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Strategic support for the distribution of vaccines against Covid-19 to Brazilian remote areas: A multicriteria approach in the light of the ELECTRE-MOr method

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Abstract

The pandemic caused by the new coronavirus has brought to light a series of concerns for the Brazilian population and government departments due to the different costly consequences that it has generated. It has also mobilized different strategic fronts that plan and implement several mitigating measures against the virus. Besides, the search for solutions for adequate care for individuals in need of support has been constant. This work uses ELECTRE-MOr, a Multi-Criteria Decision Aid (MCDA) method, to support the logistic plan for the vaccine distribution throughout Brazil, essentially to remote areas. The method allows an objective and structured classification of ideal types of thermal boxes for the storage of immunobiological inside the Cold Chain, presenting the best alternative that maintains the quality of materials until the final destination and has the best cost-benefit. Currently, the ELECTRE-MOr model is under development in a computational tool in Python, allowing the use of the method intuitively and clearly, enabling professionals of any area of expertise to apply it.

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Keywords: Multicriteria; ELECTRE-MOr; MCDA; Distribution of Vaccines; Coronavirus

1. Introduction

The pandemic of the new coronavirus is plaguing the world and has mobilized large research laboratories in search of an effective vaccine for the prevention of the disease. Many universities, pharmaceutical companies,

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and scientific institutes worldwide are pursuing the same goal in a race that involves first-rate research, high technology, billions of dollars, and great expectation [1].

Once the creation and production of COVID-19 vaccines are established, it is necessary to set up a distribution plan throughout the Brazilian territory. This has to be in accordance with the requirements of the National Brazilian Health Surveillance Agency (*ANVISA*) and, especially, the National Immunization Program (NIP), because it addresses the distribution of vaccines to remote areas. Due to several factor, the population that live in these areas have lack basic survival conditions, and there is a difficulty in accessing these places geographically and economically.

In 1973, the NIP was created by the Ministry of Health to promote the control of diseases, such as measles, tuberculosis, diphtheria, tetanus, whooping cough, polio, and smallpox. The main objectives of the NIP were to extend vaccination to rural areas, expand, and improve, throughout the country, the epidemiological surveillance system for diseases included in its scope of care [2].

The world expects the vaccine to be one of the most cost-effective measures to control the COVID-19 pandemic and relieve the impacts on health, the economy, and society [3]. According to [4], the immunological efficacy to an epidemic becomes effective due to the collective, what is known as "herd immunity" or "collective immunity". The greater the number of people immunized, the weaker the spreading power of a pathological agent is. The reduction of morbidity and mortality from diseases preventable by immunization is only possible if the first vaccination coverage rates are high and homogeneous. In a country with a territorial extension such as Brazil, one of the challenges of a program with this dimension is reaching the most remote points of the national territory. Considering the complexity of making vaccines reach the most remote regions of the country, especially the Amazon, immunization services must work based on knowledge and practices that make their actions more effective and efficient [5].

The Cold Chain is the process of storing, preserving, distributing, and transporting the NIP immunobiological. It must be defined as refrigeration conditions from the production laboratory to the moment when the vaccine is administered. Its final objective is to ensure that all immunobiological administered keep their initial characteristics to confer immunity since they are thermolabile products, that is, they deteriorate after a certain time when exposed to improper temperature variations for their conservation [6].

Siffert [7] affirms that the logistical complexity of the distribution of vaccines against Covid-19, in Brazil, is being called "The Challenge of the Century", since the country, due to all its geographic coverage, incurs risks of losses of material along the way, which would mean more risk to the population and new sanitary chaos. Siffert [7] also states the statistics of the World Health Organization (WHO) that 50% of the vaccines distributed in the world end up discarded at the expense of loss of temperature during their transport, which burdens the economic resources of the country that are already small, due to the current global situation.

In another publication on the subject, in the magazine "*Isto é*" of October 5, 2020, the pandemic reveals deficiencies in supply chains worldwide. It shows the need for a strategy for the successful supply of items and an assertive definition of the necessary resources to accomplish this operation. It facilitates the reach of regions most in need of resources and away from the large urban centers, whose logistics are difficult to access.

This study promotes a multicriteria analysis using a sensitivity and transparency method - ELECTRE-MOr, to support complex logistics planning of vaccine distribution. It guarantees the reliability in the classification of an alternative of the thermal box to ensure the preservation of the cold chain necessary to maintain the non-perishability of vaccines in long transport, regardless of the transportation to long periods of mobile storage.

The use of a Multi-Criteria Decision Aid (MCDA) method allows an objective analysis of alternatives and relevant criteria for a classification to be carried out [9]. Consequently, the use of the ELECTRE-MOr method for the classification of the most appropriate equipment for the distribution of vaccines to remote regions allows a careful, clear, and objective analysis of the available alternatives. It permits the decision-makers to glimpse through pre classes, defined by the attributes of the most relevant criteria to this preposition, and obtain an impartial and satisfactory result when applying a method available to use in a computational tool developed in the Python language, of easy use.

2. Background

For the success of vaccination programs, the safety and efficacy of immunobiological depend on the use by health professionals and the population's adherence to vaccination. The literature usually addresses these issues by discussing strategies for expanding vaccine coverage, developing researches on immunogenicity, reactogenicity, and proving the effectiveness of immunobiological. However, a factor that can compromise effectiveness is the handling of vaccines during transport and storage [10].

According to [5], vaccine distribution activities must be carefully planned, taking into account mainly logistics, which can be a little complex. Besides, there are some main factors to consider, as they can strongly influence the definition of the resources to use. They are the knowledge of the area to explore; the seasons; the identification of the population register, guaranteeing supplies that meet the needs of the region; the amount of dry ice or ice coils according to the travel time; and the knowledge of the types of coolers that can be used on the operation. These items might assure the mitigation of risks to the quality of the transported immunobiological.

Immunization activities in remote areas are called extramural. In this sense, the work of immunization under these conditions commonly brings together a series of peculiarities and challenging specificities, such as lack of electricity in constant time, maintenance of the cold chain, considerable geographical dispersion, difficulties in geographic access, adverse environmental conditions, and characteristics of the cultural diversity of people on the target population. Careful planning becomes an instrument that improves the performance, effectiveness, and efficiency of immunization activities [5].

Based on the regulations established by the National Health Foundation [6], the ideal temperature for mobile vaccine maintenance is between +2ºC and +8ºC. The transport of immunobiological uses expanded polystyrene thermal boxes to pack the immunobiological, and the transportation is by air or land in an air-conditioned vehicle or not. For this, it must take into account the storage temperature and the estimated time for displacement.

The use of Styrofoam coolers is not indicated in this case since this study aims to cover remote areas. They do not allow periodic temperature control, and the thermal capacity is limited. It is necessary to use efficient tools to structure, model, define, and classify the alternatives, given the pandemic complexity [11]. It is essential to determine the relevant criteria to classify the best alternative for the problem in question. The criteria can be based on the sources such as goals of the agreed processes, on the criteria identified in the specifications, on the data sources in general, security integrity levels or legal and other requirements [12]. From these definitions, it is possible to apply an MCDA tool to support decision-making.

Operational Research (OR) is the area of knowledge that studies and develops advanced analytical methods to assist better decision-making in the most diverse areas, whose primary interest was the efficient management of operations (typically military logistics). However, with the methodological and computational advances, combined with constant demands from other areas, the OP has modernized and expanded its field [13]. Therefore, MCDA tools have unique relevance, providing a technical and scientific basis to support from simple decisions to complex ones in the civil, military, and different disciplines.

3. Methodology

For the basis of this study, a bibliographic search was previously carried out to obtain knowledge about the Cold Chain and the handling of immunobiological. Also, it was analyzed the peculiarity of the thermal boxes and their specificity for this type of transport.

The decision-making process generally involves a choice between several alternatives. The feasible alternatives of meeting the objective, and selected for evaluation, are compared according to criteria and under the influence of attributes [14]. The MCDA methods are very useful to support the decision-making process in these cases because they consider value judgments and not only technical issues, to evaluate alternatives to solve real problems, presenting a highly multidisciplinary [15], ensuring greater accuracy and reliability in the decision-making process [16], [17]. The MCDA methods have been employed to support the decision-making process in several recent complex problems, as presented in [18]–[25].

The decision criteria can be quantitative when they correspond to attributes such as price, speed, area, and others, that is, according to well-defined numerical scales; or qualitative, such as comfort, quality, environmental impact, and others on which there are no quality units defined measures. Depending on the pre-orders established by the decision agent's preferences, the criteria may be maximized or minimized [26].

The ELECTRE-MOr method is hybrid, ordinal, and non-compensatory, an evolution of the pre-existing ones of the ELECTRE family (*Elimination Et Choix Traduisant la Réalité*), where all previous models have cardinal input. In general, ELECTRE-MOr develops in two main stages:

a) Turning ordinal criteria preferences in a vector of criteria weights;

b) Integrating the vectorial criteria of different decision-makers.

Each analyzed criterion has a weight, which is the numerical value according to their importance. To provide this, ELECTRE-MOr uses an adaptation of the MCDA method called SAPEVO (Simple Aggregation of Preferences Expressed by Ordinal Vectors), which uses qualitative and quantitative variables, and considers that, in a scenario of multicriteria classification, only the essential criteria should be used [27]. A 5-point scale (-2, -1, 0, 1 and 2) is used, where a comparison of preference between the criteria with each other is made, attributing the evaluations: from “it is much less important than“ to “it is much more important than” [9]. According to [11], ELECTRE-MOr uses three indices: agreement, disagreement, and credibility. They are represented by the following axiomatic (figure 1):

Agreement*	**Global Agreement**	**Disagreement****	**Credibility**
$c_j(a,b_h) = \begin{cases} 0 \; se \; g_j(b_h) - g_j(a) \geq p_j(b_h) \\ 1 \; se \; g_j(b_h) - g_j(a) \leq q_j(b_h) \\ se \; p_j \geq g_j(b_n) - g_j(a) > q_j \\ 1 - \left(\frac{-g_j(b_h) + g_j(a) + q_j}{-p_j - q_j}\right) \end{cases}$	$c(a,b_h) = \frac{\sum_{j \in F} w_j c_j(a,b_h)}{\sum_{j \in F} w_j}$	$d_j = \begin{cases} 0 \; se \; g_j(a) - g_j(b) \leq p \\ 1 \; se \; g_j(a) - g_j(b) > v \\ se \; v > g_j(a) - g_j(b) \geq p \\ \left(\frac{g_j(a) - g_j(b) - p}{v - p}\right) \end{cases}$	$\sigma(a,b_h) = c(a,b_h) \prod_{j \in F} \frac{1 - d_j(a,b_h)}{1 - c(a,b_h)}$
*Where *p>q*, for the result do not be Zero		**Where *v>p* for the result do not be Zero	

Fig. 1 – Axiomatic of the ELECTRE-Mor method indexes.

The ELECTRE-MOr method allows two ways to establish class profiles – *bh* and *bn*, which is defined by expressions (1) and (2):

$$b_h = g^- + h * k \tag{1}$$

$$k = \frac{g^* - g^-}{h+1}; \; g^* = max_j g_{ij}; \; g^- = min_j g_{ij}; h \; is \; the \; number \; of \; profiles \; or \; classes$$

$$b_n = g[(h + 1 - n) * L] \tag{2}$$

$$L = \frac{j}{h+1}; \; n \; is \; the \; profile \; index; \; j \; is \; the \; number \; of \; alternatives; \; h \; is \; the \; number \; of \; classes$$

The cut-off level λ is adopted to define the outranking ratio of an alternative over a class profile.

ELECTRE-MOr presents two ways to obtain the thresholds of predefined classes (*bh* and *bn*) and two ordering of the alternatives: the optimistic and the pessimistic scenario. It allows a better sensitivity analysis that makes the method transparent and well structured.

4. Case Study

The research brought five equivalent models of five distinct brands of imported, certified, and professional thermal boxes. Their manufacture is specifically for the storage of immunobiological and other medical products, with no commercial purpose. At the moment of the search, some information about the equipment was not available on the web, so it was obtained in contact with each manufacturer. Table 1 presents the alternatives and their main characteristics, which are strictly relevant for the proper transport of vaccines.

Table 1: Alternatives of certified thermal boxes and their technical characteristics

Brand/Model	**LABCOLOD**	**DOMETIC TropiCool TCX 35 Professional**	**LEC MEDICAL VCP18UK**	**SURE CHILL LTV35**	**MEDICAL SYSTEMS RCW4**
C_1. Price (EUR)	£490.00	£229,94	£164.00	£510.00	£153,46
C_2. Thermal conservation	Temperature range: -5º to +60ºC	Temperature range:-27° a +65ºC	Temperature range: -10°C a +40°C	No information available from the manufacturer, but the specification ensures the range	Temperature range: +5°C a +43°C
C_3. Volume (L)	40	33	13	7,8	20
C_4. Temperature Control	It has a digital control with a set point display for easier reading and adjustment.	Isothermal, automatically controls the temperature according to the programmed temperature. It has a temperature reading led and it also has a record function	Manual	It uses the water properties to provides 4 ° C cooling. While pre-frozen ice packs provide cooling energy, Sure Chill ensures that vaccines are never frozen and always safely stored at 2 to 8 ° C for long periods of travel.	Manual
C_5. Temperature display	Yes	Yes	Yes	Yes	No
C_6. Ease of handling	Lightweight equipment and it has easy handling	Lightweight, but without a handle for manual loading	Very lightweight and has a handle for manual loading	Complex transportation. It is divided internally into two compartments, one for vaccines and others for ice, and due to its material having great resistance to external temperature. But it has a higher weight than the other models and has no handle.	Lightweight and has a handle

C_7. Type of supply for the cooling process	It needs to use the vehicle's electric power.	Uses electricity, but has a powerful battery, that gives autonomy to access places without electricity.	It has an internal system able to generate mechanical cooling, does not use electrical energy.	It does not need electricity, its internal system works with ice cooling.	It has a self-insulation against the environment, its system maintains a stable temperature even with higher installations. In addition, a polyurethane foam injected into the double walls of these transport systems ensures excellent insulation, even in longer transport times.
C_8. Material	Resistant plastic	Resistant plastic, but digital panels and controls are exposed externally and may be more sensitive to transportation.	It is covered in aluminum, with medium-strength plastic finishes	Very resistant and safe, it has security locks to prevent accidental opening and loss of temperature to the external environment.	It has an extraordinarily robust casing that is almost impervious to external forces.

5. Results Analysis

A Likert scale was employed to compose the decision matrix. It varies from 0 to 4, according to the classification of the attributes of each alternative. For qualitative criteria - thermal conservation capacity, control and temperature adjustment, manual movement, refrigeration, and type of material, it will receive grade "4" when it has an optimal condition and "0" when it presents the worst situation. However, the temperature display (Tables 2 and 3) criterion has a binary evaluation: the value "1 " is considered when the device is present, and "0" for the opposite.

After analyzing data collected, the values of q, p, and v, which represent weak preference, strict preference, and veto, respectively, were deliberated.

Table 2: Decision Matrix

Alternatives		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
LABCOLOD		-490,00	4	40	4	1	4	1	3
DOMETIC TropiCool TCX 35 Professional		-229,94	3	33	4	1	2	2	2
LEC MEDICAL VCP18UK		-164,00	2	13	2	1	4	3	2
SURE CHILL LTV35		-510,00	1	7,8	4	1	1	3	4
MEDICAL SYSTEMS RCW4		-153,46	3	20	2	0	3	4	4
b_h	b_2	-272,31	3,00	29,27	3,33	0,67	3,00	3,00	3,33
	b_1	-391,15	2,00	18,53	2,67	0,33	2,00	2,00	2,67
b_n	b_2	-164	3	33	4	1	4	3	4
	b_1	-229,94	3	20	4	1	3	3	3
Preference values	q	50,00	0,50	5,00	1,00	2,00	0,50	0,50	1,00
	p	120,00	1,00	6,00	2,00	3,00	1,00	1,00	2,00
	v	500,00	4,00	40,00	3,00	4,00	4,00	4,00	3,00
Weights		0,16	0,94	0,56	1,00	0,19	0,50	0,56	0,25

Assigned the cut-off level (λ) of 0,7, the following result was obtained (Table 3):

Table 3: Results

Alternatives	b_n Pessimist	Optmist	b_h Pessimist	Optmist
LABCOLD	A	A	A	A
DOMETIC TropiCool TCX 35 Professional	B	B	A	A
LEC MEDICAL VCP18UK	C	C	B	B
SURE CHILL LTV35	C	C	C	C
MEDICAL SYSTEMS RCW4	B	B	A	A

6. Conclusion

The LABCOLD alternative had the best classification according to the results presented. It got an A in both thresholds of both scenarios, pessimist and optimist. However, the DOMETIC and MEDICAL SYSTEMS alternatives presented a very positive classification, being the second-best options.

The objective of this work was reached, once it was possible to comprehend the classification and analyze the attributes of each criterion in face of the presented alternatives.

The ELECTRE-MOr method is being applied in different areas to solve real issues of society and public health. Due to the simplicity and clarity of the computational tool, it can be used by professionals of any field without requiring advanced mathematical knowledge.

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