Title: Multi-Criteria Decision Aid methodology applied to highway truck selection at a mining company

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Resumo:

Em todos os empreendimentos minerários, os custos de transporte têm grande impacto no lucro líquido da empresa e, por causa disso, merecem estudos econômicos prévios. Assim, nas fases de aquisição ou substituição de frotas de transporte, torna-se de fundamental importância a realização de estudos de viabilidade econômica para se determinar, dentre as alternativas existentes no mercado, a melhor combinação possível de equipamentos de carga e transporte que atendam às demandas de produção com um menor custo. No presente trabalho são mostrados os resultados de um estudo de caso relativo à seleção de caminhões rodoviários para o transporte de minério *run of mine* (ROM) em uma empresa mineradora de bauxita do Estado de Minas Gerais por meio da metodologia de Auxílio Multicritério à Decisão (AMD).

Palavras-chave: seleção de equipamentos de mineração, AMD, pesquisa operacional, bauxita.

Abstract:

In all mining projects, transportation costs largely impact net profit, justifying economic feasibility studies before transport fleet acquisition or replacement. These studies can provide the best loading and hauling equipment combination to meet production demands at lower costs by evaluating the alternatives available in the market. Herein is presented the case of selecting hauling trucks used to transport run of mine (ROM) ore at a bauxite mining company, located in the State of Minas Gerais, Brazil, using the Multi-Criteria Decision Aid methodology (MCDA).

Keywords: mining equipment selection, MCDA, operational research, bauxite.

1. Introduction

The complexity and risks involved in the implementation of mining projects demand fast and constant evaluation of the expected mining operation results. This process involves evaluating all the exploitation, construction, operation and maintenance phases. To acquire the production goods necessary for mining operations, economic resources are required and are considered as part of the the economic viability calculus of the mining enterprise (REVUELTA and JIMENO, 1997). According to the aforementioned authors, the acquisition of these goods is considered to be *cash flow*, which is the basis for the economic evaluation of investment projects. This evaluation, by the way, is a set of production and market price predictions, referring to costs, amortizations and taxes. As the forecasts become more detailed and reliable, their economic evaluation becomes closer to reality.

For example, a mining industrial complex that has operated for more than 20 years now has the acquisition and replacement of their assets as part of their investment portfolio.

The acquisition or replacement of equipment using financial indicators like the internal return rate (IRR), net present value (NPV) and payback are common to mining enterprises that have a long-term production horizon within which they use their equipment until the end of its useful life and distribute its cost over a long period of time.

When the evaluated asset alternatives are of relatively similar importance from the decision-making point of view and the technical characteristics like production capacity, cycle time and acquisition, operation and maintenance costs are considered, then qualitative factors can be considered together to determine the selection of the most suitable alternative.

Among the techniques used in the decision-making process, supported by the analysis of qualitative and quantitative data, is the Multi-Criteria Decision Aid (MCDA) methodology. When using this methodology, the aim is to create a support structure for the person or group of decision-makers to be able to better understand the critical aspects that will generate the resolution of the problem in focus, accepting not only one solution as valid, but creating a preference structure that allows the explicit representation of the judgment instead of artificial numerical representations (GOMES *et al.,* 2009).

Despite being applicable in other fields of knowledge, in mining, the MCDA methodology selects the alternatives with scientific help. There are a few studies that apply MCDA for mining affairs. In this way it is possible to highlight the studies performed by Almeida *et al.* (2005), Xinchun and Youdi (2004), Lozano (2006) and Basçetin *et al.* (2006).

Almeida *et al.* (2005) used the Prométhée II method to help select the excavation method to be used for mining ornamental stones (granite and marble) in Brazil. Xinchun and Youdi (2004) proposed the evaluation of Chinese coal reserves using the AHP method. These two authors used criteria that considered the big demand for this energetic resource within the country, the decrease of the reserves and the social and economic factors involved at those enterprises. Lozano (2006) used the multiplicative variant of the AHP method to evaluate the possible alternatives of places to build a tailings dam in Colombia. Basçetin *et al.* (2006) showed an MCDA application for the selection of equipment at an open pit coal mine in Turkey, reporting his experience with the development and application of the EQS (Equipment Selection) software.

For our study, the MCDA methodology was applied to the problem of highway truck selection for working under mining conditions. These trucks were used as the main transportation system of ROM ore in a bauxite mining company.

This methodology was used because it provides:

- the use of qualitative and quantitative data to structure the decision making model;
- the choice of a method within the MCDA methodology that supplies the desired results, which could be: to order, to sort, to separate in groups, etc;
- the flexibility to use the steps according to the necessities of each problem;
- the analysis of the obtained results and the simulation of the effects of each judgment and criteria used for the result;
- the election of one or more alternatives that have similar or very near economic values from the viewpoint of the decision maker;
- the use of data from a time series, using the experience of each person involved in the decision.

2. Methods

Two lines of investigation were identified to be the most developed MCDA methods known as the *American School* and the *French School*. Even with other lines of investigation related to MCDA, these two Schools have the majority number of consistent data published.

The American School is bound to the Multi-Attribute Utility Theory (MAUT). This theory assumes that the decision maker is capable of breaking the objective function into criteria, and then the alternatives will be evaluated in a hierarchic way. The MAUT theory can be used in many situations of real problem evaluation, but some fundamental questions must be known by decision maker before MAUT is applied (GOMES *et al.*, 2004).

In Keeny and Raiffa (1976) *referenced by* Gomes *et al.* (2004), nine steps were suggested for applying the MAUT theory: 1. to identify and define the decision maker; 2. to identify and define the alternatives; 3. to define the criteria relevant to the decision problem; 4. to evaluate the alternatives using the previous selected criteria; 5. to determine the relative importance of the criteria; 6. to determine the global evaluation of each alternative; 7. sensibility evaluation; 8. to present the results and recommendations; 9. to implement the proposed results and to feedback the system with the generated results.

Many authors (Lootsma, 1997; Watson and Freeeling, 1982; Belton and Gear, 1983; etc) criticize the use of the classic AHP method because there is a likelihood that the phenomenon called *order inversion* happens. This fact occurs when an alternative is inserted or removed after the evaluation and the order of the remaining selected alternatives that are henceforth generated by the method is changed.

To avoid this effect, Triantaphyllou (2001) proposed the creation of a new multiplicative variant of the classic AHP, the Weighted Product Model (WPM). To do that, the author applied the steps of the classic AHP and proposed a weight comparison using the generated alternatives to finalize the decision process,

The study herein used WPM with the following steps: 1. preparation of the judgment matrices; 2. standardization of the judgment matrices; 3. calculation of the local average priorities; 4. calculation of the intermediate priorities; 5. calculation of the global average priorities; 6. calculation of the global priorities; 7. consistency evaluation; 8. application of the multiplicative variant; 9. sensibility evaluation; 10. conclusion and recommendations.

To the French School were assigned the studies of the Electre and Prométhée family methods. For those methods, the nine steps of the MAUT were used but with different scales, aggregation valor structures and types of results. The use of these three additional steps by the French School differentiates it from the American School.

The Electre I method was chosen because it presented a simple and direct way to express the basis of this family of methods. For the application of this method, the work of Gomes *et al.* (2004) was used, generating the following steps: 1. use of the standardized judgment matrices from WPM; 2. calculation of the agreement index; 3. calculation of the disagreement index; 4. presentation of the thresholds of agreement and disagreement; 5. sensibility evaluation; 6. conclusion and recommendations.

The Prométhée II method was applied to the case study because it uses the steps of Prométée I plus one final step and passes from a partial order to a total order. This fact generates the expected results for the case study. The following seven steps were used for the application of the described method: 1. use the standardized judgment matrices from WPM; 2. comparison of two alternatives at a time for each criterion; 3. calculation of the preference index; 4. calculation of the overcoming index; 5. calculation of the total order; 6. sensibility evaluation; 7. conclusion and recommendations.

The main criteria were elected during meetings with a group of experts in fleet management at the company. In order to construct the objective function that evaluated the problem of selecting the highway trucks for mining, this group of experts was formed by the CEO of the company, a manager and an *in loco* administrator. From these meetings the following five criteria were defined.

Criterion 1: Manufacturer prestige

The logistic operator has worked for more than a decade in the market using several highway truck models. This operator always had preferences for some activities, but over time, technological advances reduced the distance between the suppliers, creating doubts for the operator regarding the decision to continue working with the same truck manufacturer / model or to switch to another supplier.

Such changes should be studied more carefully because they are only worth it if the strong points of the different equipment from the current dealer are much better and could justify the transition period of the technology replacement. In the studied case, this condition was justified by the fact that the company already had operational, maintenance and support crews highly trained and familiar with the current supplier.

Criterion 2: Resale

An important requirement for the company is the purchased equipment resale. Unlike off-highway trucks, which in general are used until the end of their useful life, the highway trucks can be sold for other types of activities, such as civil construction, junkyard, retail trade, among others, even before their useful life ends.

The resale factor is not so important for off-highway truck solutions because: 1st, the payback of an off-highway truck is much greater than that of a highway truck; 2nd, there are usually no significant technological changes that justify an off-highway truck replacement over a short span of time; 3rd, there is not a clearly defined resale market for used off-highway trucks; and 4th, the off-highway truck's residual worth consists only of its scrap steel value and the value of its reusable parts and components for other similar units in operation.

On the other hand, there is the possibility of using an old highway truck as input for the acquisition of a new one, but this possibility changes according to the supplier. It is known that some company's suppliers are more reputable than others, so some models are easier to be resold.

According to studies conducted within the company, after three years of use the trucks begin to require greater maintenance, such as motor and gearbox grinding. It is advisable to replace the fleet at this period of time. This practice ensures investment return and minimizes operational and maintenance costs, ensuring quick resale liquidity because of a relatively new fleet. This was considered a good planning strategy to bypass prolonged crisis periods.

Criterion 3: Mechanical services from the authorized network

This criterion refers to the quality of the accredited repair shops to do repairs for the equipment supplier. First, the distance of the authorized service from the mine site must be considered. This distance can often derail an asset purchase. In the case study, this did not happen, since the mileage between the mine and shop was acceptable.

The infrastructure of the authorized service network must also be considered. We should also consider the infrastructure that the authorized network has. If the shop does not have the infrastructure and sufficient personnel, the service time will extend beyond limits. There are reports in the history of the studied company about equipment that stood still for more than three months for lack of spare parts in stock.

Criterion 4: Guarantee

Purchase guarantees for the motor and gearbox are generally linked to the usage time or distance traveled. However, suppliers extended warranties can be purchased by the buyer after an evaluation of how extensively the equipment is being used or according to the insurance policies purchased. Another important type of guarantee to be evaluated is the one offered by authorized service because such services, when requested, are valuable and should have a guarantee.

Criterion 5: Acquisition cost

The value of the equipment itself did not differentiate one alternative from another for the company studied, since the operational and maintenance costs outweighed the purchase value in a short time of use. Besides considering the value of assets, other factors can be evaluated together, such as credit line availability with longer payment time.

After listing the main characteristics that determined the acquisition of a highway truck adapted for mining, it was possible to establish the hierarchical structure shown in Figure 1. It contains the five criteria and their 12 sub criteria ramifications that were selected for the case study.

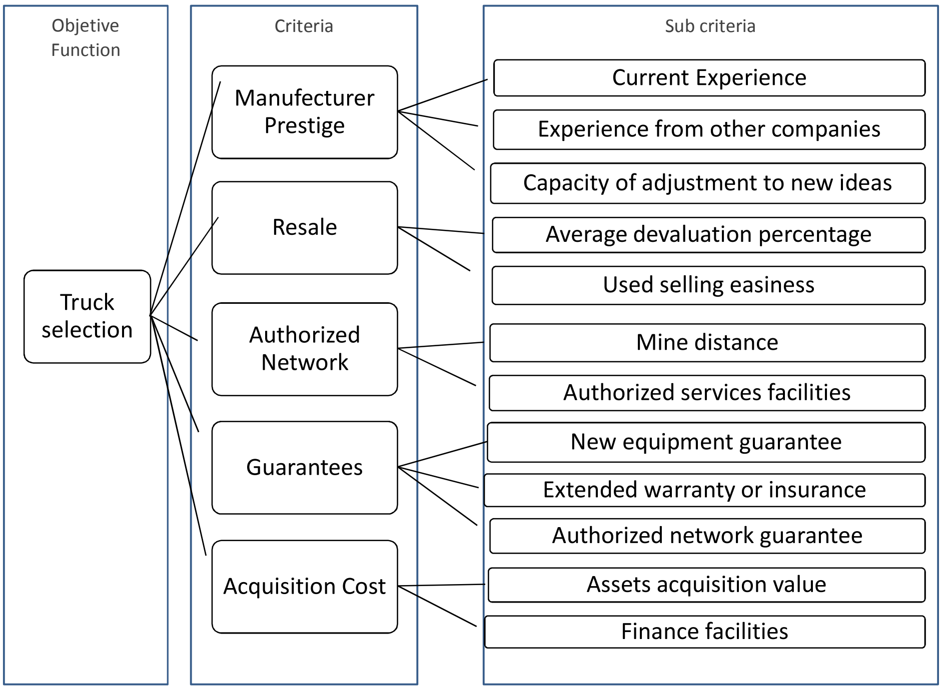

Figure 1: Hierarchy of the problem of selecting highway trucks

From the selection of the criteria and the sub criteria, the weights were determined for each in accordance with Table 1.

Table 1: Weight of the criteria and sub criteria of the objective function.

Criterion	Weight (%)	Sub criteria	Weight (%)
Manufacturer Prestige	35	Current experience	60
		Experience from other companies	30
		Capacity of adjustment to new ideas	10
Resale	25	Average devaluation percentage	20
		Used selling easiness	80
Authorized Network	15	Mine distance	50
		Authorized services facilities	50
Guarantees	15	New equipment guarantee	50
		Extended warranty or insurance	25
		Authorized network guarantee	25
Acquisition Cost	10	Assets acquisition value	80
		Financing facilities	20

Among the many models identified as being able to transport ROM, only three highway trucks were selected for evaluation because they met the technical conditions for mining operations. The trucks were identified as V1, V2 and V3 to preserve the company image.

Table 2 contains the judgment matrix generated by the evaluation of the three alternatives based on a 0-10 scale. The given score means that the alternative level meets the possible requirements for a particular sub criterion. This evaluation was performed by comparing the best market practices (benchmark). The maximum score (10) is seen as fulfilling all the requirements desired for a particular sub criterion. A grade equal to five or less means that the criterion of a given alternative obtained a rating that was equal to or less than the minimum desired.

Table 2: Alternatives V1, V2 and V3 assessment

Objetive Function	Criterion	Sub criteria	Assessment (0-10 scale)		
			V1	**V2**	**V3**
Truck selection	Manufacturer Prestige	Current experience	8	6	4
		Experience from other companies	7	7	7
		Capacity of adjustment to new ideas	9	8	8
	Resale	Average devaluation percentage	7	5	3
		Used selling easiness	9	5	3
	Authorized Network	Mine distance	5	5	5
		Authorized services facilities	5	5	5
	Guarantees	New equipment guarantee	7	6	6
		Extended warranty or insurance	8	7	7
		Authorized network guarantee	8	7	7
	Acquisition Cost	Assets acquisition value	5	7	9
		Financing facilities	5	7	8

3. Results and discussion

In the case study, we used three methods: WPM, Electre I and Prométhée II. The order V1> V2> V3 was obtained in the first and last methods and in the second method, the selection was V1> V2, leaving V3 isolated with no direct relationship with the two other highway truck alternatives.

It was found that the results obtained by Electre I were not satisfactory since it does not accurately express the opinion of the decision-maker. This reinforces the idea that we need a deep understanding of the MCDA methods to choose the most suitable one.

Moreover, the WPM and Prométhée II methods showed consistent results. The MCDA methodology proved to be quite useful for solving the problem of mining equipment selection in the sense that it provided a systematic analysis of the problem even considering the qualitative aspects. In addition, the methodology is easy to be understood and can be applied to other scenarios.

4. Conclusions

This article analyzed the problem of selection and purchase of mining equipment using the WPM, Electre I and Prométhée II methods, all three belonging to the MCDA methodology. The case study examined the acquisition and replacement of 10 highway trucks adapted to be used in the transport of bauxite ROM ore of a mining company in Minas Gerais State, Brazil.

According to the classical literature related to the equipment selection problem, it’s common to use the analysis of economic indicators, such as the net present value, internal return rate and payback. Assuming that the three truck alternatives analyzed have very close economic indicators from the standpoint of the decision maker, we used a method to select the equipment that considers both qualitative and quantitative data. The advantage in using the MCDA methodology is that it evaluates a series of qualitative and quantitative factors in the same judgment structure leading to a result that sums the experiences of those involved in the decision making process.

In the evaluation of alternatives for the acquisition of highway trucks adapted for mining, it was possible to get satisfactory results with the application of the WPM and

Prométhée II methods. The results consistently expressed the opinion of the decision maker which validated the use of the MCDA methodology to support the process of equipment selection in the mining industry.

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