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Selection of Gensets Using Multicriteria Analysis

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Abstract

The paper presents a procedure for the optimal selection of diesel generators used to supply electrical units in military camps. Using a multi-criteria analysis based on the criteria presented in the paper, a new method is introduced that's not been used before for making decisions on optimal equipment. Daily load curves were created for the selection of diesel generators. These curves, together with the performance diagrams, served as the basis for calculating diesel consumption. The results allow an accurate assessment of the relative importance of the criteria used in the multi-criteria analysis. In addition to fuel consumption, other criteria such as maintenance costs, reliability, noise level, etc. were also examined. Their relative importance was assigned on the basis of technical documentation and existing maintenance records showing the frequency of breakdowns and maintenance costs. The AHP method was used to solve problems with multiple criteria. The results were processed using Expert Choice software. The analysis showed that an appropriate choice of diesel generator power can lead to lower fuel consumption. The results based on the established criteria show that the optimal choice is a 100 kW diesel generator.

Introduction

Diesel generators are used as an electricity source in off-grid systems. They're often used to supply power to rural areas, military camps and in the event of natural disasters [1]. To increase energy efficiency and system reliability, photovoltaic systems and small wind farms are used in addition to diesel generators, and various hybrid systems are being developed [2-4]. The share of renewable energies in the total power generation in military camps is relatively low compared to diesel generators. For this reason, the right choice of diesel generators is important. One of the most important criteria is fuel consumption [5,6]. Other criteria must also be taken into account, such as the price of the generator, its reliability and maintenance and servicing costs [7,8]. Additional requirements are possible, such as minimum noise emission [9] and optional operation in different modes. To avoid arbitrary decisions, a system for the optimal selection of diesel generators is modelled. The importance of optimising such and similar systems has been confirmed in a number of research papers [10-13]. This paper presents the application of the multi-criteria analysis method [14] for the selection and elaboration of one of the most important criteria, namely fuel consumption. In addition, other criteria are elaborated and the results are presented.

The correct selection of diesel generators contributes significantly to the energy efficiency of the system, i.e. an incorrect selection can negate all the advantages gained by using renewable energy sources and significantly reduce system efficiency. Based on the reference works studied, no paper was found that deals with the optimal selection of generators taking into account the criteria listed below. The novel scientific contribution of the paper is the development of a hierarchical model with the definition of the criteria for decision making on the optimal type of generator. The procedures presented below can also be applied to other technical systems, especially to systems using a large number of similar generators whose behaviour is monitored during operation. In order to be able to talk about the optimal choice of diesel generator, it's necessary to know the diagrams of electricity consumption in military camps [15].

During the day, consumption is variable, resulting in fluctuating loads on the diesel generators. The load fluctuations have a major impact on fuel consumption. The increased load increases the power of a diesel generator and decreases the fuel consumption per kWh gained. For this reason, the question arises as to the economic efficiency of a single large diesel generator or several smaller generators. Using the daily load curve and the power diagram, the daily diesel consumption was calculated for the case where three 100 kW generators are used and for the case of a single 300 kW generator.

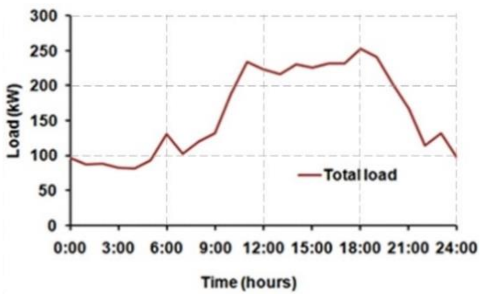

Figure 1: Daily load of military camp

The fuel consumption calculation has been confirmed with experimental results and is based on fuel consumption records that are continuously monitored and recorded. The elaboration of fuel consumption improves the accuracy in assessing the relative importance of the fuel consumption criteria used in the analytical hierarchy process. The assignment of relative importance of the other criteria was based on technical documentation and existing records of equipment maintenance and use. The data used to determine an optimal choice is processed in the Expert Choice software. The selection is based on six criteria among four alternatives representing four different types of generators. The analysis showed that the optimal choice is a 100 kW diesel generator with a non-turbocharged diesel engine drive. The proposed choice of the optimal diesel generator was confirmed by an analysis of the utilisation and maintenance costs recorded in the worksheets during operation.

Power supply to camps

As mentioned earlier, military camps are supplied with electricity from various sources in combination with electricity storage.

As it's an infrastructure that's used in different ways, the conditions and equipment differ depending on the location and purpose of the camp. For this reason, the power sources are adapted to the specific situation, so that in some camps only diesel generators are used. Other sources, such as photovoltaic panels and small wind turbines, may also be installed but are out of service at certain times, so that the entire power supply depends on diesel generators.

The electricity demand, i.e. the total load in one of the camps, is shown in Figure 1 [15]. As mentioned earlier, the demand varies depending on the equipment installed and the size of the camp or the number of people staying in a particular place.

By comparing several graphs of daily electricity consumption, it was found that the power curves have a similar shape. Simply put, the increase in consumption occurs in the morning and continues for the most part throughout the day until the evening. It's important to note that the maximum value of power consumption is up to three times higher than the minimum value.

Optimal selection of power and number of diesel generators can lead to significant savings. When selecting the optimal power system, a number of criteria must be taken into account, and multi-criteria analysis was used to make the right decision.

Diesel generator fuel consumption

One of the most important criteria in choosing the power of a diesel generator is fuel consumption. It depends on the load on the engine, i.e. the generator. As the load increases, fuel consumption increases, but so does the efficiency of diesel generators. This means that the specific fuel consumption is lower at higher loads, i.e. more kWh of energy is obtained from 1 kg of fuel. The maximum specific consumption is at minimum load. In other words, the worst case is when a power generator is running at idle. Then it consumes fuel without producing any power. Moreover, such operation has negative effects on the diesel engine. Figure 2 shows the relationship between fuel consumption and load as well as the relationship between power and load of a 160 kW diesel generator [16].

For diesel engines used to drive various machines, including diesel generators, the specific consumption is generally above 0.2 kg/kWh. The lower the engine power, the higher the specific consumption [17].

This means that smaller engines have lower efficiency, i.e. they deliver less energy per 1 kg of fuel consumed than larger engines with higher efficiency.

Some diesel generators use older engine designs with slightly lower energy efficiency, and their consumption is also slightly higher than that of newer engine designs [18].

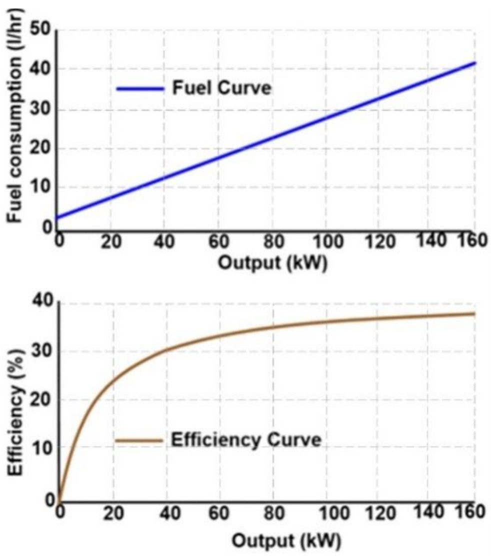

Figure 2: Diesel generator fuel consumption and output graph

Consumption can also increase through the use of fuels that have different properties than diesel, such as blends with biodiesel [19] or the use of F-34 and JP-8 jet fuels [20-22] used in international military operations.

The greatest savings in diesel generator fuel consumption can be achieved by choosing the right diesel generator output or by combining several diesel generators. In this case, a number of diesel generators are switched off when the demand for electrical power is reduced. The diesel generators that are still in operation operate at a higher load and have a higher efficiency, i.e. lower fuel consumption per kWh of output power. Lower fuel consumption also reduces pollution. In terms of efficiency, it's advantageous if the diesel generator operates at more than 70 % of its rated power. This is usually not possible when a single diesel generator is used for power supply without the use of batteries or other power sources. Therefore, if a single diesel generator is used, its output must be high to cover the peak loads that occur during a day. As the daily load fluctuates, such diesel generators operate below 50% load for quite some time, which is unprofitable. This paper will examine critical cases, i.e. situations where only diesel generators are used as a power source. During peak loads, all the power is supplied by a diesel generator. This is still a common case in military camps that aren't supplied with accumulator batteries.

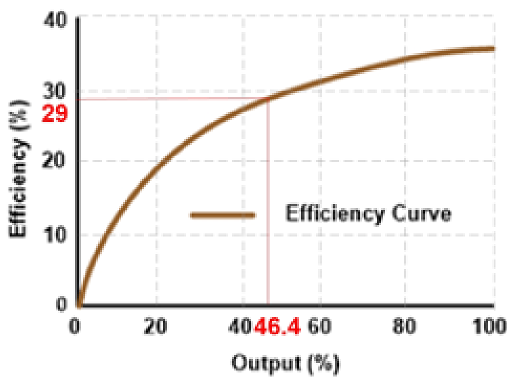

Figure 3: Diesel generator output graph

To achieve maximum energy efficiency in such cases, it's necessary to use several diesel generators with lower power. In this way, each diesel generator can operate at a higher load level. Considering only fuel consumption and simplifying the case, it's better to use 3 diesel generators with a rated power of 100 kW than one diesel generator with 300 kW to supply power to a military camp with a daily load, as shown in Figure 1. In this way, only one diesel generator runs at low load. When the rated power of the one diesel generator is utilised to 90 %, the second and then the third diesel generator are switched on. For the calculation of consumption, the diesel generator power curve shown in Figure 3 was used, in which the load is given as a percentage and which can be applied to diesel generators of different power [23].

Figure 3 shows that the maximum power of η-diesel generators is at 100% load and in this case it's 36%.

This means that 36% of the fuel power is converted to electricity and the rest is loss.

The calculation confirms that the specific consumption of this type of diesel generator is about 0.23 kg/kWh. It's important to emphasise that we're talking here about the specific consumption of the diesel generator, which is different from the specific consumption of the diesel engine itself due to the losses in the generator.

$$b_e = \frac{1}{\eta \cdot Q_f} \quad (1)$$

The calorific value of diesel Q_f used in the calculation is 43 250 kJ/kg [24], i.e. 12.0138 kWh/kg.

For this analysis, the same specific fuel consumption can be used for a 100 kW and a 300 kW diesel generator at nominal load, i.e. the power according to the diagram in Figure 3, since the reduction in diesel consumption is described in [17]:

$$y = -9 \cdot 10^{-6} \cdot x + 0.2261 \quad (2)$$

where x is the nominal power in kW and y is the dependence of consumption on the power of the diesel engine. The consideration of different consumptions would make sense if differences in the power of diesel generators of the order MW are involved.

The total energy E_e for supplying the consumers in one day according to the load diagram in Figure 1 is shown in Table 1. In addition to the electricity, the diesel consumption is also given. Based on the average power in each hour, the electricity demand in that hour was determined and at the bottom of the table the total energy demand in one day is given.

The column labelled "n_{DG}" indicates how many diesel generators are on in this case when 3 diesel generators of 100 kW each are used to power the warehouse. While the required power is up to 90 kW, one diesel generator is switched on and works up to 90 % of its nominal load. After that, another diesel generator is switched on.

Two diesel generators operate up to a load of 180 kW, after which a third diesel generator is switched on. Column C_{100} shows the fuel consumption in kg required to generate electricity with a 100 kW diesel generator.

These values were determined by first reading the number of diesel generators switched on at a given time. Then the power $E_e$is divided by the number of diesel generators in operation to obtain the load of a single diesel generator. For this load, the diesel generator power is read in Fig. 3 and the specific consumption be is calculated in kg/kWh using the formula in (1).

Table 1: Diesel generator fuel consumption

T_{0-24}	P, kW	E_e, kWh	n_{DG}	C_{100}, kg	C_{300}, kg
0:00	97.3				
		92.8	2	26.6	29.7
1:00	88.2				
		88.6	1	21.1	33.5
2:00	88.9				
		86.2	1	20.5	32.6
3:00	83.5				
		82.7	1	19.7	31.3
4:00	81.8				
		87.8	1	20.9	33.2
5:00	93.7				
		112.6	2	30.2	36.0
6:00	131.4				
		117.3	2	31.5	37.6
7:00	103.2				
		112.1	2	30.1	35.9
8:00	121				
		126.9	2	32.5	36.4
9:00	132.8				
		160.5	2	38.2	43.1
10:00	188.1				
		211.3	3	51.7	51.7
11:00	234.5				
		229.3	3	56.1	56.1
12:00	224				
		220.3	3	53.9	53.9
13:00	216.5				
		223.7	3	54.8	54.8
14:00	230.9				
		228.2	3	55.9	55.9
15:00	225.5				
		228.5	3	55.9	55.9
16:00	231.5				
		231.7	3	56.7	56.7
17:00	231.8				
		242.4	3	57.6	57.6
18:00	253				
		247.3	3	58.8	58.8
19:00	241.5				
		221.8	3	54.3	54.3
20:00	202				
		184.9	3	47.3	47.3
21:00	167.7				
		141.5	3	34.6	40.6
22:00	115.2				

The specific consumption is multiplied by the power load of a single generator to obtain its consumption. Multiplying this by the number of diesel generators currently in operation gives their consumption in the respective hour, as shown in columnC_{100}.

In the case of a load of 92.8 kW, as seen above in Table 1, two diesel generators are in operation. Each of them is loaded with half of this load (46.4 kW), which also corresponds to a load factor of 46.4%. Fig. 3 shows an efficiency of 29%. Inserting the efficiency and Q_f (12.0138 kWh/kg) into formula 1, we get the value of be (0.287 kg/kWh).

Multiplying the result by the load of a single diesel generator results in a fuel consumption of 13.3 kg for the single diesel generator. The consumption of both diesel generators is twice as high, amounting to 26.6 kg, which can also be seen in the table below, column C100. All other values were determined using the same methods.

If a single 300 kW diesel generator is used, its consumption is shown in column C300. The calculation of the consumption is based on the same principles as for the 100-kW diesel generator presented earlier. First, the percentage of load is recorded, then the corresponding efficiency is read from Fig. 3, whereupon the value of be and the consumption are calculated as shown above. From the results shown, the amount of fuel required for 3 diesel generators with a rated power of 100 kW each is less than the amount of fuel required for a single diesel generator with a rated power of 300 kW

The difference in fuel consumption is even more pronounced at lower loads.

Use of multicriteria analysis for optimal selection of diesel generators

In order to prioritise the use and maintenance of certain types of diesel generators, it's necessary to consider a number of different criteria and make the right decisions. This should be taken into account especially when buying new equipment. To avoid arbitrary decisions, a system for the optimal selection of diesel generators is modelled using multi-criteria analysis. One of the most commonly used methods for solving such problems is the Analytical Hierarchical Process (AHP) method [25 - 27].

The method is one of the best known and most commonly used methods for multi-criteria decision making. Its popularity stems from the fact that it's very close to the way a human intuitively solves complex problems by breaking them down into simpler problems. Solving complex decision problems with this method is based on breaking them down into components. At the top of the hierarchical model is the goal, the criteria and sub-criteria are at the lower levels, and the alternatives are at the bottom (Figure 4).

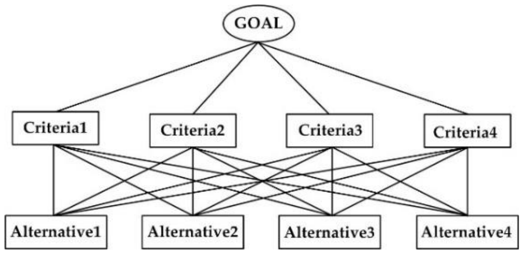

Figure 4: AHP hierarchical structure model

The AHP method is carried out in four steps:

1. a hierarchical model of the decision problem is developed, with an objective at the top, criteria and sub-criteria at the lower levels, and alternatives at the bottom.

2. at each level of the hierarchical structure, the elements of the structure are compared in pairs, expressing the preferences of the decision-makers using an appropriate scale of 5 levels and 4 intermediate levels of verbally described intensities and corresponding numerical values in the range of 1-9, Saaty scale [28].

3. on the basis of the assessed relative importance of the elements of the corresponding hierarchical problem structure level, the local priorities (weights) of the criteria, sub-criteria and alternatives are calculated using a mathematical model.

4. sensitivity analysis.

The analytical hierarchical process is based on the following axioms:

- Reciprocity condition - When two elements of a pair are compared, the first element dominates the second with intensity x according to the Saaty scale, then the second element dominates the first with intensity 1/x.
- Homogeneity - A comparison only makes sense if the elements are comparable. If you compare

two elements on the Saaty scale, the latter must be sufficient for the comparison, i.e. for the creation of a consistent comparison table.

- Dependency - A pairwise comparison of elements from one hierarchy level is only possible in relation to elements from a higher hierarchy level.
- Expectation - Any change in the structure of the hierarchy requires a recalculation of the priorities in that hierarchy.

The mathematical model of the AHP method is presented in [29, 30].

For example, take n as the number of criteria (or alternatives) the weights (priorities) of which (w_i) should be determined based on an estimate of the values of their ratios, expressed as $a_{ij} = w_i/w_j$. Based on the ratios of relative importance a_{ij}, the matrix of relative importance A is formed:

$$A=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = n \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \quad (3)$$

For the case of consistent estimates where $a_{ij} = a_{ik} \times a_{jk}$ applies, matrix A satisfies the equation $A \cdot w = n \cdot w$, where w is the priority vector:

$$A=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = n \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \quad (4)$$

Since the matrix A has special properties (all its rows are proportional to the first row, all elements are positive and satisfy the reciprocity condition $a_{ij} = 1 / a_{ji}$), the rank of the matrix is 1 which is why only one of its eigenvalues is different from 0 and is equal to n (all other eigenvalues are 0).

If the matrix A contains inconsistent estimates, the weight vector w can be determinated by solving the following equation:

$$\left(A-\lambda_{\max} \cdot I\right) \cdot w = 0 \text{ provided } \sum w \cdot i = 1 \quad (5)$$

where λ_{max} is maximum eigenvalue of matrix A. Due to the properties of the matrix A, $\lambda_{max} \geq n$ applies, and $(\lambda_{max} - n)$ difference is used in measuring the consistency of change.

The consistency indexindex $CI = (\lambda max - n)/(n-1)$is used to calculate the consistency ratio $CR=CI/RI$, where $RI$is a random index or consistency index for matrices of order n of randomly generated pairwise comparisons.

The Expert Choice software package, which takes several criteria into account, was used to select the optimal diesel generator. This package is often used for the selection of optimal solutions [31]. As mentioned in the introduction, the aim of this paper is to shed more light on one of the criteria, namely fuel consumption, and to present a multi-criteria analysis method for selection that will eventually be applicable to most military equipment. Four alternatives, or four types of diesel generators, were used to demonstrate the multicriteria analysis methodology.

Table 2: RI random index values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

There are two types with 100 kW and two types with 300 kW. One 100 kW diesel unit is older and has no turbocharger, the other 100 kW unit is newer and has a turbocharger. Both types of 300 kW gensets have a turbocharger, one is an older generation engine and the other is a newer generation engine.

The following criteria were considered:

1. Fuel consumption
1. Maintenance cost
2. Purchase cost
3. Output deviations when kerosene is used
4. Noise emission
5. Reliability

These six criteria are considered most important in selecting the optimal power generator. No reference book mentions a selection method based on these seven criteria. No other authors were found that discuss the power generator performance variance when using paraffin. Most of the discussions in the reference works refer only to fuel consumption.

<u>Criterion 1</u> (fuel consumption) is considered for the power supply of a military camp, whose power consumption is shown in Figure 1. From the first part

of this paper, it can be seen that powering the camp requires less diesel consumption if diesel generators with lower power are used. In our case, four types of diesel generators are considered, two of which are 100 kW. The turbocharged diesel generator type has lower fuel consumption. Thus, it was found that the daily load on the bearing achieves lower fuel consumption when 100 kW generators are used. In addition to this conclusion, it's important to know which of the two different 100 kW types, type A or type B, has lower fuel consumption for further calculation. The monthly records of fuel consumption in military organisations show that generators with turbo engines have a lower fuel consumption than diesel engines with naturally aspirated engines. This means that type B has lower fuel consumption than type A. On this basis, weights are added to all options - the generator types - as shown in Table 4. At the top of the table, where Type A and Type B are compared, weight 3 is added under Type B and shown in red, which is an inversion of the matrix and, according to the Saati scale, means that Type B has a slight advantage over Type A. The comparison of type C and type D shows the value 2 in red under type D, which represents a lower consumption of type D compared to type C. This is logical, as type C was described above as an older generation generator and its fuel consumption is higher. The same principle was used to weight all other criteria.

Criterion 2 (maintenance costs) includes the total costs for preventive and corrective maintenance. Some types of diesel generators fail more frequently and require more repair work than others.

The frequency of the failures themselves need not be decisive, but the severity of the failures, i.e. the costs incurred for corrective maintenance, must be. The costs of corrective maintenance, like the costs of preventive maintenance, are the sum of the costs of materials and labour. They're easily accessible in military organisations, as all maintenance work is recorded. In this case, maintenance costs are considered per kWh of electricity gained, so they're usually lower for larger diesel generators.

Criterion 3 (purchase cost) also plays an important role, as a large amount of equipment is usually purchased in military systems. Here, the price per kW is taken into account, so that the price for larger gensets is usually cheaper than that for smaller ones.

Criterion 4 (output deviations when using F-34 kerosene) is used to consider frequency and voltage deviations when F-34 kerosene is used. Previous studies have shown that the performance of a diesel engine is lower when using F-34 kerosene fuel. Therefore, at rated load, the engine speed may decrease, which directly affects the frequency reduction of the output voltage and may also affect the voltage amplitude.

The differences in speed are particularly pronounced at surge loads. In turbocharged engines, the crashes and peaks that occur during surge loads and generator unloads are even more pronounced [32].

Criterion 5 (noise emission) plays an important role in military camps, especially in smaller camps where the diesel generators are relatively close to the soldiers' working and resting places. As a rule, the noise of smaller generators is lower than that of larger generators. Newer versions of diesel generators also have lower noise emissions. This is due to better insulation and a more modern design of the exhaust, cooling and air circulation systems.

Criterion 6 (reliability) is very important for the use of equipment in international military operations. The safety of equipment and personnel can often depend on the proper operation of diesel generators. The maintenance process itself is much more complex in international military operations, so the goal is to make the equipment used in international operations as reliable as possible.

As mentioned earlier, 4 different types of diesel generators were considered. Since disclosure of detailed information isn't common for equipment used in the armed forces, the diesel generators are designated as follows:

Type A: 100 kW, non-turbocharged,
Type B: 100 kW, turbocharged,
Type C: 300 kW, older generation,
Type D: 300 kW, newer generation.

The detailed characteristics aren't important to present the proposed model. What's important is the approach and operating principle of the model so that it can be applied to other types of diesel generators.

The Expert Choice software package was used to decide on the optimal diesel generator types. The decision is made on the basis of the criteria mentioned and described above.

The information on the alternatives, i.e. on the individual diesel generator types, can be found in the technical documentation of the units, including the technical brochure, manuals and maintenance orders. Any missing data is determined by testing.

The Expert Choice software is first populated with the criteria with the estimated importance ratio as shown in Table 3. The criteria are compared in pairs according to how often one of them is more important than the other for achieving a goal. The Saaty scale [28] is used, where 1 indicates equal importance, 3 slightly higher importance and 9 extreme importance. As a rule, the inversion in the matrix, i.e. another criterion is more important, is marked in red.

Table 3: Criteria with the estimated importance ratio

CRITERIA	Lower maintenance cost	Lower purchase cost	Lower output deviation	Lower noise level	Higher reliability
Lower fuel consumption	3.0	5.0	5.0	1.0	3.0
Lower maintenance cost		3.0	3.0	3.0	3.0
Lower purchase cost			3.0	2.0	5.0
Lower output deviation				2.0	3.0
Lower noise level					2.0

Table 4: The weights to all alternatives in relation to each specific criterion

CRITERIA	ALTERNATIVE	Type B	Type C	Type D
Lower fuel consumption	Type A	3.0	9.0	7.0
	Type B		8.0	6.0
	Type C			2.0
Lower maintenance cost	Type A	2.0	7.0	9.0
	Type B		5.0	9.0
	Type C			3.0
Lower purchase cost	Type A	1.0	4.0	4.0
	Type B		5.0	5.0
	Type C			2.0
Lower output deviation	Type A	2.0	4.0	6.0
	Type B		5.0	7.0
	Type C			2.0
Lower noise level	Type A	2.0	9.0	7.0
	Type B		7.0	5.0
	Type C			3.0
Higher reliability	Type A	2.0	4.0	3.0
	Type B		2.0	2.0
	Type C			3.0

Then all alternatives are weighted in relation to each criterion, as shown in Table 4, also according to the Saaty scale.

The functioning of the model and the results of the data processing are illustrated using images from the Expert Choice software package.

Figure 5 shows the selection of diesel generators according to the above criteria. The criteria according to which the selection was made and the alternatives between 4 different types of diesel generators, type A,...type D, are listed. For a better overview, the results have been summarised and presented in Table 5 and can be read in Figs. 5 and 6. The table shows that type A is the optimal choice with an overall priority of 0.412, followed by type B with a priority of 0.296.Both diesel generator types have an output of 100 kW. This is followed by type D with a priority of 0.179, while type C comes last with a priority of 0.113. Table 5 also shows the priorities of the alternatives, led by reliability with 0.345 and power deviation in last place with 0.056, which is also shown in Expert Choice in Fig. 6. At the bottom of Fig. 6 is inconsistency 0.09, which corresponds to an inconsistency of 9%. This shows that the relationship of the importance of the criteria is well structured.

Table 5: Diesel generator selection results

ALTERNATIVE	Type A	0.412
	Type B	0.296
	Type D	0.179
	Type C	0.113
	Σ	1.000
CRITERIA	Higher reliability	0.345
	Lower fuel consumption	0.230
	Lower noise level	0.180
	Lower maintenance cost	0.115
	Lower purchase cost	0.074
	Lower output deviation	0.056
	Σ	1.000

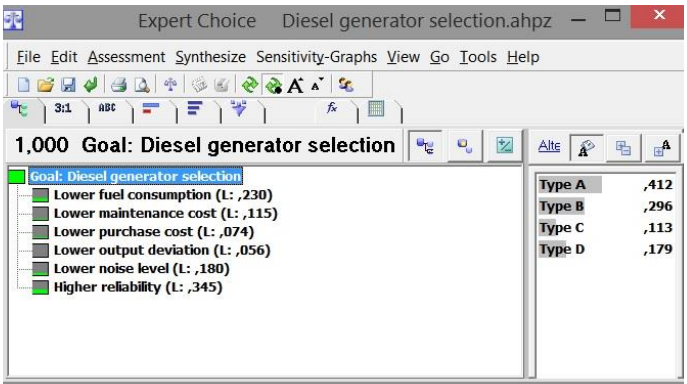

Figure 5: Structure of diesel generator selection in Model View window of Expert Choice program

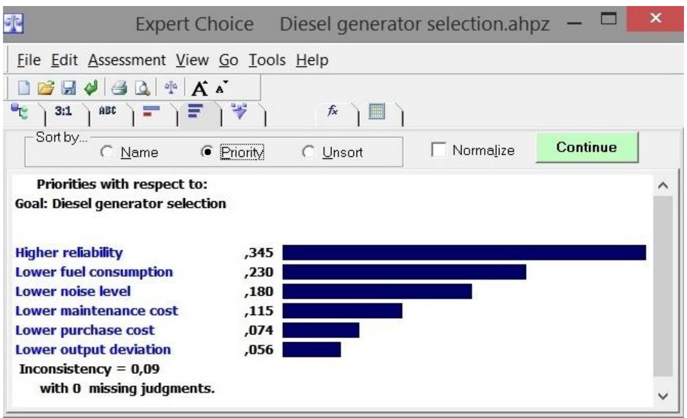

Figure 6: Calculated importance of criteria from estimated ratios for diesel generator selection

Reliability has the highest weight, which is understandable when it comes to military equipment. Fuel consumption comes second.

Both are important, especially when the equipment is used in international operations where highly skilled maintenance mechanics aren't always available and fuel supply can be difficult.

Figure 7 shows a comparison of Type A and Type B diesel generators according to the first criterion, i.e. fuel consumption per kWh of electricity generated.

The results shown in the figure indicate that type B is optimal in terms of fuel consumption. The text (Incon: 0.08) in the lower part of Fig. 7 shows that the importance ratios are well structured. .

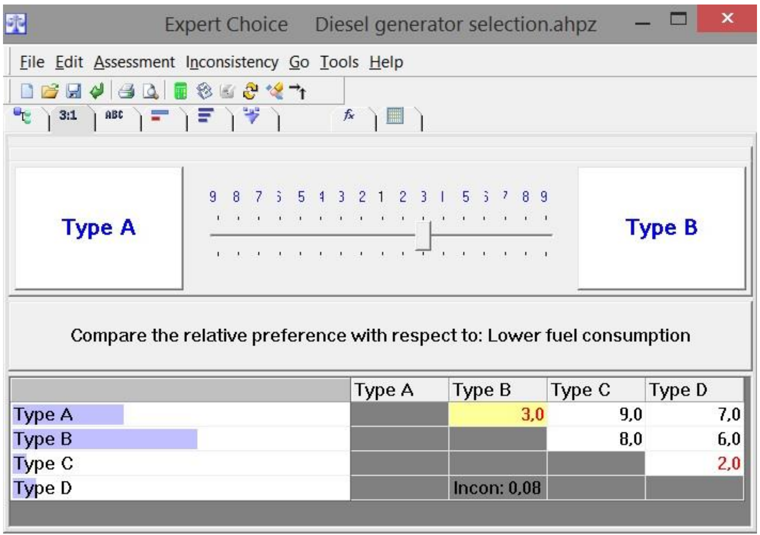

Figure 7: Comparison of Type A and Type B diesel generators according to the fuel consumption criterion

Conclusion

The adequate selection of equipment is essential for the efficient functioning of military organisations. Optimal selection of diesel generator increases the efficiency, reliability and availability of the system.

The elaboration of the fuel consumption criterion has shown that the use of several low-power diesel generators reduces fuel consumption in military camps with fluctuating power demand.

When power demand drops, one set of diesel generators can be switched off while the others operate close to their rated load. This gives them maximum efficiency, which is confirmed by monitoring diesel generator consumption at different loads.

A number of other criteria play an important role in the selection of military equipment. In order to consider all the criteria and make the right decision, a multi-criteria analysis was carried out and the optimal selection of diesel generators was shown using the AHP method.

The method presented is suitable for use in military and similar organisations that have up-to-date records of equipment usage, frequency of breakdowns and maintenance costs. Based on such records, a reliable assessment of the relative importance of the criteria is possible, which is essential for making a correct decision.

The results were processed using the Expert Choice software package. The results show that according to the criteria set, the optimal choice is a type A diesel generator, although in terms of fuel consumption type B is optimal.

This means that the weighting and number of the other criteria are on the side of type A. Both types have an output of 100 kW, which means that choosing one of these two types is more optimal than choosing a 300 kW diesel generator.

The results show that 300 kW generators aren't an optimal solution in this case. This leads to the conclusion that in cases with large fluctuations in 24-hour power consumption, a larger number of small diesel generators offers better cost efficiency than a single large generator.

Nomenclature

A	- relative importance matrix
a_{ij}	- relative importance ratio
b_e	- specific fuel consumption
C_{100}	- fuel consumption in case of 100 kW diesel generator
C_{300}	- fuel consumption in case of 300 kW diesel generator
CI	- consistency index
E_e	- total energy for consumer supply
E_e *[kWh]*	- consumption in kWh
n	- number of criteria
n_{DG}	- number of diesel generators in operation
P [kW]	- power in kW
Q_f	- calorific value of diesel fuel
RI	- random index
T_{0-24}	- diesel generator operating time
w	- priority vector
w_i, w_j	- weights of criteria
x	- rated power (kW)
y	-consumption dependency on diesel engine power
η	- diesel generator efficiency
λ_{max}	- maximum eigenvalue of matrix A

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