 is hereby presented in Table 4 as thus:

Table 4. Response table for the joint standard and aspect ratios of the turning process Adegoke et al. (2022).

Levels	C	V	F	C/V	F/V
1	-28.8785	-25.0528	-28.8789	-28.8787	-28.8791
2	-28.8788	-28.5739	-28.8788	-28.8794	-28.8791
3	-28.8799	-33.0105	-28.8794	-28.8791	-28.8791
Delta values	0.001374	7.957736	0.000634	0.000677	1.1974E-08
Ranks	2	1	4	3	5

Optimum parametric settings are C_1 V_1 F_2 C/V_1 F/V_1

The technical elements expressed in Table 4 are:

1. The delta values are the maximum value minus the minimum value of the three levels of each parameter. At the same, it helps to select appropriate ranks.
2. The ranks are the positions of parameters from the maximum value to the minimum value; this, in return, reveals how powerful and beneficial each parameter is; in the economics of the turning operation.

3. Optimum parametric settings, which are the maximum values between levels one to three of each parameter. It is also the most beneficial economic value for the turning process.

The response table is further illustrated in Figures for simplicity and understanding. The performance flow diagram to obtain PW_C, PW_V, PW_F, $PW_{C/V}$, *and* $PW_{F/V}$ are in Figs. 2a, b, c, d, and e, respectively.

In this section, the combined present worth (interest rate and inflationary factor) is applied to the averaged signal-to-noise ratios of the ordinary Taguchi signal-to-noise ratio presented in Table 3. All the twelve alternatives of the standard and aspect ratios enumerated in Table 2 must be considered while carrying out the present worth analysis. The results obtained after this present worth analysis were compared with a discussion of results. Below are a few tables of the analysis. The current interest rate in Nigeria, which is 11.5%, declared by the Central Bank of Nigeria (CBN) as of January 2020, is considered in this present work. Here, Equations (1a) and (1b) is applied. By illustration, considering the first parameter of the response Table 4, $28.8785(1+0.115)^{1}(1+0.156)^{1}] = -29.9404$, which is the result for level 1. The result for level 2 is obtained as $[-28.8788\ (1+0.115)^{-2}(1+0.156)^{2}]$, which gives -69.222883, and $[-28.8798\ (1+0.115)^{-3}(1+0.156)^{3}]$, which gives -120.037016 is for level 3. Therefore, the present worth of this parameter is the total sum of the present individual worth as expressed below; the complete table is shown in Table 4. There are changes in the rankings of the Taguchi experimental average signal-to-noise ratio and the rankings of the present worth analysis, as visible in Tables 4 and 5.

The analysis reveals that the aspect ratio of F/V had the first position in rank, C/V had the second position, feed rate had third, percentage concentration had fourth, and the cutting velocity had the fifth position in rankings, respectively. Alternative 2, aspect ratio C/F has first, aspect ratio V/F has second, feed rate, percentage concentration, and cutting velocity have third, fourth and fifth positions in ranking, respectively. In alternative 3, aspect ratio V/C, percentage concentration, aspect ratio F/C, feed rate, and cutting velocity simultaneously have first, second, third, fourth and fifth positions. The list of rankings goes on and on. At the same time, these rankings reveal the order of importance and how beneficial individual factor is; while considering the economic aspect of the cutting parameters. While trying to reduce the number of tables, the complete table of the factors across the alternatives of the standard and aspect ratios with their corresponding ranks is thus presented in Table 6.

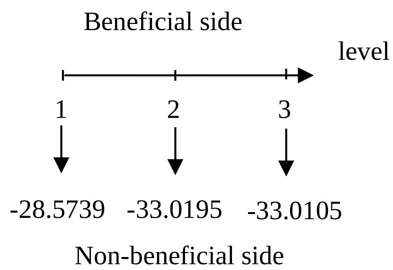

Fig. 2a. Present worth for parameter C.

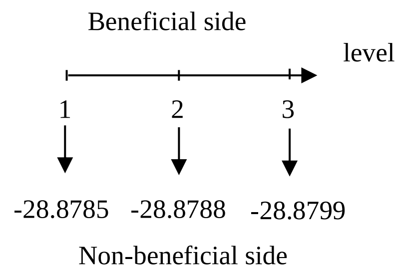

Fig. 2b. Present worth for parameter V.

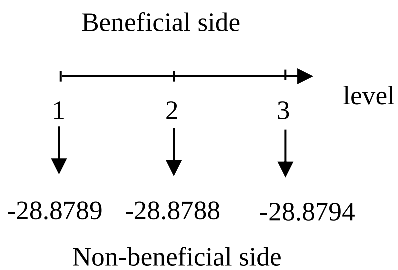

Fig. 2c. Present worth for parameter F.

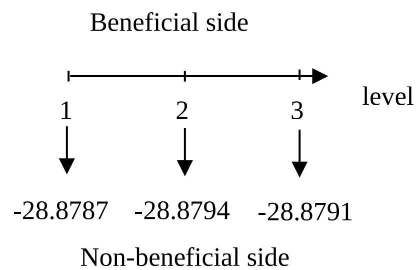

Fig. 2d. Present worth for parameter C/V.

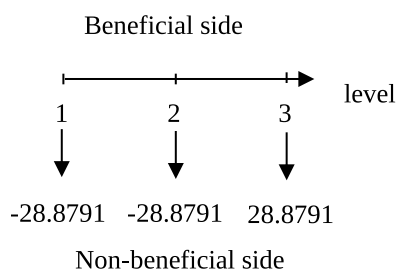

Fig. 2e. Present worth for parameter F/V.

Table 5. Present worth analysis table for alternative one of the aspect ratios.

Description	PW_C	PW_V	PW_F	$PW_{C/V}$	$PW_{F/V}$
Present worth values	-219.2003	-231.6717	-219.1990	-219.1986	-219.1981
Ranks	4	5	3	2	1

Table 6 summarizes the results when Equation (1a) was applied. Since the data obtained from Adegoke et al. (2022), which had optimized the direct and indirect parameters were used, the method described in case 1 is said to be an integrated Taguchi method and the present worth method. To further analyze the results, an effort was made to evaluate the global rank of the parameters for each alternative. It is understood that it is a rough rank result since for each combination of parameters with an initial three common direct parameters the indirect parameters vary widely and the rank for a combination of five parameters, which were averaged for alternatives as 1 to 6 and then alternatives 7 to 12 are therefore roughly estimated. It is through that that conclusions reached from this analysis are merely approximate and not precise. Therefore, the errors expected from these results may not be significant. Now, computing the marks of factors in each of the alternatives in a global sense, each of the factors had its ranks originally converted to 3 numbers. Therefore, each of these numbers was summed and the averages were obtained. For instance, the sum of 18, 30, 21, 10, 10, 3, 5, 2, 3 and 3 was obtained for each of the parameters namely C, V, F, C/V, F/V, 1/C, 1/V, 1/F, C/V and F/V, respective averages of 3, 5, 4, 2, 2, 3, 5, 2, 3 and 3. Now considering the interest rate, it affected the factors, while some factors are affected significantly (positively), others are not significantly affected. Considering Table 6, the factors C/V, F/V and 1/F are sensitive to the interest rate and therefore preferred because of their positions in ranks (second). However, the worst factors are V and 1/V, which are not sensitive to the interest rate. Furthermore, it is known that interest rates for different loan categories are influenced by several factors. While it is noted that three periods of analysis are considered, the credit risk, and tax consideration might have varied even for the same factor analyze each time. If for the first computational period, the loan was sourced from a particular bank and between this first computational period and the second one, there is a chance in management, the new management may change the source of borrowing and the organization patronized has its own tax consideration and credit risk policy, which may affect how much they set their interest rate at within the room of government set limitations. Therefore, this issue might be attributed to the poor performance of others, besides, it should be noted that the explanation given for Table 6 (case 1) is also applicable in certain regards to other cases. However, in other cases, inflationary effects are introduced, which are affected by marketing forces.

Table 6. Complete table of rankings of the economic parameters across the twelve alternatives.

Alternative 1	C 4th	V 5th	F 3rd	C/V 2nd	F/V 1st	Alternative 7	1/C 2nd	1/V 5th	1/F 1st	C/V 4th	F/V 3rd
Alternative 2	C 4th	V 5th	F 3rd	C/F 1st	V/F 2nd	Alternative 8	1/C 3rd	1/V 5th	1/F 2nd	C/F 4th	V/F 1st
Alternative 3	C 2nd	V 5th	F 4th	V/C 1st	F/C 3rd	Alternative 9	1/C 3rd	1/V 5th	1/F 2nd	V/C 1st	F/C 4th
Alternative 4	C 2nd	V 5th	F 4th	V/C 1st	F/V 3rd	Alternative 10	1/C 3rd	1/V 5th	1/F 2nd	V/C 1st	F/V 4th
Alternative 5	C 4th	V 5th	F 3rd	F/C 2nd	F/V 1st	Alternative 11	1/C 2nd	1/V 5th	1/F 1st	F/C 4th	F/V 3rd
Alternative 6	C 2nd	V 5th	F 4th	C/V 3rd	C/F 1st	Alternative 12	1/C 2nd	1/V 5th	1/F 1st	C/V 3rd	C/F 4th

4.2. Case 2 - Determining the present worth evaluation when the economic factor of the current interest rate in Nigeria is being put into consideration to study the engineering economics effect on the turning operation

The Central Bank of Nigeria (CBN) declares the interest rate as 11.5% as of January 2020, which is used in this work. The interest rate is used as a multiplier of the signal-to-noise ratios of the whole experimental run. This interest-rated signal-to-noise ratio is thus presented in Table 7 here below. Afterwards, another response evaluation is extracted from the experimental analysis in Table 7, following the readily known procedure of obtaining a response table described by Adegoke et al. (2022). The deltas values help obtain the ranks and the optimal parametric setting, as shown in Table 8.

Table 7. Taguchi experimental analysis with interest rated signal to noise ratios.

	C	V	F	C/V	F/V	SNR	*i* (SNR)		C	V	F	C/V	F/V	SNR	*i* (SNR)
1	1	1	1	1	1	-25.0517	-2.8810	15	2	2	3	1	3	-28.5737	-3.2860
2	1	1	1	1	2	-25.0517	-2.8810	16	2	3	1	2	1	-33.0104	-3.7962
3	1	1	1	1	3	-25.0517	-2.8810	17	2	3	1	2	2	-33.0104	-3.7962
4	1	2	2	2	1	-28.5734	-3.2860	18	2	3	1	2	3	-33.0104	-3.7962
5	1	2	2	2	2	-28.5734	-3.2860	19	3	1	3	2	1	-25.0543	-2.8813
6	1	2	2	2	3	-28.5734	-3.2860	20	3	1	3	2	2	-25.0543	-2.8813
7	1	3	3	3	1	-33.0103	-3.7962	21	3	1	3	2	3	-25.0543	-2.8813
8	1	3	3	3	2	-33.0103	-3.7962	22	3	2	1	3	1	-28.5746	-3.2861
9	1	3	3	3	3	-33.0103	-3.7962	23	3	2	1	3	2	-28.5746	-3.2861
10	2	1	2	3	1	-25.0523	-2.8810	24	3	2	1	3	3	-28.5746	-3.2861
11	2	1	2	3	2	-25.0523	-2.8810	25	3	3	2	1	1	-33.0107	-3.7962
12	2	1	2	3	3	-25.0523	-2.8810	26	3	3	2	1	2	-33.0107	-3.7962
13	2	2	3	1	1	-28.5737	-3.2860	27	3	3	2	1	3	-33.0107	-3.7962
14	2	2	3	1	2	-28.5737	-3.2860								

Key: i is 0.115

Table 8. Response evaluation of Taguchi experimental analysis.

Levels	C	V	F	C/V	F/V
1	-3.3210	-2.8811	-3.3211	-3.3211	-3.3211
2	-3.3211	-3.2860	-3.3211	-3.3211	-3.3211
3	-3.3212	-3.7962	-3.3211	-3.3211	-3.3211
Delta values	0.0002	0.9151	7.29E-05	7.7816E-05	1.38E-09
Ranks	2	1	4	3	5
OPS	$C_1V_1F_2C/V_1F/V_1$				

From Table 8, the cutting velocity has the first position in rank, and this means that the factor is the best among others, while 40m/mm of cutting velocity is a beneficial economic factor of the turning operation followed by 0.25% of percentage concentration, 0.17mm/rev of feed rate, etc.

The response table is further illustrated in pictorial views for simplicity and understanding, thus being presented in the following Figures. The performance flow diagram to obtain PW_C, PW_V, PW_F, $PW_{C/V}$, *and* $PW_{F/V}$ are in Figs. 3a, b, c, d, and e, respectively.

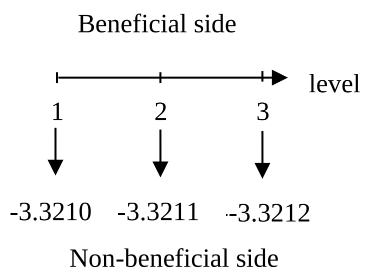

Fig. 3a. Present worth for parameter C

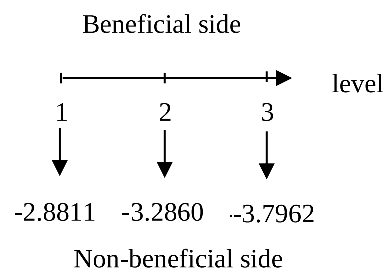

Fig. 3b. Present worth for parameter V

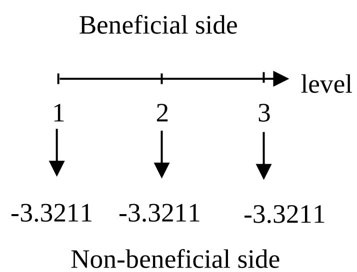

Fig. 3c. Present worth for parameter F.

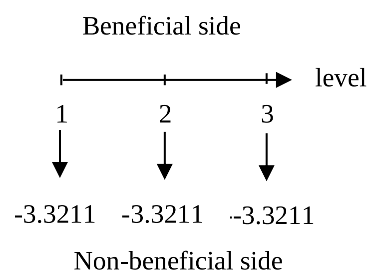

Fig. 3d. Present worth for parameter C/V.

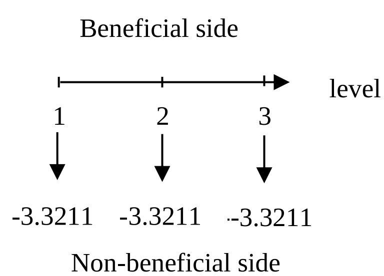

Fig. 3e. Present worth for parameter F/V.

Furthermore, the present worth formula for interest rate $PW = L(1+i)^{-n}$ based on levels are used as multipliers of the response evaluation in Table 7. For illustration, 0.8969*(-3.3210) = -17.8715 at level 1, 1.7933*(-3.3211) at level 2 and 2.6905*(-3.3212) at level 3. The complete set is revealed in Table 9.

Table 9. Present worth analysis table for alternative one of the aspect ratios.

Factors	PW_C	PW_V	PW_F	$PW_{C/V}$	$PW_{F/V}$
Values	-17.8715	-18.6921	-17.8714	-17.8714	-17.8713
Ranks	3	5	2	4	1

There is a drastic change in the rankings between the Taguchi experimental response evaluation and the present worth evaluation. In this aspect, the aspect ratios of feed rate to cutting velocity are ranked first, followed by the feed rate as second, then the percentage concentration as third, aspect ratios of percentage concentration to cutting velocity as fourth, and lastly, cutting velocity as fifth. The rankings show how important or how beneficial the parameter is to the economic aspect of turning operation. The analysis of this work comprises twelve alternatives, and the rankings of economic parameters between these alternatives are to be compared with each other. Hereunder is the comprehensive table that shows the comparison, Table 10.

Table 10. Rankings of the economic parameters across the twelve alternatives.

Alternative 1	C 3rd	V 5th	F 2nd	C/V 4th	F/V 1st	Alternative 7	1/C 2nd	1/V 5th	1/F 1st	C/V 4th	F/V 3rd
Alternative 2	C 1st	V 4th	F 2nd	C/F 3rd	V/F 5th	Alternative 8	1/C 2nd	1/V 2nd	1/F 1st	C/F 3rd	V/F 4th
Alternative 3	C 1st	V 4th	F 2nd	V/C 3rd	F/C 5th	Alternative 9	1/C 3rd	1/V 5th	1/F 2nd	V/C 1st	F/C 4th
Alternative 4	C 2nd	V 5th	F 4th	V/C 1st	F/V 3rd	Alternative 10	1/C 3rd	1/V 5th	1/F 2nd	V/C 1st	F/V 4th
Alternative 5	C 3rd	V 4th	F 2nd	F/C 2nd	F/V 1st	Alternative 11	1/C 2nd	1/V 5th	1/F 1st	F/C 4th	F/V 3rd
Alternative 6	C 2nd	V 4th	F 1st	C/V 1st	C/F 3rd	Alternative 12	1/C 2nd	1/V 4th	1/F 1st	C/V 3rd	C/F 5th

In alternatives 2 and 3, percentage concentration has the first rank, feed rate has the second, aspect ratio C/F and V/C has the third rank, cutting velocity has the fourth rank, while aspect ratios V/F and F/C has the fifth rank, and list goes on and on.

Table 10 is a summary of the results when Equation (1a) together with the signal-to-noise ratios of the parameters is considered. To further analyze the results, an effort was made to assess the global rank of the parameters considering each alternative of ranks. Now computing the ranks of factors in each of these alternatives globally, each factor had its ranks converted to members. Therefore, each of these members was summed and the averages were obtained. For instance, the sum of 12, 26, 13, 14, 18, 14, 26, 8, 16 and 23 was obtained for each of the parameters namely C, V, F, C/V, F/V, 1/C, 1/V, 1/F, C/V and F/V, respectively, to yield the respective averages of 2, 3, 2, 2, 3, 2, 4, 1, 3 and 4. Now considering the interest rate, it affected the factors. While some factors are affected significantly in a positive manner, others are not significantly affected. By considering Table 10, the factor 1/F, which attains a rank of 1 is the most sensitive to the interest rate. Besides, with an interest rate, it is known that credit risk and tax considerations might have significantly affected the results. Furthermore, the factors V, 1/V and F/V are not sensitive.

4.3. Case 3 – Determine Signal to noise ratios (with inflation factor), optimal parametric setting, and present worth value

The smaller, the better: SNR = β [-10log1/n∑y^2] where n is the sample size, and β is the inflationary rate. In this case, the current Nigerian inflationary rate is given preference in analyzing the signal-to-noise ratios, and its response evaluation was obtained using the already-known Taguchi method. The analysis is thus presented in Table 11.

Table 11. Taguchi SNR analysis with inflationary factor consideration.

Sr. No.	C	V	F	C/V	F/V	SNR	B	β (SNR)
1	1	1	1	1	1	-25.0517	0.156	-3.9081
2	1	1	1	1	2	-25.0517	0.156	-3.9081
3	1	1	1	1	3	-25.0517	0.156	-3.9081
4	1	2	2	2	1	-28.5734	0.156	-4.4575
5	1	2	2	2	2	-28.5734	0.156	-4.4575
6	1	2	2	2	3	-28.5734	0.156	-4.4575
7	1	3	3	3	1	-33.0103	0.156	-5.1496
8	1	3	3	3	2	-33.0103	0.156	-5.1496
9	1	3	3	3	3	-33.0103	0.156	-5.1496
10	2	1	2	3	1	-25.0523	0.156	-3.9082
11	2	1	2	3	2	-25.0523	0.156	-3.9082
12	2	1	2	3	3	-25.0523	0.156	-3.9082
13	2	2	3	1	1	-28.5737	0.156	-4.4575
14	2	2	3	1	2	-28.5737	0.156	-4.4575
15	2	2	3	1	3	-28.5737	0.156	-4.4575
16	2	3	1	2	1	-33.0104	0.156	-5.1496
17	2	3	1	2	2	-33.0104	0.156	-5.1496
18	2	3	1	2	3	-33.0104	0.156	-5.1496
19	3	1	3	2	1	-25.0543	0.156	-3.9085
20	3	1	3	2	2	-25.0543	0.156	-3.9085
21	3	1	3	2	3	-25.0543	0.156	-3.9085
22	3	2	1	3	1	-28.5746	0.156	-4.4576
23	3	2	1	3	2	-28.5746	0.156	-4.4576
24	3	2	1	3	3	-28.5746	0.156	-4.4576
25	3	3	2	1	1	-33.0107	0.156	-5.1497
26	3	3	2	1	2	-33.0107	0.156	-5.1497
27	3	3	2	1	3	-33.0107	0.156	-5.1497

Table 12. Response evaluation of Taguchi experimental analysis.

Levels	C	V	F	C/V	F/V
1	-4.5051	-3.9082	-4.5051	-4.5051	-4.5051
2	-4.5051	-4.4575	-4.5051	-4.5052	-4.5051
3	-4.5053	-5.1496	-4.5052	-4.5051	-4.5051
Delta values	0.0002	1.2414	9.89E-05	0.0001	1.87E-09
Ranks	2	1	4	3	5
OPS	$C_1V_1F_2C/V_1F/V_1$				

From the response analysis, 40m/mm of cutting velocity is the best parameter of the machining operation because it's ranked first with level one optimal parametric setting. The percentage concentration is ranked second, with 0.25% as the optimum value of the operation. The aspect ratio of percentage concentration to cutting velocity had the third rank, with 0.00625%mm/m as the optimal parametric value. The feed rate parameter had the fourth rank with 0.17mm/rev optimal parametric value and an aspect ratio of feed rate to cutting velocity with 0.0035mm^2/rev.m optimal parametric value. The response table is further illustrated in pictorial views for simplicity and understanding, thus being presented in the following Figures.

The performance flow diagram to obtain PW_C, PW_V, PW_F, $PW_{C/V}$, *and* $PW_{F/V}$ are in Figs. 4a, b, c, d, and e, respectively.

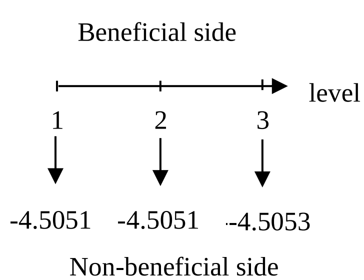

Fig. 4a. Present worth for parameter C.

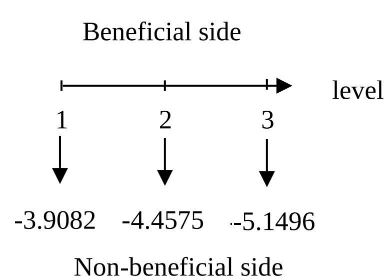

Fig. 4b. Present worth for parameter V.

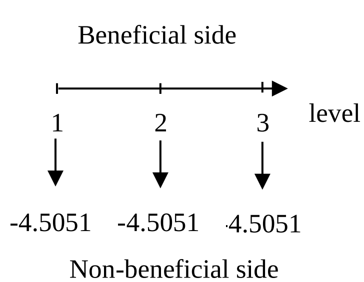

Fig. 4c. Present worth for parameter F.

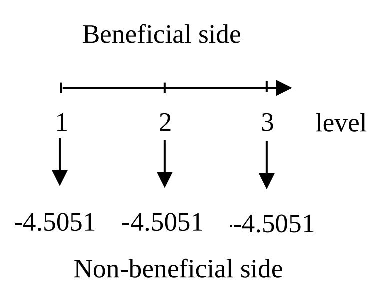

Fig. 4d. Present worth for parameter C/V.

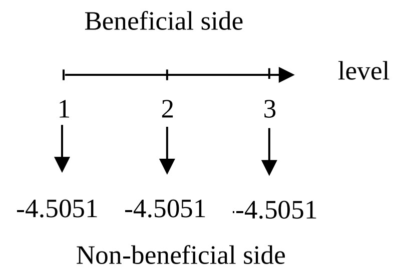

Fig. 4e. Present worth for parameter F/V.

We apply Equation (2) to the data, where *L* represents the response value of each level obtained from Taguchi response analysis, *β* represents the value of the current inflationary factor in Nigeria and *n* represents the number of levels. The current inflationary factor in Nigeria, which is 0.156, is used as a multiplier of each value of the Taguchi response analysis. Afterwards, Table 13 is obtained.

Table 13. Present worth analysis for the inflationary factor of alternative one of the aspect ratios.

Factors	PW_C	PW_V	PW_F	$PW_{C/V}$	$PW_{F/V}$
Values	-18.1879	-18.4299	-18.1879	-18.1879	-18.1879
Ranks	1	2	1	1	1

The ranking of the results remains the same for parameters; percentage concentration, feed rate, aspect ratios of percentage concentration to cutting velocity, and feed rate to cutting velocity. They all had the same present worth value and were ranked first in the analysis, other than the cutting velocity that is ranked second. This means that those parameters ranked first had economic influences compared to other rankings, Table 14.

Table 14. Rankings of the economic parameters of inflationary factors across the twelve alternatives.

Alternative 1	C 1st	V 2nd	F 1st	C/V 1st	F/V 1st	Alternative 7	1/C 2nd	1/V 4th	1/F 1st	C/V 5th	F/V 3rd
Alternative 2	C 1st	V 2nd	F 1st	C/F 1st	V/F 3rd	Alternative 8	1/C 1st	1/V 1st	1/F 1st	C/F 2nd	V/F 3rd
Alternative 3	C 2nd	V 5th	F 4th	V/C 1st	F/C 3rd	Alternative 9	1/C 3rd	1/V 5th	1/F 2nd	V/C 1st	F/C 4th
Alternative 4	C 2nd	V 5th	F 4th	V/C 1st	F/V 3rd	Alternative 10	1/C 3rd	1/V 5th	1/F 2nd	V/C 1st	F/V 4th
Alternative 5	C 1st	V 2nd	F 1st	F/C 1st	F/V 1st	Alternative 11	1/C 2nd	1/V 4th	1/F 1st	F/C 5th	F/V 3rd
Alternative 6	C 2nd	V 4th	F 1st	C/V 1st	C/F 3rd	Alternative 12	1/C 2nd	1/V 3rd	1/F 1st	C/V 4th	C/F 5th

Table 14 summarizes the results when Equation (1b) together with the optimal parametric setting is considered. To further analyze the results, an effort was made to assess the global rank of the parameters similarly to cases 1 and 2. Now computing the ranks of factors in each of these alternatives globally, each factor had its ranks converted to members. Therefore, each of these numbers was summed and the averages were obtained. For instance, the sum of 9, 20, 12, 6, 14, 14, 13, 22, 9, 18 and 22 was obtained for each of the parameters namely C, V, F, C/V, F/V, 1/C, 1/V, 1/F, C/V and F/V, respectively, to yield the respective averages of 2, 3, 2, 1, 2, 2, 4, 2, 3 and 4. Now, considering the inflation factor, affected the factors. While some factors are affected significantly in a positive manner, others are not significantly affected. By considering Table 14, factor C/V, which attains a rank of 1 is the most sensitive to the inflation factor. Besides, factors 1/V and F/V are not sensitive to the inflation rate.

4.4. Case 4 - Determining the present worth evaluation considering only the optimal parametric settings {parametric values} across all the alternatives considered in this present work

The present worth comprises of interest rate with inflation factor. Here, $PW_{C}/_{CV}/_{FR}/_{C/V}/_{F/V}$ is the present worth, L represents the parameter's value at particular levels, n is the parameter's level, and β is the inflationary factor. The response table of Adegoke and Oke (2022) is used to obtain this. The latest customer price index report by the National Bureau of Statistics (NBS) has shown that Nigeria's inflation rate reversed back to its pre-December levels after dropping to 15.6% in January 2022. The statement depicts that the inflationary rate as of January 2022 is 15.6%. In addition, recall that the current interest rate in Nigeria as of January 2022 is 11.5%. These interest rates and inflationary factors are used to obtain the present worth of the optimal parametric values. The results obtained for the present worth values were rated in rankings, done through the alternatives. This aspect considers all the optimal parametric settings across all the twelve alternatives. At the same time, the interest rate and inflationary factor are multipliers of the optimal parametric values through the aspect ratio analysis. Afterwards, the obtainable results were compared in ranking formats with relevant discussions.

We apply Equation (3) to the data, where L represents the response value of each level obtained from Taguchi response analysis, i represents the current interest rate in Nigeria, β represents the current inflationary factor in Nigeria and n represents the number of levels. Both current interest rates coupled with inflationary factors in Nigeria, which are 0.115 and 0.156, respectively, were used as multipliers of each value of the Taguchi response analysis. Afterwards,

Table 15 is obtained. By illustration, PW_{C1} = [-28.8785 $(1+0.115)^{-1}$) $(1+0.156)^{1}$] = -29.9404. By following this computational approach, PW_{CV1}, PW_{FR1}, $PW_{C/V1}$, and $PW_{F/V1}$ are obtained as -25.9740, -69.2230, -29.9406, and -29.9410, respectively, Table 15.

Table 15. Present worth evaluation of the optimal parametric setting.

	PW_C	PW_V	PW_F	$PW_{C/V}$	$PW_{F/V}$
PW values	-29.9404	-25.974	-69.223	-29.9406	-29.9409731
Ranks	2	1	5	3	4

Table 16. Complete table of rankings of the present worth of the optimal parametric settings across the twelve alternatives.

Alternative 1	C 2nd	V 1st	F 5th	C/V 3rd	F/V 4th	Alternative 7	1/C 4th	1/V 1st	1/F 3rd	C/V 2nd	F/V 5th
Alternative 2	C 4th	V 3rd	F 5th	C/F 1st	V/F 2nd	Alternative 8	1/C 5th	1/V 3rd	1/F 4th	C/F 2nd	V/F 1st
Alternative 3	C 4th	V 1st	F 2nd	V/C 3rd	F/C 5th	Alternative 9	1/C 4th	1/V 1st	1/F 3rd	V/C 2nd	F/C 5th
Alternative 4	C 1st	V 2nd	F 4th	V/C 5th	F/V 3rd	Alternative 10	1/C 4th	1/V 1st	1/F 3rd	V/C 2nd	F/V 5th
Alternative 5	C 2nd	V 1st	F 5th	F/C 3rd	F/V 4th	Alternative 11	1/C 4th	1/V 1st	1/F 3rd	F/C 2nd	F/V 5th
Alternative 6	C 3rd	V 1st	F 5th	C/V 4th	C/F 2nd	Alternative 12	1/C 5th	1/V 2nd	1/F 4th	C/V 3rd	C/F 1st

Table 16 summaries. The results when present worth and optimal parametric setting using the Taguchi method are considered. To further analyze the results, each of the numbers representing the factors in their direct and indirect forms was summed and the averages were obtained. For instance, the sum of 15, 9, 26, 19, 20, 26, 9, 20, 13 and 22 was obtained for each of the parameters, namely C, V, F, C/V, F/V, 1/C, 1/V, 1/F, C/V and F/V, respectively, to yield the respective averages of 3, 2, 4, 3, 3, 4, 2, 3, 2, and 4. Now considering the present worth factors, which contain interest rate, the factors that are sensitive to the method are V, I/V, and C/V, which attain the second position. However, the factors F, 1/C and F/V are not sensitive to the method.

4.5. Case 5 - Determining the present worth related S/N ratios (with interest rate and inflation factor), optimal parametric setting, present worth evaluation, and rankings

This case combined the effect of interest rate and inflationary factor on the signal-to-noise ratio and the present worth analysis. The interest rate and inflationary factor multiply the ordinary Taguchi signal-to-noise ratio to obtain another set of signals-to-noise ratios, as shown in Table 17.

Table 17. Taguchi SNR analysis (with interest rate and inflationary factor) consideration.

	C	V	F	C/V	F/V	SNR	β	i	SNR (β_i)
1	1	1	1	1	1	-25.0517	0.156	0.115	-0.4494
2	1	1	1	1	2	-25.0517	0.156	0.115	-0.4494
3	1	1	1	1	3	-25.0517	0.156	0.115	-0.44943
4	1	2	2	2	1	-28.5734	0.156	0.115	-0.5126
5	1	2	2	2	2	-28.5734	0.156	0.115	-0.5126
6	1	2	2	2	3	-28.5734	0.156	0.115	-0.5126
7	1	3	3	3	1	-33.0103	0.156	0.115	-0.5922
8	1	3	3	3	2	-33.0103	0.156	0.115	-0.5922
9	1	3	3	3	3	-33.0103	0.156	0.115	-0.5922
10	2	1	2	3	1	-25.0523	0.156	0.115	-0.4494
11	2	1	2	3	2	-25.0523	0.156	0.115	-0.4494
12	2	1	2	3	3	-25.0523	0.156	0.115	-0.4494
13	2	2	3	1	1	-28.5737	0.156	0.115	-0.5126
14	2	2	3	1	2	-28.5737	0.156	0.115	-0.5126
15	2	2	3	1	3	-28.5737	0.156	0.115	-0.5126
16	2	3	1	2	1	-33.0104	0.156	0.115	-0.5922
17	2	3	1	2	2	-33.0104	0.156	0.115	-0.5922
18	2	3	1	2	3	-33.0104	0.156	0.115	-0.5922
19	3	1	3	2	1	-25.0543	0.156	0.115	-0.4495
20	3	1	3	2	2	-25.0543	0.156	0.115	-0.4495
21	3	1	3	2	3	-25.0543	0.156	0.115	-0.4495
22	3	2	1	3	1	-28.5746	0.156	0.115	-0.5126
23	3	2	1	3	2	-28.5746	0.156	0.115	-0.5126
24	3	2	1	3	3	-28.5746	0.156	0.115	-0.5126
25	3	3	2	1	1	-33.0107	0.156	0.115	-0.5922
26	3	3	2	1	2	-33.0107	0.156	0.115	-0.5922
27	3	3	2	1	3	-33.0107	0.156	0.115	-0.5922

Table 18. Response evaluation of Taguchi experimental analysis.

Levels	C	V	F	C/V	F/V
1	-0.5181	-0.4495	-0.5181	-0.5181	-0.5181
2	-0.5181	-0.5126	-0.5181	-0.5181	-0.5181
3	-0.5181	-0.5922	-0.5181	-0.5181	-0.5181
Delta values	2.46E-05	0.1428	1.14E-05	1.21E-05	2.15E-10
Ranks	2	1	4	5	3
Optimal parametric setting: $C_1V_1F_1C/V_1F/V_1$					

After which the response evaluation was obtained, the cutting velocity gives the best response with 40 m/mm of this parameter is beneficial to economically optimize the cutting parameter, followed by percentage concentration with 0.25% of this parameter is beneficial for the turning operation economically. Then, the aspect ratio of feed rate to cutting velocity with 0.0035mm^2/rev.m as the beneficial economic parameter, followed by feed rate with 0.14mm/rev as the beneficial economic parameter, and lastly, the aspect ratio of percentage concentration to cutting velocity with 0.00625%.mm / m, which is the beneficial economic value of the cutting process.

The performance flow diagram to obtain PW_C, PW_V, PW_F, $PW_{C/V}$, and $PW_{F/V}$ are in Figures 5a, 5b, 5c, 5d, and 5e, respectively.

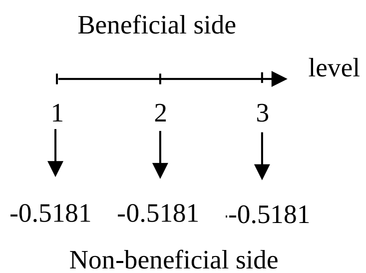

Fig. 5a. Present worth for parameter C.

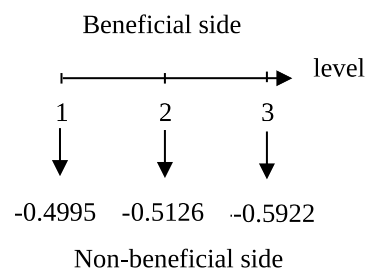

Fig. 5b. Present worth for parameter V.

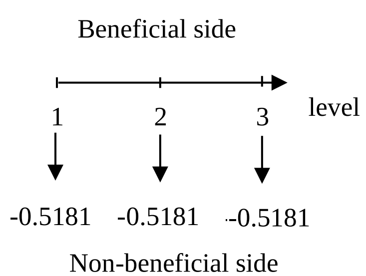

Fig. 5c. Present worth for parameter F

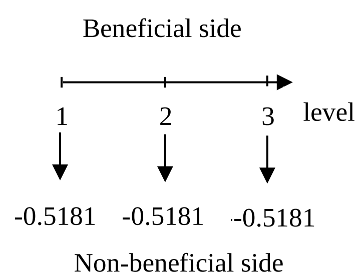

Fig. 5d. Present worth for parameter C/V

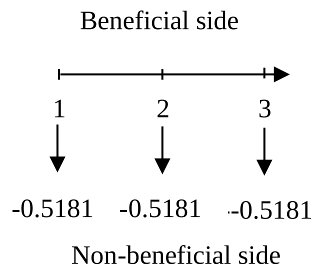

Fig. 5e. Present worth for parameter F/V.

We apply Equation (3) to the data, where L represents the response value of each level obtained from Taguchi response analysis, i represents the current interest rate in Nigeria, β represents the current inflationary factor in Nigeria and n represents the number of levels. Both current interest rates coupled with inflationary factors in Nigeria, which are 0.115 and 0.156, respectively, were used as multipliers of each value of the Taguchi response analysis expressed in Table 18 and were later added together in the order of the parametric levels. The parametric value per level is the present worth value of each parameter. Afterwards, Table 19 is obtained.

Table 19. Present worth analysis table for the inflationary factor of alternative one of the aspect ratios.

Factors	PW_C	PW_V	PW_F	$PW_{C/V}$	$PW_{F/V}$
Values	-3.93245	-4.15619	-3.93243	-3.93242	-3.93241
Ranks	4	5	3	2	1

Table 19 shows the summary of the results only considering alternative 1. In this case, F/V is the most sensitive factor while V is the most insensitive factor.

5. CONCLUSIONS

In the present competitive world of component manufacturing for automotive and aerospace industries, new performance enhancement strategies are needed to continuously overcome the conventional challenges of manufacturing, such as extended product lifecycle, high surface integrity of products, minimized environmental impacts from products and processes, enhanced production rate, high product quality, and component accuracy. The Taguchi method is a performance optimization strategy that is best appropriate for the turning operation in the machining of Inconel X750 alloy subjected to a lubricated environment. However, it is rare to find methods that integrate the economic aspects with the Taguchi method in the turning operations domain. More surprising is the complete absence of a mechanism to identify the most important parameters to focus resources on while implementing the optimization scheme.

Furthermore, this article is concerned with the combined economic and optimization characteristics of X750 alloy during the cutting process, where the cutting operation was performed under a lubricated scheme where Al_2O_3 nanoparticles were randomly dispersed in liquid coconut oil and applied to the cutting process to reduce the temperature during cutting, control heat generation and promote high-quality surface finish of the cutting process. Although super alloys such as TMS alloys, Inconel, MP98T, Hastelloy, CMSX single crystal alloys, Rene alloys, Waspaloy, and Incoloy have traditionally been analyzed and optimized with the Taguchi method in mind, the idea of economic methods have been extended to super alloys, which is the focus of the present study and is benefiting from such economic methodical application in this work is X750 alloy. Characteristically known to have been built to resist high temperatures with no deformation and creep, the X750 is a nickel-chromium alloy, which is precipitation-hardenable through the aluminum and titanium elemental additions. The X750 alloy demonstrates superior confrontation to corrosion and oxidation and elevated tensile characteristics up to 70°C of temperature. Because of the technical significance of the superalloys, their cutting characteristics during machining have been largely investigated; however, most of the research is associated with the optimization of these superalloys; their economic aspect or the optimization-economic (optim-eco) concerns are not fully addressed. Thus, the present study was undertaken to analyze the optim-eco concerns of the X750 alloy while cutting in a lubricated environment. The optimal-eco attributed to the X750 alloy is evaluated, and efforts are made to understand their implications in practice. Five cases, viz, present north evaluation, present north with interest factor, signal-to-noise ratios with present north values, present north to signal-to-noise ratios, interest rate and inflation factor, and present worth with optimal parametric settings. A detailed study of the above fire cases was conducted, and a comparison was made among cases. The following are the major conclusions of the study:

1. In determining the present worth of the turning operation while considering only the primary result obtained from the experimental data containing the direct factors and aspect ratios. Since the analysis excludes Taguchi results, it requires no response table, and the analysis may be shown in pictorial representation.
2. The parameters C, CV, FR, C/V, and F/V of the turning process for the Inconel X750 alloy exhibited increased values with growth in the level of the parameters on the non-beneficial side of the scale. This is due to the changing system capacity, which could accommodate more of the system's parameters compared to the use of smaller machines.
3. The present worth evaluation for the Taguchi experimental run with interest rate exhibited an extremely marginal increase for the parameters C, CV, FR, C/V, and F/V of the turning process for the Inconel X750 alloy when the increasing level was considered. The main reason is the effect of interest rates, which drastically reduced the performance of the parameters. The magnitude of the values of C, CV, FR, C/V, and F/V for the turning operation was close to six times reduction. This reveals that the interest rate greatly impacts the performance of the parameters during the turning operation.
4. The S/N ratios, optimal parametric settings, and present worth with inflation factor showed a greatly reduced but slightly improved performance than the present worth evaluation for the Taguchi experimental run with interest rate. The principal reason is the influence of the present worth and inflation factor, which greatly reduces the performance of the

parameters. The magnitude of C, CV, FR, C/V, and F/V for the turning operation was as close to about five times the value.

5. The S/N ratios (with interest rate and inflation factor) and optimal parametric setting revealed a rare but extremely reduced performance, but the results of the independently considered inflation factor and interest rate revealed better performance than the present results. The main reason is the effect of the combined interest rate and inflation factor on the performance of the parameters. However, compared to the present worth evaluation alone, the present results are more than ten times worse.
6. For the present worth evaluation of inflationary factors (Table 6) and considering the ranking order of parameters, namely C, F, C/V, F/V, C/F, V/C, F/C, 1/F, and 1/C, for all the twelve alternative combinations, the first position attained by each of the mentioned parameters are C with 3/12 alternative, F with 4/12 alternative, C/V with 2/12 alternative, F/V with 2/12 alternative, C/F with 1/12 alternative, V/C with 4/12 alternative, F/C with 1/12 alternative, 1/F with 4/12 alternative and 1/C with 1/12 alternative. The equivalence of this result is 25% for C, 33% for F, 17% for C/V, 17% for F/N, 8% for C/F, 33% for V/C, 8% for F/C, 33% for 1/F, and 8% for 1/C.
7. For the present worth evaluation of inflationary factors (Table 6) and considering the ranking order of parameters, namely C, F, C/V, F/V, C/F, V/C, F/C, 1/F, and 1/C, for all the twelve alternative combinations, the last position (5^{th}) being the worst parametric performance attained by each of the parameters mentioned above are as follows. The parameters C, F, F/V, V/C, 1/F, and 1/C are excluded from the worst position (5^{th}), having performed better. The parameter V had the 5^{th} position in the 2/12 alternative, C/V in the 1/12 alternative, 1/V in the 2/12 alternative, F/C in the 1/12 alternative, and C/F in the 1/12 alternative. This is equivalent to 17% for V, 85% for C/V, 17% for 1/V, 8% for F/C, and 8% for C/F.
8. For the present worth evaluation (Table 13) and considering the ranking order of parameters, namely F/V, C/V, F, C, V, C/F, V/F, V/C, F/C, 1/F, 1/C, and 1/V for all the twelve alternative combinations, the first position attained by each of the mentioned parameters are F/V with 2/12 alternative, C/F with 2/12 alternative, V/C with 5/12 alternative and 1/F with 3/12 alternative. The result equivalence is 17% for F/V, 17% for C/F, 42% for V/C, and 25% for 1/F.

9. For the present evaluation (Table 14) and considering the ranking order of parameters, the authors reflected on the worst-performing parameters (5^{th} position) and noted the following. The parameters F/V, C/V, F, C, C/F, V/F, V/C, F/C, 1/F and 1/C were excluded from the worst position (5^{th}) since they performed better than this status. However, parameters V and 1/V were the worst in performance, with 6/12 alternatives each from all the alternatives coming out as the worst performance for the respective parameters.
10. For the present worth evaluation (Table 10) and considering the ranking order of parameters, for all the twelve alternative combinations, the first position attained by each of the mentioned parameters are F/V with 2/12, C with 2/12, V/C with 3/12, F with 1/12, C/V with 1/12, 1/F with 3/12 and V/F with 1/12 alternative. The equivalence of the respective results are 17%, 17%, 25%, 8%, 8%, 25% and 8% for F/V, C, V/C, F, C/V, 1/F and V/F, respectively.
11. For the present worth evaluation (Table 10) and considering the ranking order of parameters, for the last position (5^{th}), each parameter's worst parametric performance is as follows. The parameter V had the 5^{th} position in the 2/12 alternative, V/F in the 1/12 alternative, F/C in the 1/12 alternative, 1/V in the 5/12 alternative, and C/F in the 1/12 alternative. The equivalence of these are 17%, 8%, 8%, 42% and 8% for V, V/F, F/C, 1/V and C/F, respectively.
12. For the present worth of the optimal parametric settings (Table 16) and considering the ranking order of parameters, for all the twelve alternatives, the first position attained by each of the mentioned parameters are V with 4/12 alternative, C/F with 2/12 alternative, C with 1/2 alternative, 1/V with 4/12 alternative, 1/V with 4/12 alternative, and V/F with 1/12 alternative. The equivalence of this result is 33%, 17%, 8%, 33%, and 8% for the respective parameters of V, C/F, C, 1/V, and V/F, respectively.
13. For the present worth of the optimal parametric setting (Table 16), and considering the ranking order of parameters for all the twelve alternatives, the last position (5^{th}), being the worst parametric performance attained by each of the parameters, the following are true. The parameter F had 5^{th} position in 4/12 (i.e., 33%) alternative, F/C had 2/12 (i.e., 17%) alternative, V/C had 1/12 (i.e., 8) alternative, F/V had 3/12 (i.e., 25%) alternative and 1/C had 2/12 (i.e., 17%) alternative.

In the future, studies focused on the use of more aspect ratios could be attempted. Also, aspect ratios involving squares, cubes, and reciprocals of squares and cubes could be used to test the method.

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