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Original Article

Acquisition of mechanical respirators for a hospital unit: a multi-criteria approach to the decision

Aquisição de respirador mecânico para unidade hospitalar: uma abordagem multicritério à decisão

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ABSTRACT

The mechanical respirator is mandatory equipment by law in hospitals in the quest to maintain life in cases of respiratory failure. The objective of this work is to propose a method for selecting the most suitable mechanical respirator for private health institutions, using a multi-criteria-hybrid method, for the analysis of four respirators common to three hospitals included in the study carried out in 2023. Six criteria were established: ventilation modes, non-invasive ventilation, safety, monitoring, price and guarantee. The weights of the criteria were established and subsequently balanced using the AHP method, and the ranking was carried out using the Promethee method. The Leistung LUFT3 respirator was the best ranked. Thus, in addition to confirming the applicability of the method in the evaluation of mechanical respirators with a view to purchasing them, it was possible to conclude that this analysis allows the hospital administrator to be more assertive in identifying the equipment that specifically meets their needs. The proposed methodology helps to minimize the unforeseen variable effect on the decision- making process, such as the influence of company representatives and equipment sales strategies.

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RESUMO

O respirador mecânico é um equipamento obrigatório por lei nos hospitais, fundamental para a preservação da vida em casos de insuficiência respiratória. O objetivo deste trabalho é propor um método para a seleção do respirador mecânico mais indicado para instituições privadas de saúde, por meio do método multicritério-híbrido, para a análise de quatro respiradores comuns a três hospitais incluídos no estudo realizado em 2023. Para isso, seis critérios foram estabelecidos: modos ventilatórios, ventilação não invasiva, segurança, monitoração, preço e garantia. Os pesos dos critérios foram estabelecidos e posteriormente balanceados com o método AHP. Já o o ranqueamento foi realizado por meio do método Promethee. O respirador Leistung LUFT3 foi o melhor ranqueado. Assim, além de confirmar a aplicabilidade do método na avaliação de respiradores mecânicos com vista a sua compra, foi possível concluir que esta análise permite ao administrador hospitalar uma maior assertividade quanto à identificação dos equipamentos que especificamente atendam às suas necessidades. A metodologia proposta contribui para minimizar o efeito variável não previsto no processo decisório, como a influência de representantes de empresas e estratégias de venda de equipamentos.

INTRODUCTION

The Covid-19 pandemic caused a shortage of mechanical ventilators, leading to the accelerated production of various models. The correct selection of these devices is crucial to meet the health needs of each institution, posing a challenge for hospital management[1]. The III Brazilian Consensus on Mechanical Ventilation listed the ventilators available in Brazil, and this number has been increasing over time, especially during the Covid-19 pandemic[2]. Anvisa implemented exceptional measures to increase the production of these devices, including them in the publication of RDC 356/2020[3].

RDC 7/2010 from the National Health Surveillance Agency[4] states that an Intensive Care Unit (ICU) must have at least one multiprocessor ventilator for every 10 beds. Furthermore, the regulation requires that 60% of the ventilators in the ICU be of the multiprocessor type, ensuring adequate capacity for the management of critical patients. These guidelines aim to ensure the quality of intensive care and the availability of essential equipment for mechanical ventilation of patients. However, the practical application of these standards can vary, especially in post-pandemic contexts, where demand and equipment availability may have been impacted.

The acquisition of medical devices is a complex task, requiring reliable methods due to the many decisive variables. It is noted that hospital administration bases its purchasing decisions on professional experiences or observational studies[5]. Many hospitals face difficulties in evaluating and selecting efficient medical equipment.

With the professionalization of hospital management, managers recognize the importance of making appropriate purchases for the success of hospitals. Reducing risks and costs, maximizing the value of purchases, improving performance, and meeting operational demands are key objectives in the equipment acquisition process[6-8].

Purchasing behavior is influenced by various factors, including cultural, social, personal, and psychological ones. Culture and social relationships shape individual perceptions and preferences, playing a fundamental role in purchasing decisions. This influence affects choices of products, brands, and behaviors. Therefore, having mechanisms that are not affected by these influences is essential for a rational and assertive purchase[9].

The decision-making process significantly influences the fate of companies due to its high complexity. With the volatility of the corporate world, substantial investments, and environmental uncertainty, companies need to adopt innovative strategies to maximize management indicators[10]. The use of tools that facilitate the acquisition of equipment, without considering social and interpersonal factors, also improves efficiency in resource allocation, reducing potential abuses of discretionary power that could favor certain companies. These companies, in turn, may exploit these advantages for profit[11].

The aim of this study is to verify the performance of the hybrid multicriteria AHP/PROMETHEE model for the purpose of acquiring mechanical ventilators for private hospital units, in order to select the equipment most suitable to the health institution's needs.

MATERIALS AND METHODS

The Analytical Hierarchy Process (AHP) simplifies comparisons by converting them into manageable numbers. This facilitates the evaluation of hierarchical elements, setting it apart from other similar methods. After comparisons and the determination of the weights of factors, the value of each method is calculated, prioritizing environmental objectives. Paired comparisons between methods are conducted based on Saaty's Fundamental Scale after a series of judgments[12].

Once the comparison matrices are complete, prioritization vectors can be calculated. The computation of the most important factors or preferences is the mathematical foundation on which the AHP method is based. Several methods have been proposed for calculating salience vectors from paired comparison matrices. The steps for applying the approximate method will be presented next[12].

a) Sum of the elements of column j:

$$sj = \sum aijni=1 ,j = 1, \ldots . , n$$

b) Normalization of comparison values:

$$nij = aijsj ,parai = 1, \ldots , n, j = 1, \ldots , n$$

c) Calculation of the priority vector by the mean of row i:

$$pi = \sum nijnj=1 n ,i = 1, \ldots , n$$

To select the acquisition criteria for ventilators in three private hospitals, hereafter referred to as A, B, and C, the characteristics suggested in the III Consensus on Mechanical Ventilation were used. These include: ventilatory modes, the ability to use the equipment with non-invasive ventilation, safety features, and monitoring capabilities, in addition to the introduction of criteria related to price and warranty period. The adopted criteria are described in **Table 1**.

Ventilatory modes are ways in which patients are ventilated, taking into account different configurations of triggering, cycling, uses, and pressure controls. Each characteristic of a specific ventilator must be considered during ventilation according to the specificity of the patient as well as the pathology affecting them.

The availability of non-invasive ventilation capabilities in a ventilator, in addition to avoiding the need to purchase a specific device for this purpose, can drastically reduce the number of patients mechanically ventilated when used.

In evaluating the safety of ventilators, it is important to consider the specifics of alarms and safety devices. Some alarms should not be deactivated, such as those indicating a lack or high distribution of gas, failure in the opening or closing of the expiratory valve, interruption of the gas or electric power supply, and deactivation of the ventilator.

The warranty of the mechanical ventilator is important, as it ensures the availability of the equipment for a legally stipulated period, at no cost to the buyer. Depending on the time between the purchase and a failure or defect, there is a possibility of an immediate replacement of the equipment with a new one.

The price of the mechanical ventilator is the commercial value for the acquisition of the equipment, reported in Brazilian currency (real), considering the various models available and that the purchase should be made only from devices regulated by ANVISA.

To establish the direction of preference, it was determined that the criteria - monitoring, warranty period, safety items, having NIV, and ventilatory modes - should be maximized while the price should be minimized, in order to achieve the best scenario for the acquisition of hospital equipment.

For the assignment of weights, clear identification and formulation of the decision problem were required. This involved the characterization of relevant criteria and alternatives as explained in the previous section. The Ipê 1.0®

Table 1 - Criteria adopted in the study and description

Criterion	Description
Ventilatory modes	Number of ventilatory modes available
Has NIV*	Non-invasive ventilation mode available
Safety features	Characteristics of alarms and safety mechanisms
Warranty	Manufacturer's coverage period for defects
Monitoring	Ventilatory monitoring available
Price	Equipment cost

software was used after a meeting with at least two managers who have direct participation in the selection of equipment for purchase, in which the interviewees reached a consensus on the application of the method.

Through the Visual Promethee Software, it was possible to elaborate the preference matrix based on pairwise comparisons between the alternatives for each criterion, creating a partial preference matrix (P). The preference index was calculated from the preference indices for each alternative in relation to the others. Finally, the ordering of alternatives that were ranked based on the preference indices, indicating the order of relative preference.

The PROMETHEE method is a decision support method that ranks alternatives. Its starting point is an evaluation matrix of alternatives that relates to the criteria, where for each criterion "j", a preference function "Pj" must be established, which can have values between 0 and 1. The preference function reproduces the manner in which the decision-maker's preference increases with the performance difference between alternatives for a given criterion, [gj(a) – gj(b)], where gj(a) corresponds to the performance of alternative a in criterion j[13].

The intensity of preference is established across all criteria for each pair of alternatives. The preference index is calculated through the preference intensities and the weights assigned to each criterion by the decision-makers. This preference index is a parameter that measures the intensity of preference of one alternative over another, considering all criteria. This can be obtained by the following equation, where $W = \sum^{n} wj$, onde w_j is the weight of criterion j[13].

$$P(a, b) = \frac{1}{W} \sum_{j=1}^{n} w_j P_j (a, b)$$

Belton and Stewart (2002)[14] report that the preference index establishes a measurable preference relationship to be used in the ranking of alternatives. When determining the preference index, the goal is then to calculate the positive outranking flow (Q+ (a)), and the negative outranking flow (Q- (a)). The positive flow establishes a relationship of preference intensity of one alternative over all others, that is, how much one alternative outranks the others. Thus, the higher Q+ (a), the better the alternative. The positive flow is given by the following equation where n is the number of alternatives.

$$Q+ (a) = \frac{\sum_{a*b} P(a, b)}{n - 1}$$

Belton and Stewart (2002)[14] continue by explaining that the negative flow corresponds to the intensity of preference of all alternatives over a specific alternative, meaning how much one alternative is outranked by the others. Thus, the best alternative has a lower Q- (a). The negative flow is given by the equation:

$$Q- (a) = \frac{\sum_{a*b} P(a, b)}{n - 1}$$

In PROMETHEE II, a complete preliminary order of the alternatives is derived from a net flow calculated for each alternative. The net flow is established by the difference between the positive and negative flows[14].

Therefore, an alternative a will outrank an alternative b if the net flow of a is greater than the net flow of b, that is, Q(a) > Q(b). An alternative a will be indifferent to an alternative b if the calculated net flows are identical, that is, Q(a) = Q(b). From this data of net flows, it is possible to generate the rankings for each decision-maker, ordering the alternatives according to the descending order of their respective net flows[14].

The criterion for choosing the four brands of ventilators was due to all units having the same equipment in common, making the analyses more assertive and thus excluding from the study the ventilators that are not present in all units.

This manuscript was translated with the assistance of ChatGPT, an AI language model de-veloped by OpenAI.

RESULTS AND DISCUSSION

At the top of the hierarchical structure, the main objective is found: the selection of the best mechanical ventilator, while at the second level of the structure, the six most relevant criteria for the choice process can be identified. Finally, at the third level, the various models of ventilators are located (**Figure 1**).

Thus, with the hierarchies defined, it is necessary to proceed with pairwise comparisons involving six criteria from the second level in relation to the first hierarchical level. In this phase, the purpose was to determine the relative importance of each criterion in achieving the defined objective. As there is only one element at the first hierarchical level, a single matrix was constructed to assess the intensity of the pairing relationships among the six criteria for each hospital studied (**Tables 2, 3, and 4**).

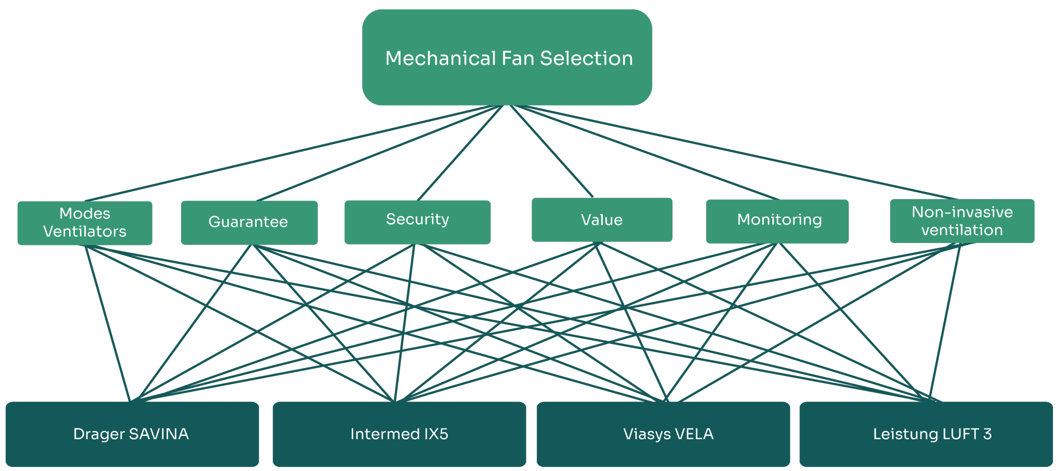

Figure 1. Structuring the problem

Table 2. Comparison matrix - Hospital A.

VENTILATORS -HOSPITAL A	SAFETY	COST	NIV	MONITOR	MODES	WARRANTY
SAFETY	1	2	3	4	4	6
COST	1/2	1	4	5	6	7
NIV	1/3	1/4	1	3	3	4
MONITOR	1/4	1/5	1/3	1	1/4	2
MODES	1/4	1/6	1/3	1/4	1	2
WARRANTY	1/6	1/7	1/4	1/2	1/2	1

Table 3. Comparison matrix - Hospital B.

VENTILATORS -HOSPITAL B	SAFETY	COST	NIV	MONITOR	MODES	WARRANTY
SAFETY	1	1/3	3	4	8	6
COST	3	1	6	8	4	7
NIV	1/3	1/6	1	1/2	3	2
MONITOR	1/4	1/8	2	1	1/7	3
MODES	1/8	1/8	1/3	1/7	1	3
WARRANTY	1/6	1/7	1/2	1/3	4	1

Table 4. Comparison matrix - Hospital C.

VENTILATORS -HOSPITAL C	SAFETY	COST	NIV	MONITOR	MODES	WARRANTY
SAFETY	1	1	3	5	7	5
COST	1	1	4	6	8	6
NIV	1/3	1/4	1	3	7	5
MONITOR	1/5	1/6	1/3	1	5	2
MODES	1/7	1/8	1/7	1/5	1	3
WARRANTY	1/5	1/6	1/5	1/2	3	1

Subsequently, this matrix was normalized by adjusting all criteria to the same unit. This was achieved by dividing each value in the matrix by the total of its respective column. In this way, by calculating the average value, it was possible to obtain the weight attributed to each criterion, representing the relative importance of each in selecting the best mechanical ventilator in each hospital studied (**Tables 5, 6, and 7**).

As observed in **Figure 2**, the criteria "Price" and "Autonomy" had the most significant impact on the objective.

From the calculation of priorities, it was possible to obtain consistency ratios of 0.075,

Table 5. Normalized matrix (Hospital A)

	1	2	3	4	5	6
1	0,4	0,531982267	0,336448598	0,290909091	0,216216216	0,272727273
2	0,2	0,265991133	0,448598131	0,363636364	0,324324324	0,318181818
3	0,133333333	0,08866347	0,111949685	0,072727273	0,108108108	0,090909091
4	0,1	0,053198227	0,037383178	0,072727273	0,216216216	0,090909091
5	0,1	0,04435186	0,037383178	0,036363636	0,054054054	0,090909091
6	0,066666667	0,037978983	0,028037383	0,036363636	0,027027027	0,045454545

Table 6. Normalized matrix (Hospital B)

	1	2	3	4	5	6
1	0,205128205	0,158640227	0,233766234	0,445623342	0,258064516	0,311688312
2	0,615384615	0,475920678	0,467532468	0,334215017	0,516129032	0,688311688
3	0,068376068	0,079320113	0,077922078	0,055702919	0,096774194	0,062937063
4	0,051282051	0,158640227	0,155844156	0,111405836	0,451612903	0,093073593
5	0,025641026	0,079320113	0,025974026	0,015915119	0,064516129	0,093073593
6	0,034188034	0,067986069	0,038961039	0,037135279	0,129032258	0,051948052

Table 7. Normalized matrix (Hospital C)

	1	2	3	4	5	6
1	0,452586207	0,637168142	0,345773875	0,318471338	0,258064516	0,25862069
2	0,452586207	0,318584071	0,461038961	0,489958158	0,516129032	0,517241379
3	0,150862069	0,159292035	0,115226337	0,183574879	0,193548387	0,172413793
4	0,090517241	0,05398283	0,03815261	0,031847134	0,064516129	0,068965517
5	0,064655172	0,031847134	0,03815261	0,031847134	0,064516129	0,103448276
6	0,045689655	0,031847134	0,023009246	0,015923567	0,032258064	0,051724138

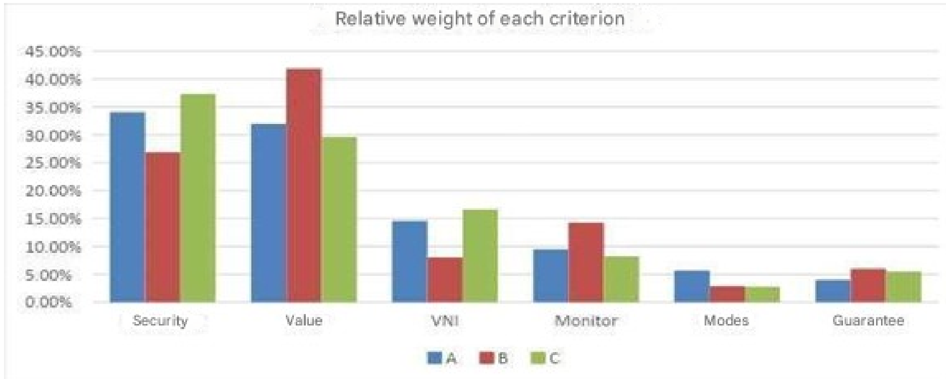

Figure 2. Relative weight of each criterion.

0.063, and 0.093 for hospitals A, B, and C respectively. Considering that these values are within the acceptable standards (CR <= 0.1), it can be concluded that the comparisons made are coherent. **Table 8** presents the structuring of the ranking problem for application in the Visual PROMETHEE software, with the criteria, their respective weights, and direction of preference, as well as the values attributed to the alternatives.

O comando *Gaia* do Visual Promethee, que forThe Gaia command of Visual PROMETHEE, which provides the corresponding Gaia Plane (**Figure 3**), allowed for a visual analysis of the decision problem studied where the Leistung LUFT3 model showed the highest net flow for Hospital A. With this result, it was possible to characterize that, among the alternatives studied, it was the one that showed the greatest distance from the origin in the direction of the decision axis (π), performing best in relation to the other criteria. It is important to highlight that a value of Δ = 99.4% was presented in the Gaia plane, a measure of the quality of the graph, which can be considered adequate since Δ was higher than 70%, the minimum value for its reliability.

The Intermed IX5 model showed the highest net flow for Hospital B, with a Δ value of 99.4% on the Gaia plane (**Figure 4**), while the Intermed Leistung LUFT3 model presented the highest net flow for Hospital C, with a Δ value of 99.4% on the Gaia plane (**Figure 5**).

Table 8. Problem structuring (Visual Promethee)

		Criteria					
		Ventilatory modes	VNI	Security	Monitoring	Value	Guarantee
	Unit	Unitary	Y/N	Unitary	Unitary	Real	Months
	Min/Max	max	Max	max	max	min	max
Alternatives	Drager SAVINA	6	Yes	4,5	8	80000	12
	Intermed IX5	8	Yes	8,0	6	65000	12
	Viasys VELA	6	Yes	8,5	8	84000	24
	Leistung LUFT 3	10	Yes	9.0	5	65000	24

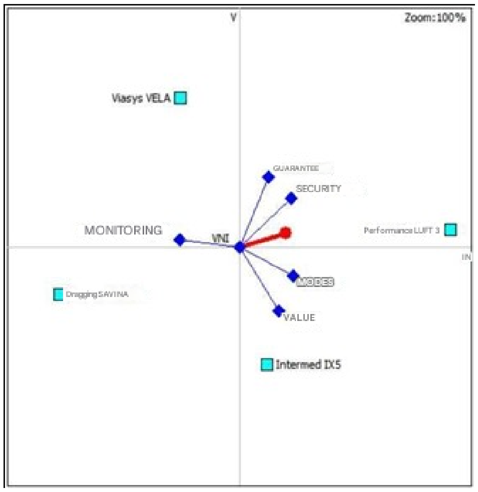

Figure 3. PROMETHEE GAIA (Hospital A).

Figure 4. PROMETHEE GAIA (Hospital B).

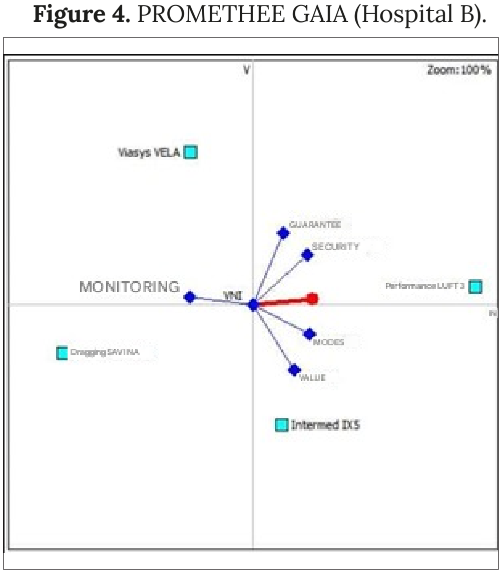

Figure 5. PROMETHEE GAIA (Hospital C).

In this study, addressing the concern about the need to implement improvements in the instruction of the process for acquiring ventilators, essential equipment in the treatment of hospitalized patients, a selection method for mechanical ventilators was proposed for three private health institutions in Campos dos Goytacazes/RJ, considering the compatibility of the ventilator with the service specificity and cost, among other selected factors.

Regarding the alternatives, it was possible to demonstrate the similarity between them as they are closer to each other. Indeed, when analyzing the obtained graphs, it is observed that the models to the right of the vertical axis are closer, indicating similar characteristics. However, the Drager SAVINA model stands out as it is isolated from the other models, a fact due to its positioning as the high-value model, but with limited safety features.

As for the criteria, they are represented by axes extending from the center, with criteria sharing analogous preferences represented by similarly oriented axes. Conversely, criteria with divergent preferences or that are in conflict were depicted by axes pointing in opposite directions, as seen in the ventilators to the left of the vertical axis of the Gaia plane.

In the scenarios presented, it was observed that the “monitoring” criterion, when appearing in isolation, indicates that it conflicts with some criteria, such as “value” and “ventilatory modes”.

This occurs because models with higher values in the “price” criterion generally offer a greater number of ventilation modes. Regarding the monitoring criterion, its isolated appearance signals a conflict with other criteria and modes. This is likely because devices focused on monitoring generally tend to offer fewer ventilatory modes.

To conclude the graphical analysis, it is crucial to consider the decision axis represented by the thicker red axis shown in the GAIA plane. This axis resembles a weighted average of the criterion axes, providing valuable data for identifying criteria that may be underestimated or overestimated. Moreover, it represents the direction of compromise, taking into account the decision-makers' perceptions of the relative importance of the criteria, i.e., the weights assigned.

Safety, in the case of clinical alarms, is focused on the clinical staff, as the overlap of alarms can compromise actions in more urgent cases due to numerous sounds in the environment of severely ill patients[15, 16]. Having the ability to prioritize and not allow the alarm to be turned off until the initial problem is resolved can be an important feature in practice[15].

In the studies by Lima Junior and colleagues, price was the third and first criterion among the studied criteria, respectively, affecting the evaluation and selection of equipment, which aligns with the results of the present study[17]. Velasquez and Hester (2013)[18] noted that the price of products and services is very important for the profitability of all hospitals; that hospital managers should seek low-cost suppliers and, in this way, price is very important in agreement with what was observed in the three hospitals included in the study.

Macharis and colleagues (2004)[19] point out that determining weights is an important step in most multicriteria methods and reinforce the viewpoint of Velasquez and Hester (2013)[18]. The latter identify the lack of precision in obtaining weights and assigning values as a disadvantage of using the PROMETHEE method in isolation, highlighting the absence of a clear method for these tasks. They suggest integrating the AHP method to improve the assignment of these values.

Ivlev and colleagues (2015)[8] observed that some multicriteria methods used for the acquisition of MRI equipment in hospital settings had a significant disadvantage because the methods did not take into account the expertise of specialists in the selection task. This fact was, unlike in this study, addressed in the present research, thus overcoming the described weakness.

Bahadori and colleagues (2020)[20] describe the direct relationship between the correct choice of medical equipment and supplies and the recovery of patients, as well as the smooth functioning and performance of healthcare professionals. They highlight the importance of this study not only for managerial and financial purposes but also for human aspects concerning the health recovery of patients. The authors also recommend that hospital managers and the purchasing team of the unit develop a protocol for assessing the quality of equipment and supplies, which should be periodically evaluated by nurses, doctors, and patients, making them key components in the development of criteria weights.

The Danish Centre for Health Technology Assessment underscores the need for better decision-making using a suitable tool to support decision-makers concerning medical devices acquired in the context of South African healthcare[21]. This finding is corroborated by Amid and colleagues (2011)[6], who also demonstrated the importance of new strategies in a supply chain, describing the selection of suppliers and equipment as a multicriteria decision problem in which the criteria have different relative importance, reinforcing the attributes of this research.

Essig (2011)[22] clarifies that formulating a single global strategy for the purchasing function is a challenging task and points out that applying a diverse set of strategies and tactics, adapted to different purchases and suppliers, may be more effective. He further emphasizes that the development of a purchasing strategy can only be comprehensible when a hierarchical model is applied that differentiates while integrating different levels of analysis.

The resulting synergy from this process of integrating more than one MCDM plays a crucial role in building more comprehensive and robust decision-analysis models. By overcoming the individual limitations of each method, this approach provides a more complete, holistic, and effective view in solving complex decision problems, becoming a valuable tool for decision-makers in various fields. This fusion of methods not only reflects the search for more comprehensive solutions but also highlights the need for adaptability in the face of the diversity of challenges encountered in decision-making. This innovative approach drives continuous evolution in the field of Multicriteria Decision Support, emerging as a promising path to address the increasing complexity in contemporary decision-making processes[23].

The current study aimed to propose and verify the performance of the hybrid multicriteria AHP/PROMETHEE model for the purpose of acquiring mechanical ventilators for private hospital units. Four ventilators common to the three hospitals were analyzed. Based on the collected data, a multicriteria analysis among the manufacturers was conducted using the PROMETHEE II method, which highlighted the Leistung LUFT3 ventilator as the top performer in meeting the demands of hospitals A and C, while the Intermed IX5 was most suitable for hospital B. This confirmed the applicability of such methods in the context of evaluating mechanical ventilators for purchase. This type of analysis allows hospital administrators to more accurately identify which ventilators meet their needs without any influence from equipment representatives and/or sales strategies.

Finally, as a perspective and suggestion for future work, it is recommended to involve various professionals responsible in the weighting of the criteria, since including insights from those who operate the equipment is of great importance and can directly influence the choice of mechanical ventilators.

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