Management Science Letters 12 (2022) 153–164

Contents lists available at GrowingScience

Management Science Letters

homepage: www.GrowingScience.com/msl

# Selecting maintenance strategy in a combined cycle power plant: An AHP model utilizing BOCR technique

**Mohammad Ali Arjomandi[a*] and Behzad Mosallanezhad[b]**

[a]*Department of Maintenance, Abadan Oil Refining Co, Abadan, Iran*
[b]*Tecnológico de Monterrey, Escuela de Ingeniería y Ciencias, Puebla, México*

**C H R O N I C L E**

*Article history*:
Received: November 2, 2021
Received in revised format: December 10 2021
Accepted: February 19, 2022
Available online: February 21, 2022

*Keywords:*
*Maintenance Strategy Selection*
*AHP*
*BOCR*
*Power Plant*

**A B S T R A C T**

Maintenance philosophies and their activities have always been a major concern in industry. So, every industrial complex needs a clear and comprehensive maintenance plan to keep its equipment reliable and available. In this study, we proposed an AHP model combined with the BOCR method to select the most reliable maintenance strategy for a combined cycle power plant (GTG-HRSG). Five well-known maintenance alternatives including root cause analysis, condition-based maintenance, reliability-centered maintenance, run-to-failure and preventive maintenance are chosen to be evaluated by several experts from various departments of operation, planning and maintenance via three priorities of economic, technical and operation and 30 sub criteria and controls. Then, five different BOCR synthesize methods have been utilized to rank maintenance alternatives. The final result shows that four out of five synthesize methods have ranked RCA as the top maintenance strategy and RCM as second. In one other method, the rank of these two strategies is vice versa.



## 1. Introduction

In today's world, organizations are struggling with different aspects of volatility in the business atmosphere and they want to approach a higher level of competitive advantage using powerful tool such as maintenance and supply chain management (Mosallanezhad *et al*., 2021a; 2021b). The concept of maintenance has changed through recent decades from a labor-based activity to a cutting-edge scientific process. The cost of maintenance is one of the most significant expenses in an industrial complex annual bill. In addition, more expenses mean less profits, and in this competitive market every cent should be taken into account. So, the companies funded academics and maintenance professionals to find new methods for reducing and optimizing maintenance costs. MIT university has done research which illustrates companies in North America pay more than $200 billion annually for maintenance activities (Asuquo *et al*., 2019). Suffice it to say that the money which is spent on maintenance can rise up to 70% of total payments or sometimes be more than net profit (Özcan *et al*., 2019).

Technology plays an important role in developing maintenance strategies and notable prospers in technology allow experts to design more efficient programs. The existence of new maintenance approaches like CBM[1], RBI[2] and RCM[3] is undoubtedly related to advances which have taken place in computer science, data analysis, management and electronics. Nowadays, we are able to predict failures before they occur or eliminate the roots of critical damages by analyzing data and evidence. Safety,

[1] Condition-Based Maintenance
[2] Risk-Based Inspection
[3] Reliability Centered Maintenance

* Corresponding author.

E-mail address: mohammadaliarjomandi@gmail.com (M. A. Arjomandi)


doi: 10.5267/j.msl.2022.2.004

energy consumption, social impacts, the environment and government regulations are some of the concerns that must be paid attention to when a maintenance strategy is under consideration (Nezami, and Yildirim., 2013).

As it mentioned above, there are varieties of factors that should be taken into account to select the best maintenance program for a specific complex. So, it can be considered as a MCDM[4] problem (Alsyouf., 2004). Since 1970s which the first models of MCDM methods were introduced, this new way of solving sophisticated problems take attention of so many academics to develop or modify previous works or present new approaches in multi-criteria decision making that lead to some methodologies like AHP[5], ANP[6], DEMATEL[7] and VIKOR[8]. The MCDM models are utilized in different fields from industrial and engineering to social and political and also hybridized with several concepts such as fuzzy sets or rough numbers (Tahmasbi *et al*., 2021; Ahmadi *et al*., 2018). To have a closer look on the history of implementing MCDM methods in finding the best maintenance strategy, Shafiee (2015) is suggested.

BOCR technique, which was introduced by Saaty and Ozdemir (2003) in the early years of the 21$^{st}$ century, is an almost new method that can help decision makers to find the best option among various alternatives. This model is based on weighting benefits, opportunities, costs and risks for each option and then synthesizing scores mathematically. Where B and O are the representatives of optimistic factors that are defined as positive criteria and C and R have negative nature and represent undesired results (Gedela *et al*., 2018). One of the most complicated concepts in the decision process is how to deal with negative priorities, and the BOCR technique offers several methods to synthesize positive and negative aspects of different options.

Because of operational conditions like high pressure vessels, high temperature fluids, diversity of flammable, toxic and explosive petroleum products and materials, oil refineries are recognized as high-risk facilities among petroleum complexes (Zaranezhad *et al*., 2019). So, undoubtedly the importance of safety and environmental issues must be applied in every evaluation. Oil Refining units are obliged to raise production time to meet the needs, so for enhancing unit's reliability it is necessary to perform more scientific and effective maintenance (Zhao *et al*., 2019).

This study tries to find a maintenance alternative among five mentioned strategies that is the most proper program for a gas turbine generator combined with heat recovery steam generation unit (GTG-HRSG[9]) using a MCDM model combined with BOCR merits. Several surveys carried out before about improving maintenance processes by MCDM models, some in the industry sector, are mentioned in literature review. But, none of them have utilized BOCR technique in their study. So, an AHP model is proposed for sub criteria and control clusters, then five different synthesizing methods are used for final evaluation.

## 2. Literature Review

A brief survey on the previous papers illustrates the scarcity of works on BOCR technique mostly due to its novelty. The method was introduced in the early years of the 21st century and most of the following literature is conducted in its modification. Table 1 summarizes the related articles to the BOCR merits and MCDM solutions for various problems.

**Table 1**
Summary of some relevant prior studies about BOCR technique and MCDM problems.

| Reference | Summary |
|---|---|
| Saaty and Ozdemir (2003) | This study represented a novel way to synthesize both positive and negative priorities has been introduced. Dealing with negative priority has been always a significant problem in thinking fashion, so an AHP model was used to define benefits, opportunities, costs and risks of US-China trade conflict and find the best strategy for US congress to tackle this problem. Also, four formulas were introduced for combining BOCR merits. |
| Saaty (2004) | This study proposed an ANP model is used to prepare four sets of priorities which were the results of synthesizing weightings to sub criteria of each BOCR merits. The final outcome illustrates the best strategy that US should choose for trading with China. |
| Erdogmus *et al.* (2005) | This study introduced an ANP model to evaluate different alternatives for renewal of a transaction processing system using BOCR rating. Three main actors (management, contracted stores and members) which were effective in decision making were associated in evaluating. |
| Feglar *et al.* (2006) | This study mentioned the limits of SWOT framework in case of ICT and business issue, introducing an ANP-based BOCR model to tackle the problem. They integrated different techniques included BMM and BOCR with AHP-ANP models. |
| Wijnmalen (2007) | This study expressed the lack of accuracy of BOCR technique when reciprocal cost and risk values are used in an AHP/ANP model and represent a new approach. He showed that there are differences between the results, when different synthesize method (multiplicative, additive with subtraction and additive with reciprocals) is chosen. |
| Liang and Li (2008) | This study considering different factors of suppliers by a fuzzy AHP model in respect of BOCR merits. The proposed model is tested for TFT-LCD backlight supplier. |
| Lee (2009) | This study introduced a FAHP approach that includes BOCR theory to takes negative side into account, where the previous works have only focused on success essential elements in the relation between buyer and supplier. The model accuracy is verified in a TFT-LCD manufacturer company. |

[4] Multi-Criteria Decision Making
[5] Analytic Hierarchy Process
[6] Analytical Network Process
[7] Decision Making Trial and Evaluation Laboratory
[8] Viekriterijumsko Kompromisno Rangiranje
[9] Gas Turbine Generator-Heat Recovery Steam Generation

| Reference | Summary |
|---|---|
| Bouzarour-Amokrane *et al.* (2012) | This study proposed a new BOCR method to define and measure risk and opportunity where the prior works did not pay enough attention to ambivalent factors. A framework that consist of actors, objectives, alternatives, attributions and indicators is introduced. The final evaluating is done by implementing satisficing game theory and the data are aggregated by Choquet integral. |
| Bouzarour-Amokrane *et al.* (2013) | This study proposed a method to weight up and improve the procedure of reverse logistics for an aircraft firm in respect of sustainability issues. They used AHP method considered BOCR merits and satisficing game techniques to solve the problem. |
| Gedela *et al.* (2018) | This study introduced a novel efficient method which is an AHP-ANP model combined with BOCR merits to verify a real-world service oriented architecture (SOA) performance that effects on quality of service (QoS). |
| Tabatabaee *et al.* (2019) | This study proposed a method using EFDM to refine BOCR list and FDEMATEL to consider inner-dependencies between benefits, opportunities, costs and risks of green roof installation. The experts are chosen among Malaysian architect, civil engineer, contractor and landscape designer with academic or industrial background. |
| Bertolini *et al.* (2009) | This study proposed a RBI&M instruction to help oil refineries to reduce risks with considering time, budget and human resources for turnaround and work order management. Failures and their severity and probabilities are investigated to find the most proper action. |
| Mohan *et al.* (2013) | This study presented a novel quantitative method based on BOCR technique with AHP-ANP models to find the best alternative according to evaluations done by experts. |
| Arjomandi *et al.* (2021) | This study proposed a fuzzy DEMATEL-ANP-VIKOR model to choose the best maintenance alternative for an oil refining unit among four alternatives of RTF, PM, CBM and RCM. Three main criteria of economy, safety and sustainability with 12 sub criteria are evaluated by experts. Finally, according to the results, RCM and CBM have been selected as the best maintenance strategies for case study. |
| Bevilacqua and Braglia (2000) | This study proposed an AHP method to select the most suitable maintenance program for an Italian oil refining company. They have used four criteria of cost, added value, applicability and damage to evaluate and rank maintenance strategies of CBM, PdM, PM, OM and CM. According to the results, PM and PdM are the best strategies when it comes to safety critical assets. Also, for non-critical equipment, CM was the most proper maintenance strategy. |
| Bashiri *et al.* (2011) | This paper introduced an interactive fuzzy linear assignment methodology to choose the most appropriate maintenance plan among TBPM, PdM, CM and CBM. The experts have expressed their opinions about six criteria in linguistic terms and then the variables were compiled by trapezoidal fuzzy numbers. |
| Borjalilu and Ghambari (2018) | This study introduced a fuzzy ANP model for finding the most appropriate maintenance program for a power plant. They have evaluated five alternatives of CBM, PdM, RCM, TBPM and CM in respect to safety, staff, organization, technical requirements and administration. According to the results, the most proper maintenance strategy was PdM. |

ICT: Information and Communication Technologies; BMM: Business Motivation Model; RBI: Risk Based Inspection;

## 3. Benefits, Opportunities, Costs and Risks (BOCR)

Obviously, every decision is the outcome of weighting up positive and negative aspects. According to this vision, Saaty and Ozdemir (2003) introduced a new model based on prioritizing offered options in respect of four aspects of benefits (B), opportunities (O), costs (C) and risks (R). The basic principal of this method is the bipolarity essence of attitudes in supporting or rejecting issues, though there are some difficulties in quantifying and defining factors and relationships (Bouzarour-Amokrane *et al.*, 2012). Saaty has presented five different methods for synthesizing BOCR merits that are mentioned below (Lee, 2009):

Subtractive (*SBT*): $bB+oO-cC-rR$ (1)

Additive (*ADT*): $bB+oO+c(1/C_{Normalized})+r(1/R_{Normalized})$ (2)

Multiplicative (*MPT*): $BO/CR$ (3)

Probabilistic additive (*PAT*): $bB+oO+c(1-C)+r(1-R)$ (4)

Multiplicative priority powers (*MPP*): $B^bO^o[(1/C_{Normalized})]^c[(1/R_{Normalized})]^r$ (5)

The model was used to find the most proper strategy for trade between US and China which was under investigation by US Congress. Some of the previous works which have used BOCR technique are briefly expressed in literature review.

## 4. Case Study: A Combined Cycle Power Plant

Energy supply is one of the most critical concerns of the modern world. Almost every aspect of our life is related to energy resources today, and power plants have a key role in producing stable and affordable electricity power. An industrial complex like a crude oil refinery needs a reliable and powerful electricity network for a continuous production process. So, some of the large refineries build a power plant in their complex to be independent in power supply.

The power plant which is considered in this paper consists of gas turbine generators (GTG) combined with a heat recovery steam generation (HRSG) system and located in a crude oil refinery complex. A simple process flow diagram of a GTG-HRSG power plant is shown in Fig. 1.

As Fig. 1 illustrates, air, gas, fuel and distilled water are inputs of a GTG-HRSG power plant and the outputs are electricity and high-pressure steam. Consumable air is supplied by the air intake system which is mounted on the GTG, but gas and fuel are prepared by refining units. To prevent the huge amount of energy loss, hot gases which are produced in gas turbines, will be used in the boiler to generate HP steam. Finally, the low temperature gases are ventured to the atmosphere through the chimney.

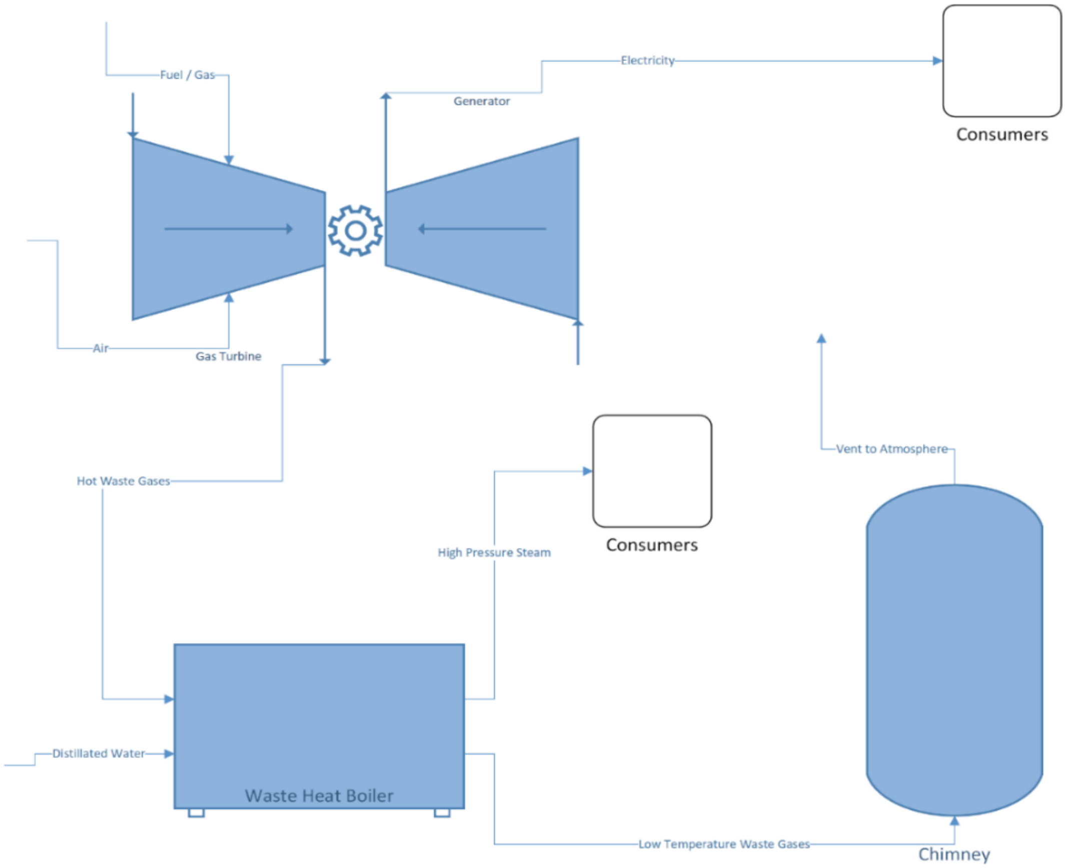


**Fig. 1.** The schematic diagram of a combined cycle power plant.

## 5. Maintenance strategies

In this paper, five different well-known maintenance strategies are considered to utilize in an oil refining unit. These strategies briefly expressed in following (Arjomandi *et al*, 2021):

- *Run-to-failure (RTF):* this alternative which is called as corrective maintenance too, is based on plans and activities that will be defined after failure occurrence.

- *Preventive maintenance (PM):* this alternative is named as scheduled maintenance tool and specifies calendar-based or operation-time-based activities that should be done on their due dates. Although the intervals have been defined based on the importance of equipment and history of its incidents, it is common in the preventive maintenance program that an unnecessary activity takes place. So, we cannot call it the most cost-effective strategy.

- *Condition-based maintenance (CBM):* in this program the repairs and replacements will be executed just when the working functions of the equipment get out of normal. In this program, the asset's operation is under control by online or portable monitoring devices in specific time intervals. CBM is the best strategy for high-valued critical equipment when a suitable and reliable monitoring system is in access.

- *Reliability centered maintenance (RCM):* where it is not possible to monitor the equipment parts or perform time-based inspections like for internal components of distillation towers and heat exchangers, this strategy can help to find all the ways that the equipment can fail, their consequences, and prioritize the failures according to their risks. RCA helps to optimize and choose the most appropriate maintenance activities according to failure modes.

- *Root cause analysis (RCA):* this maintenance strategy focuses on eliminating the causes of the failures. In RCA high-skilled experts analyze the large amount of data from operation, inspection, monitoring and previous maintenance activities to find the items which are effective in failures and perform appropriate maintenance tasks to remove them.

## 6. Weighting and Evaluation

In this section, we have presented a questioner to the experts from the departments of operation, planning and maintenance of a combined cycle power plant with more than 10 years of experience. They have expressed their opinion about evaluating decision factors (in linguistic terms) and sub criteria of BOCR merits (in crisp numbers). The determined sub criteria of each BOCR pillar are expressed in following.

*6.1. Benefits*

1. Ease of executing: the complexity of executing maintenance programs and work orders. Some modifications or work orders need special conditions to perform.
2. Reduced process failure: continuity of the production process is the main goal of the maintenance department. Absolutely, the failures are categorized based on their impact on the production process.
3. Empowered employees: the execution of the maintenance program needs skilled employees. In some cases, the Prerequisites of carrying out of the maintenance program is training talented employees or hiring high skilled persons.
4. Flexibility: the ability of the maintenance program to adopt with different and sometimes unpredictable production conditions.
5. Cost of energy consumption: the cost of the production of utilities like electricity, steam, water and air is too high for an industrial complex, so a damaged equipment can waste so much energy and money in respect.
6. Quality: the quality of productions
7. Stable power supply: the unstable power (electricity or steam) supply can lead to undesirable disturbance in upstream consumers. Therefore, a suitable maintenance strategy can guarantee a stable power generation.
8. Reduce greenhouse gases emissions: due to governmental regulations, international agreements and social responsibilities every industrial complex must have a clear and effective plant to control its greenhouse gases emissions. So, reliable equipment that work in their best efficiency can help so much to achieve this goal.
9. Selling generated steam: the main goal of the power plant is producing electricity. But, a HRSG system which works properly opens a new market for the complex.

*6.2. Opportunities*

1. Increased market share: increasing in reliability and availability of the units allows the management to plan for full capacity production.
2. Build relationships: collaboration with professional consultants, present employee's technical skills to others and benchmarking similar companies from the company are some ways that a company can share knowledge and work force with the costumers and even rivals.
3. Supplier technology: the rise in technical requirements, push the suppliers to improve their technology or make the company more interesting for high-tech suppliers.
4. Policies support: each progressive company has a vision for its future, so defines some goals based on them and declares policies to reach that goals. Therefore, every chosen strategy should be in accordance with those policies.
5. Advanced technology: a company equipped with advanced technologies in maintenance and engineering will find this opportunity to share its knowledge with stakeholders, costumers and even its rivals to gain money.
6. Sell surplus electricity production: sometimes, the amount of generated electricity is more than predicted consumer's needs. So, the plant can sell its surplus power to a new costumer.

*6.3. Costs*

1. Labor cost: the cost of labors is vary from one maintenance program to another according to the number of personnel and their skills.
2. Equipment cost: the cost of tools which are used in performing maintenance activity.
3. Cost of training: the cost of required courses that are necessary for executing the program.
4. Cost of materials: the cost of parts and materials which are used in maintenance.
5. Cost of storage: the cost of storing spare parts, materials and equipment in complex.
6. Cost of process reduction: some failures or maintenance activities cause to reduce production rate.

7. Cost of fuel and gas: gas turbines consume fuel and gas in their combustion chamber to produce energy for rotating the generator.

8. Cost of distillated water: the HRSG system needs pure distillated water to generate high pressure steam in boilers.

*6.4. Risks*

1. Budget overrun: cutting-edge solutions are so expensive most of the time. In addition, wrong estimation in defining requirements and program execution can cause a significant rise in costs.

2. Supplier profile: suppliers with negative history in delivery time, unreliable consultants, bad technical supporters and etc. can put an undeniable impact on programs.

3. Technical risks: sophisticated technical activities have their risk to accurate carry out.

4. Management support: every program and strategy needs the support of the management of the organization to reach its goals.

5. Air pollution: the huge amount of dust and other floating particles in the air, can cause damages to the air intake filters and disturb power plant process.

6. Weather condition: very high or very low weather temperature, high humidity, strong winds and massive precipitation can cause trouble for an industrial complex.

7. Personnel's injuries: unsuitable maintenance execution which causes to sudden failures of equipment and even during a maintenance activity, injury of the personnel is one of the significant concerns.

Since the impact of benefits, opportunities, costs and risks are not equal in strategic thinking, experts have prioritized them in respect to three factors of economic, technical and operation at first. Fig. 2 shows the wights of decision factors determined by experts and Table 2 illustrates the evaluated merits that lead to b, o, c and r coefficients which show the weight of each merit in decision making. Table 3 shows the value of each linguistic term.

**Table 2**
Priority rating table

| Priorities | Factors | Benefits | Opportunities | Costs | Risks |
|---|---|---|---|---|---|
| Economic (0.3) | Profit margin (0.21) | VH | M | VL | VL |
| | Added value (0.09) | H | H | VL | L |
| Technical (0.1) | Growth (0.08) | M | M | L | L |
| | Creation (0.02) | H | VH | M | VL |
| Operation (0.6) | Availability (0.18) | L | VH | H | VH |
| | Reliability (0.42) | H | M | VH | VH |

**Table 3**
Numerical values of linguistic terms.

| Linguistic Term | VH | H | M | L | VL |
|---|---|---|---|---|---|
| Numerical Value | 0.42 | 0.26 | 0.16 | 0.1 | 0.06 |

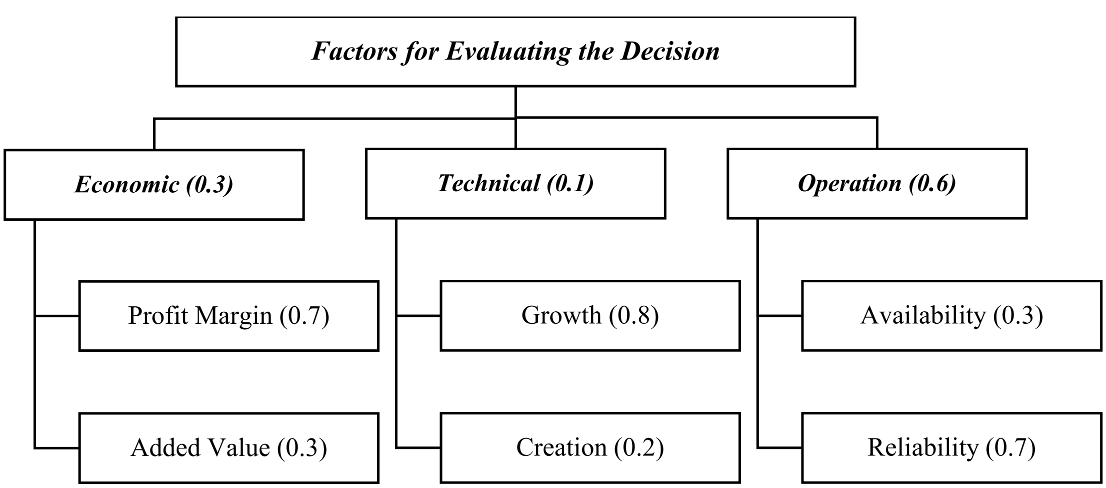


**Fig. 2.** Three main decision factors

After normalizing the rating which is the outcome of priorities table, we have obtained the preferences of four BOCR merits as Table 4.

**Table 4**
BOCR merits preferences.

| b | o | c | r |
|---|---|---|---|
| 0.34 | 0.19 | 0.22 | 0.25 |

Each expert has weighted 30 sub criteria which are related to four BOCR main categories through a questioner. The weights must be a number between 0 to 100 and the summation of each category should not exceed 100. The results of this prioritization is shown in Table 5.

**Table 5**
Sub criteria weightings.

| | Weight | | |
|---|---|---|---|
| **Benefits** | **Operator** | **Planner** | **CM** |
| Ease of executing | 10 | 20 | 10 |
| Reduced process failure | 20 | 20 | 25 |
| Empowered employees | 10 | 10 | 15 |
| Flexibility | 5 | 10 | 10 |
| Cost of energy consumption | 10 | 5 | 5 |
| Quality | 10 | 20 | 20 |
| Stable power supply | 20 | 5 | 5 |
| Reduce greenhouse gases emissions | 5 | 5 | 5 |
| Selling generated steam | 10 | 5 | 5 |

| | Weight | | |
|---|---|---|---|
| **Opportunities** | **Operator** | **Planner** | **CM** |
| Increased market share | 20 | 10 | 5 |
| Build relationships | 20 | 25 | 25 |
| Supplier technology | 10 | 25 | 20 |
| Policies support | 10 | 10 | 20 |
| Advanced technology | 20 | 20 | 25 |
| Sell surplus electricity production | 20 | 10 | 5 |

| | Weight | | |
|---|---|---|---|
| **Costs** | **Operator** | **Planner** | **CM** |
| Labor cost | 10 | 15 | 15 |
| Equipment cost | 20 | 25 | 25 |
| Cost of training | 10 | 5 | 10 |
| Cost of materials | 20 | 30 | 15 |
| Cost of storage | 10 | 10 | 5 |
| Cost of process reduction | 10 | 5 | 10 |
| Cost of fuel and gas | 10 | 5 | 10 |
| Cost of distilled water | 10 | 5 | 10 |

| | Weight | | |
|---|---|---|---|
| **Risks** | **Operator** | **Planner** | **CM** |
| Budget overrun | 10 | 25 | 15 |
| Supplier profile | 10 | 15 | 20 |
| Technical risks | 20 | 20 | 25 |
| Management support | 10 | 10 | 15 |
| Air pollution | 10 | 5 | 5 |
| Weather condition | 10 | 10 | 5 |
| Personnel's injuries | 30 | 15 | 15 |

Fig. 3 to Fig. 6 in following, will show the hierarchy charts of evaluated sub criteria and maintenance alternatives that are done by experts.

## 7. Results

The priority of maintenance alternatives in respect of benefits, opportunities, costs and risks which is obtained from hierarchy charts (Fig. 3 to Fig. 6) is shown in Table 6.

Now, we utilized five synthesized methods which were introduced as equations 1 to 5, to rank specified maintenance alternatives and illustrate the best strategy to implement in a combined cycle power plant.

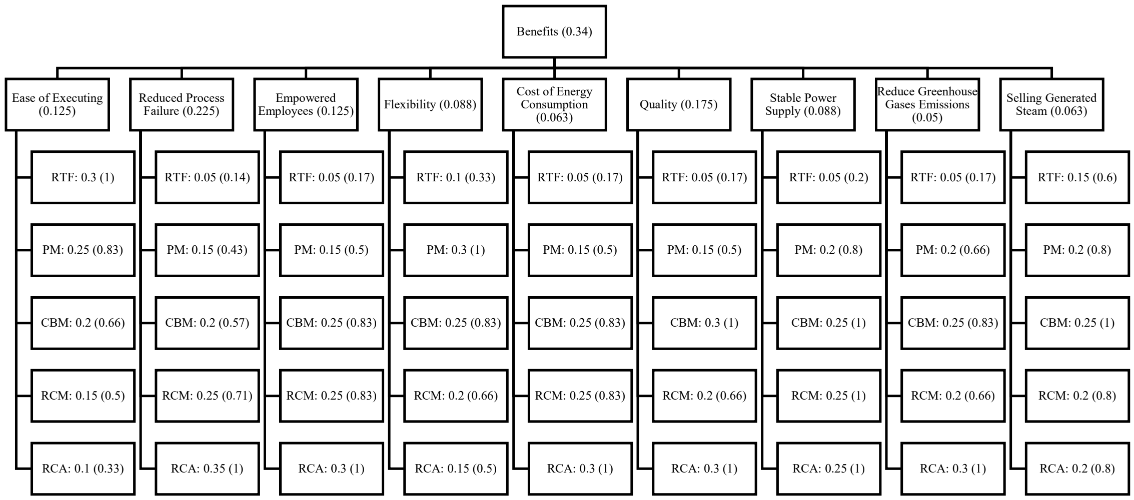


**Fig. 3.** Hierarchy chart of evaluated benefits and alternatives

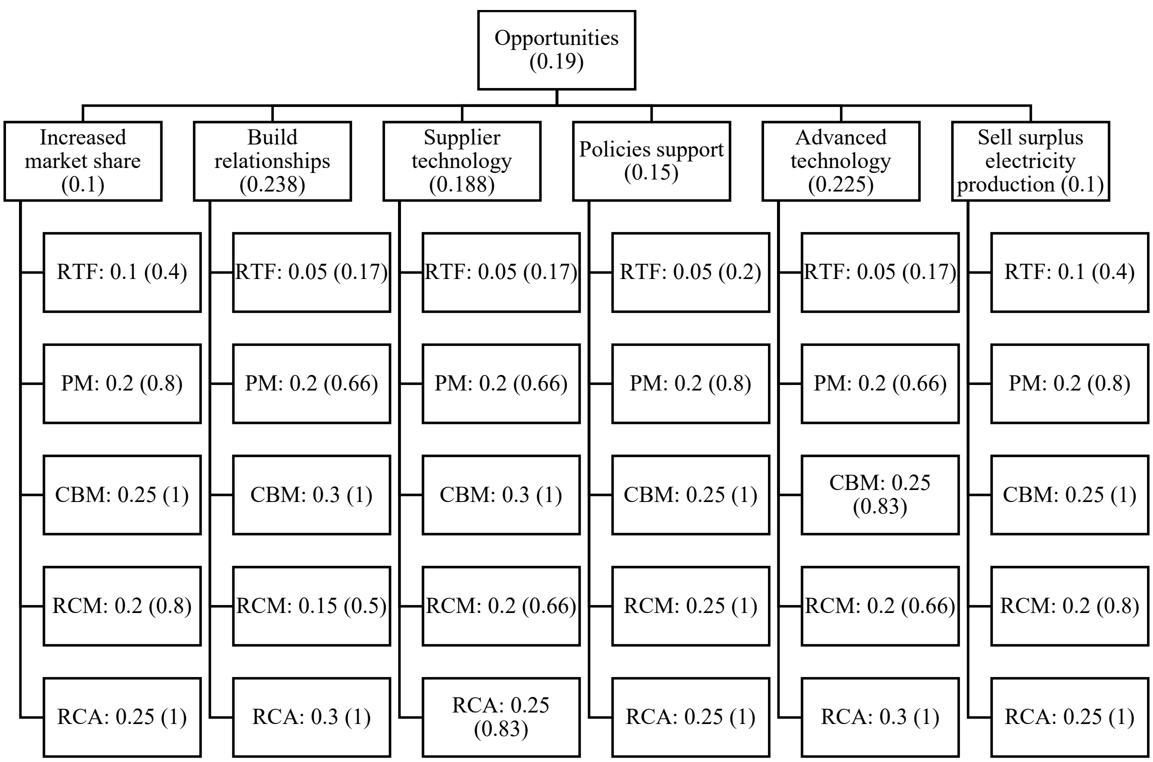


**Fig. 4.** Hierarchy chart of evaluated opportunities and alternatives

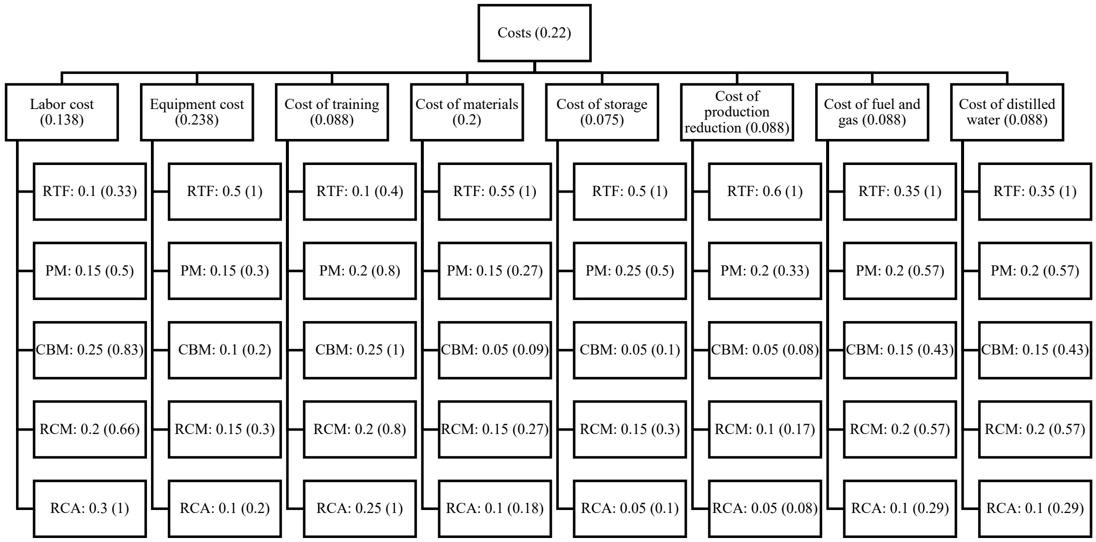


**Fig. 5.** Hierarchy chart of evaluated costs and alternatives

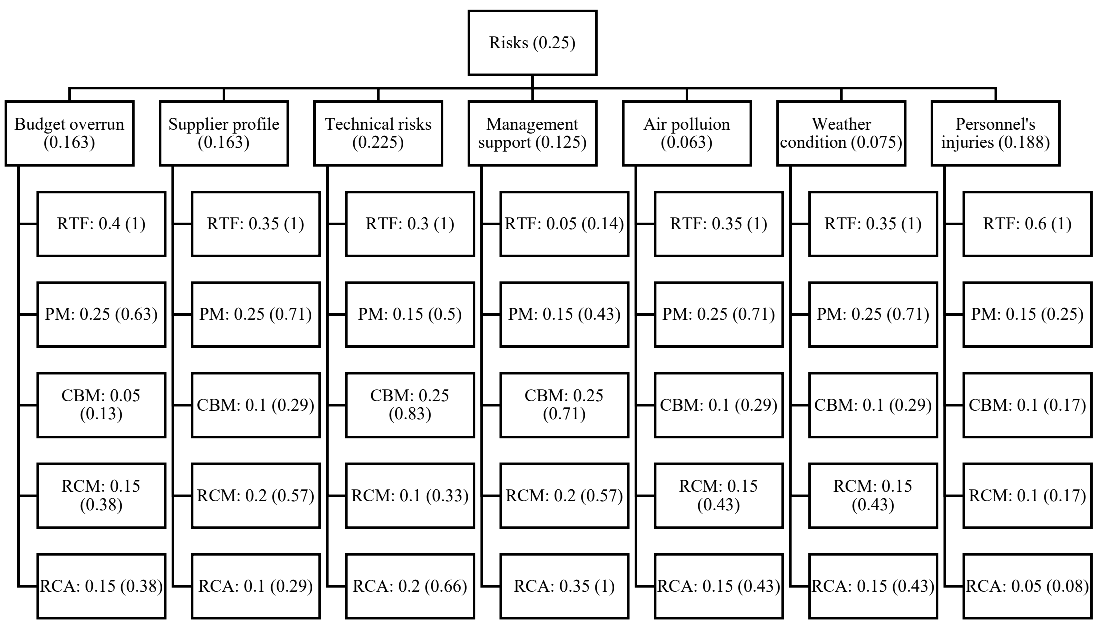


**Fig. 6.** Hierarchy chart of evaluated risks and alternatives

**Table 6**
The priority of maintenance alternatives (normalized)

| | | Benefits | Opportunities | Costs | Risks |
|---|---|---|---|---|---|
| Strategies | **RTF** | 0.36 | 0.23 | 1 | 1 |
| | **PM** | 0.72 | 0.73 | 0.50 | 0.59 |
| | **CBM** | 0.94 | 0.99 | 0.42 | 0.46 |
| | **RCM** | 0.84 | 0.72 | 0.50 | 0.44 |
| | **RCA** | 1 | 1 | 0.44 | 0.51 |

## 8. Conclusion

According to the final rankings which are mentioned in the Table 7, four of synthesize methods have ranked RCA as the top maintenance program for a combined cycle power plant and CBM as the second one. In another method, the ranking of these two strategy is vice versa. So, the best maintenance strategies for our case study are RCA and CBM.

**Table 7**
Synthesizing priorities

| | B | O | C | R | Synthesize methods | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.34 | 0.19 | 0.22 | 0.25 | SBT | ADT | MPT | PAT | MPP |
| RTF | 0.36 | 0.23 | 1.00 | 1.00 | 0.083 | -0.304 | 0.166 | 1.258 | 3.901 |
| PM | 0.72 | 0.73 | 0.50 | 0.59 | 1.782 | 0.126 | 0.596 | 0.981 | 3.951 |
| CBM | 0.94 | 0.99 | 0.42 | 0.46 | 4.817 | 0.300 | 0.770 | 0.989 | 3.988 |
| RCM | 0.84 | 0.72 | 0.50 | 0.44 | 2.749 | 0.202 | 0.672 | 0.934 | 3.921 |
| RCA | 1.00 | 1.00 | 0.44 | 0.51 | 4.456 | 0.306 | 0.776 | 1.050 | 4.047 |

**Disclosure statement**

The authors does not have any potential conflict of interest.

## References

Ahmadi, A., & Mosallanezhad, B. (2018). Using fuzzy FMEA to increase patient safety in fundamental processes of operating room. *Journal of Industrial and Systems Engineering*, *11*(3), 146-166.

Alsyouf, I. (2004). *Cost effective maintenance for competitive advantages* (Doctoral dissertation, Växjö university press).

Arjomandi, M. A., Dinmohammadi, F., Mosallanezhad, B., & Shafiee, M. (2021). A fuzzy DEMATEL-ANP-VIKOR analytical model for maintenance strategy selection of safety critical assets. *Advances in Mechanical Engineering*, *13*(4), 1687814021994965.

Asuquo, M. P., Wang, J., Zhang, L., & Phylip-Jones, G. (2019). Application of a multiple attribute group decision making (MAGDM) model for selecting appropriate maintenance strategy for marine and offshore machinery operations. *Ocean Engineering*, *179*, 246-260.

Bashiri, M., Badri, H., & Hejazi, T. H. (2011). Selecting optimum maintenance strategy by fuzzy interactive linear assignment method. *Applied Mathematical Modelling*, *35*(1), 152-164.

Bertolini, M., Bevilacqua, M., Ciarapica, F. E., & Giacchetta, G. (2009). Development of risk-based inspection and maintenance procedures for an oil refinery. *Journal of loss prevention in the process industries*, *22*(2), 244-253.

Bevilacqua, M., & Braglia, M. (2000). The analytic hierarchy process applied to maintenance strategy selection. *Reliability Engineering & System Safety*, *70*(1), 71-83.

Borjalilu, N., & Ghambari, M. (2018). Optimal maintenance strategy selection based on a fuzzy analytical network process: A case study on a 5-MW powerhouse. *International journal of engineering business management*, *10*, 1847979018776172.

Bouzarour-Amokrane, Y., Tchangani, A., & Pérès, F. (2012). Defining and measuring risk and opportunity in BOCR framework for decision analysis. In *9e International Conference of Modeling and Simulation-MOSIM'12*.

Bouzarour-Amokrane, Y., Tchangani, A., & Pérès, F. (2013). Evaluation process in end-of-life systems management using BOCR analysis. *IFAC Proceedings Volumes*, *46*(9), 105-110.

Erdoğmuş, Ş., Kapanoglu, M., & Koc, E. (2005). Evaluating high-tech alternatives by using analytic network process with BOCR and multiactors. *Evaluation and Program Planning*, *28*(4), 391-399.

Feglar, T., Levy, J. K., Feglar, T., & Feglar, T. (2006). Advances in decision analysis and systems engineering for managing large-scale enterprises in a volatile world: Integrating benefits, opportunities, costs and risks (BOCR) with the business motivation model (BMM). *Journal of Systems Science and Systems Engineering*, *15*(2), 141-153.

Gedela, R. K., Mohan, K. K., & Prasad, V. K. (2018). Application of BOCR models in service oriented architecture (SOA): study on model validation through quantification for QoS considerations. *International Journal of System Assurance Engineering and Management*, *9*(6), 1346-1354.

Lee, A. H. (2009). A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. *Expert systems with applications*, *36*(2), 2879-2893.

Liang, C., & Li, Q. (2008). Enterprise information system project selection with regard to BOCR. *International journal of Project management*, *26*(8), 810-820.

Mohan, K. K., Reformat, M. Z., & Pedrycz, W. (2013, June). Interval-based analysis of BOCR (benefits, opportunities, costs and risks) models evaluated by multiple experts. In *2013 Joint IFSA World Congress and NAFIPS Annual Meeting (IFSA/NAFIPS)* (pp. 244-250). IEEE.

Mosallanezhad, B., Chouhan, V. K., Paydar, M. M., & Hajiaghaei-Keshteli, M. (2021b). Disaster relief supply chain design for personal protection equipment during the COVID-19 pandemic. *Applied Soft Computing*, *112*, 107809.

Mosallanezhad, B., Hajiaghaei-Keshteli, M., & Triki, C. (2021a). Shrimp closed-loop supply chain network design. *Soft Computing*, *25*(11), 7399-7422.

Nezami, F. G., & Yildirim, M. B. (2013). A sustainability approach for selecting maintenance strategy. *International Journal of Sustainable Engineering*, *6*(4), 332-343.

Özcan, E., Yumuşak, R., & Eren, T. (2019). Risk based maintenance in the hydroelectric power plants. *Energies*, *12*(8), 1502.

Saaty, T. L. (2004). Fundamentals of the analytic network process—multiple networks with benefits, costs, opportunities and risks. *journal of systems science and systems engineering*, *13*(3), 348-379.

Saaty, T. L., & Ozdemir, M. (2003). Negative priorities in the analytic hierarchy process. *Mathematical and computer modelling*, *37*(9-10), 1063-1075.

Shafiee, M. (2015). Maintenance strategy selection problem: an MCDM overview. *Journal of Quality in Maintenance Engineering*.

Tabatabaee, S., Mahdiyar, A., Durdyev, S., Mohandes, S. R., & Ismail, S. (2019). An assessment model of benefits, opportunities, costs, and risks of green roof installation: A multi criteria decision making approach. *Journal of Cleaner Production*, *238*, 117956.

Tahmasdi, J., Ahmadi, A., & Mosallanezhad, B. (2021). Uncovering the hidden relation between air pollution and ischemic heart disease: Experience from Tehran. *Journal of Industrial and Systems Engineering*, *13*(3), 216-242.

Wijnmalen, D. J. (2007). Analysis of benefits, opportunities, costs, and risks (BOCR) with the AHP–ANP: A critical validation. *Mathematical and computer modelling*, *46*(7-8), 892-905.

Zaranezhad, A., Mahabadi, H. A., & Dehghani, M. R. (2019). Development of prediction models for repair and maintenance-related accidents at oil refineries using artificial neural network, fuzzy system, genetic algorithm, and ant colony optimization algorithm. *Process Safety and Environmental Protection*, *131*, 331-348.

Zhao, B., Chen, H., Gao, D., & Xu, L. (2020). Risk assessment of refinery unit maintenance based on fuzzy second generation curvelet neural network. *Alexandria Engineering Journal*, *59*(3), 1823-1831.