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Ranking of ICT providers for an HEI through TOPSIS method: a guide to Decision Making

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Abstract. This document is focused on guiding Decision Makers (DM) regarding the Information and Communications Technology (ICT) infrastructure that should be selected for proper administrative and academic operation within Higher Education Institutions (HEI). These technologies include the Internet, hardware infrastructure, institutional email, and educational platforms. This selection problem arises due to the diversity of providers offering ICT services in terms of speed, storage, number of users, and costs for each of the technologies. This decision involves a thorough evaluation of the different selection alternatives that converge in a real-life scenario increasingly influenced by the use and application of technologies. The TOPSIS method is applied due to its ease of use in evaluating the various characteristics of each of the technologies and because it offers an ordering based on the values of proximity to an ideal solution, thus offering a ranking as a guide to support the decision of the DM according to his preferences.
Keywords: decision making, HEI, ICT, ranking, TOPSIS

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1 Introduction

Multi-Criteria Decision Making (MCDM) is a discipline that deals with decisions that involve choosing the best alternative among several in a decision, subject to several criteria or attributes that can be concrete or vague.

The different MCDM methods have similar objectives but work in different ways. For example, the Combined Compromise Solution (CoCoSo) method approximates the value of zero; the Analytical Hierarchy Process (AHP) works by summation; the Simple Additive Weighting (SAW) method is based on calculating maximums, while Technique for Ordering Preferences by Similarity to the Ideal Solution (TOPSIS) uses a vector method that focuses on identifying the best case (Kacprzak, 2024), who developed a new method for assessing the similarity of classifications called TOPSIS-SM.

This paper aims to support DM in their work in deciding which ICT is appropriate for HEI. One of the crucial behavioral characteristics of DM is their cognitive abilities, which influence their susceptibility to cognitive biases and heuristics that significantly affect decision making (Wachowicz, Roszkowska, & Filipowicz-Chomko, 2024), they found descriptive findings on behaviors and their impact on the functionality of criteria methods.

In this case, it should be understood that DM may vary depending on whether the institution receives government support or is part of the private sector.

One contribution of this research work is that mathematical models for decision analysis can be applied to calculations involved or related to the measurements of the different ICT variables that operate within HEI. These ICT variables or characteristics can be measured in terms of indicators or categories according to the nature of the technology being analyzed at that time.

Among the most important characteristics of the support technologies for HEI that are susceptible to being measured is the determination of the number of users who can access the organization's internal network or intranet in an isolated or simultaneous manner. In this sense, it is known that institutions are growing more in terms of the number of students, both in-person and students connected remotely. In addition, the network must support an additional number of users, such as managers and administrators, without forgetting that some institutions have campuses spread out, either in local areas or remotely. Finally, it is necessary to point out that this last form of online or remote education has gained greater relevance in recent years and more institutions are opting for this type of educational model in all its variants of distance education, such as b-learning, e-learning and Personal Learning Environment (PLE).

The speed of operation is also measurable and constitutes one of the main parameters to consider within the decision's making scheme when selecting the appropriate technological infrastructure for the institution, since the volume of information handled within it is increasingly greater and exhaustive queries within this volume of information must be as fast as possible. We know that this process consumes a lot of resources and therefore it is necessary to maintain this parameter with a high value to immediately obtain the required information.

As for the measurable parameter that corresponds to storage capacities, it is considered that it is directly proportional to the variable that measures the speed of operation of the ICT that have been implemented in the institution, since the large volumes of stored information must be accessed more quickly, otherwise, the undesirable effect of bottlenecks may be generated, where the speeds are not synchronized, thus significantly saturating the network servers. For this reason, a more detailed study is proposed that specifically considers both the speed and the storage capacity for the selection of the appropriate infrastructure for the organization.

Latency is another variable to consider since it is the time it takes for data to be transferred over the network. In this sense, it is known that emerging applications such as the Internet or the reproduction of videos with increasingly higher resolutions, which are common practices within HEI, require technologies whose latency values are as close to zero as possible (Castro Delgado & Quintero Flórez, 2020), whose results show that the Time Transmissions Interval significantly influences latency in networks.

Like the number of users connected to the network is the variable corresponding to the number of devices that can be connected to the network in isolation or simultaneously. Remember that the performance of a network depends on both the size of the bytes transmitted over the waiting time which results in the amount of information that can be sent in a given period, as well as the number of devices that can be connected simultaneously (Linero-Ramos, Camargo-Ariza, & Medina-Delgado, 2015), who propose statistical models for the traffic behavior on networks estimating the number of devices connected simultaneously.

Furthermore, it can be concluded from this study that HEI will increasingly have to include these types of methodologies for the analysis of the technologies that will be implemented, both for their operation and for the selection of technological tools for educational purposes that must be acquired by the institution as strategies to offer education that is considered to be of quality.

Finally, it is stated that not much literature was found related to the topic, which creates fertile ground for future research to relate information technologies with mathematical models for decision making when making decisions in HEI.

The second section discusses some concepts of ranking and the characteristics of the products offered by the different providers of ICT to HEI and a general view of the TOPSIS method. The third section describes the methodology applied to the present work and the results obtained. The fourth section establishes the conclusions of the research.

2 Theoretical framework

This section provides an overview of ranking theory and the different characteristics of resources offered by ICT providers, such as the Internet, hardware infrastructure, email and educational platforms, that HEI should consider for their proper functionality, as well as an overview of the TOPSIS method.

2.1 Ranking

It is common that when making a decision, there are several alternatives among which the best one must be selected, the one that optimizes the solution. Optimization must be understood in two senses: maximization (for profits) and minimization (for costs or losses).

However, on many occasions it is desirable to have an ordered list of said alternatives or options with the purpose of considering first the best option, then the second option and so on until all possible options have been exhausted, that is, establish an order of priorities. The process of building this list of preferences is commonly known as ranking.

In decision making, comparison problems are solved to ensure the best alternative and sometimes it is not known which of them is the best or not; all of them are known and must be inferred according to statistical methods. That is why selection procedures are required to determine which alternatives should be selected and this procedure is called ranking and selection of options (Jeff HONG, FAN, & LUO, 2021). These authors analyzed the use of ranking and selection procedures in solving various practical problems.

The ordering of selection alternatives is an interesting topic since, in many situations, it is necessary to determine the order of priorities to be able to choose the best possible alternatives.

The ranking of alternatives is a topic specific to decision analysis and its methods offer various ways to calculate and determine the priority of the different alternatives that are presented as possible solutions to a specific problem.

(López Leyva, 2013) establishes in his study that there are seven elements to consider for carrying out a ranking, which are: the definition of the reasons and motives for the construction of the ranking, selection of appropriate measures for the indicators, establishment of mechanisms for data collection, establishment of scales, standardization of measures, specifying the specific weight of each indicator and creation of the general behavior index.

Also (Santos Rodrigues & Gomes Rodrigues Casado, 2020), in their work on multicriteria providers decision making through interactive and flexible compensations, tell us that the ranking uses the idea of dominance relationships between the alternatives within the current space of weights, so it is possible to establish preference relationships between the alternatives to obtain a complete or partial order in each cycle of the DM.

An issue that is dealt within the ranking processes is related to the productive units or Data Management Unit (DMU) (Solana Ibáñez, 2011) whose main function is to provide DM with an ordered classification of the units regardless of the performance indicator expressed by the efficient/deficient ratio. This author proposes that when a coherent ordering is not feasible, the Super efficient DEA method (SDEA) can be applied.

2.2 Providers of ICT services for HEI

The purchasing or acquisitions area of the HEI oversees searching and selecting the different providers of ICT services in said institutions. To do this, it is necessary to identify the essential ICT services within an HEI, which are Internet access, educational platforms, technological infrastructure and email, among others.

Below are some of the characteristics of the ICT resources that are offered by the different providers as well as a brief description of them.

Internet. Without a doubt, a fundamental resource for the operation of an HEI that offers quality educational services is the Internet. Internet Service Providers (ISP) are companies that provide Internet access service (wired or WiFi) for a monthly fee, which varies according to the connection speed (Ruíz Vanoye, Díaz Parra, & Ponce Medellín, 2011), those who, in their study, recommended carrying out strategic planning to minimize technological disadvantages. The Internet is the network that will allow connections, both external and internal (intranet), within the HEI with different objectives, among which are administrative processes, online classes and/or courses, sharing of resources, institutional emails, among other services.

Next, Table 1 provides us with some of the most important characteristics that every ISP must offer, which must be subjected to selection processes when making a decision regarding hiring an ISP.

Table 1. Characteristics of an ISP

Characteristic	Observation
Type	ADSL
	Fiber
Fixed	Yes
	No
Mobile	Included
	Not included
Technical service	With
	Without
Price	Variety
Megas	Variety

Own elaboration based on (Ramírez Hurtado & Paralera Morales, 2016)

On the other hand, regarding the degree of satisfaction that every ISP must achieve from the customers' perspective, the results obtained by (Zapata Sánchez & Pérez Hervert, 2023) stand out, which are summarized in two: the proportion of products and training in personalized attention. The proportion of products means that they adapt to the needs of the institution, which is perceived as quality of service.

Likewise, the ISP must be trained and experienced in personalized attention, have personnel who understand the real needs of clients, encourage the strengthening of relationships with HEI as well as have the capacity to support a growing number of users. In the study of (Hasan, 2013), some problems related to websites used as technological tools supported by the Internet in universities are detected. These problems are further subdivided into subproblems, which can be prioritized according to measurements and are susceptible to being ranked with the application of mathematical models for decision analysis.

These problems and their subproblems are as follows: Navigation, which contains the subproblems with weak navigation support, fake links, broken links, abandoned pages, and ineffective internal searches.

On the other hand, the design problems detected on the website are made up of the following subproblems: inconsistency, inappropriate page design, problems with images, and inappropriate choice of colors. As for the problems related to content, there is outdated content and irrelevant content.

Finally, the problems detected in terms of ease of use of communication are subdivided into the difficulty with interaction with the website and not supporting more than one language.

Educational platforms. Nowadays, HEI are required to have an alternative and/or simultaneous system to the traditional face-to-face system, such as an online class system. Educational platforms offer this service for these institutions. These educational platforms are classified within what has been called Learning Management Systems (LMS) where students are offered a closed and controlled environment in which educational institutions establish elements such as participation forums, feedback tools, modules, educational content, access to study material, online exams and more (Dans, 2009), who tells us that HEI are increasingly committed to becoming more visible through the availability of their content.

According to (Sepúlveda Parrini, Pineda Herrero, & Valdivia Vizarreta, 2024), these platforms offer three areas where the research topics are located, such as students, course and teaching staff and organization. Their findings show how the quality of online higher education is interrelated with concepts such as graduate profile and accreditation. On the other hand, quality has been identified as an area of opportunity to enhance the competitive advantage of the HEI that implements these platforms. (Esteves Edurne & Pacheco, 2023) tell us that when selecting an educational platform for an HEI, the following dimensions must be considered, which are presented in Table 2.

Table 2. Dimensions of educational platforms

Dimension	Description
Social object	Production of knowledge from academic freedom and freedom of expression
Governance	Organization of co-government and autonomy, all members of the HEI have representation in decision making
Economy	Free access and permanence of students through state resources
Technologies	Autonomy to incorporate different technologies (open and private)
Communication	Horizontal, everyone can communicate freely with their peers

Currently, there are some educational platforms such as Moodle, Microsoft Teams, Classroom, Blackboard, among others. Going deeper into the function that educational platforms should fulfill in HEI, it is found that initially these served to offer the population of the institution a controlled and familiar environment; however, when online services oriented towards the consultation of web pages without the possibility of content generation by users increased (Dans, 2009).

The students' skills also increased to the point where the institution provided its students with the platform for the development of the course, and the number of instant messaging services, as well as the number of external links to which the students referred, also increased.
Of course, this also affected the teaching work of the professor, who was forced to choose or highlight the most appropriate information for the content of the class and many times, this information was generated by the students themselves, generating a closer symbiosis in the teacher/student relationship.

Finally, among the usual considerations for the selection of the educational platform to be implemented in the institution and citing (López Neira, 2006) is the justification of its independence, as the didactic design of a distance course should not be linked to a single technology but should be complemented by it, since technology is the link that will respond to the requirements of both teachers and students. The objective of this is that the nature and content of the courses offered online do not depend on the selected educational platform. In this study, the author points out that technological resources form an essential element in the pedagogical models of distance education.

Hardware infrastructure. ICT support is provided by the physical components of a network, normally known as hardware and this set of physical components is called ICT infrastructure. For this study, the ICT infrastructure provided by the different educational and communication services within an HEI will be considered.

When selecting the hardware infrastructure for the institution, the study conducted by (Duart & Lupiañez, 2005) conclude that the technological infrastructure predicts a progressive disappearance of space and time restrictions for teaching as well as the adoption of a learning model totally directed towards students. It will also allow the institution to enter the commercialization and globalization of higher education.

Similarly, the investment that university managers made in technological infrastructure was initially directed towards providing large computing equipment; however, this perspective has changed over time, since today, these investments have become a means of providing services to the entire university population.

It is also important to note that the lack of strategic planning in hardware and technology infrastructure decisions has led to poor equipment acquisition policies, as well as to the delay of administrative processes related to technology, to the alteration of maintenance plans, as well as to their respective updates. It should also be considered that with the introduction of technological infrastructure, it is often necessary to hire or promote people to positions or jobs with a variety of new profiles according to the new emerging technologies that can be implemented in the institution. In the study carried out by (López González & Ramírez Martinell, 2016) it is found that the incorporation of hardware infrastructure is an increasingly frequent trend and that it is important to investigate the opinion of the student community on how ICT is promoted within the institution. This will undoubtedly be of great help to DM in terms of acquiring the necessary equipment for the correct operation of the institution. The study also points out the relevance of the use and exploitation of the equipment in the HEI by all the personnel involved. This use is important because it can give a tendency towards future technologies that could arise within the areas of higher education.

The study also found that equipment policies should not be homogeneous due to the diversity of teacher profiles in terms of economic conditions, technological access, computer skills, cultural capital and general knowledge.

On the other hand, it is necessary to comment that the establishment of the ICT infrastructure must be carried out in a planned manner, and to do so, (Peña Casanova & Anías Calderón, 2020) establish at least two dimensions to consider, which are the process dimension and the dimension of policies. Some of the elements of each of these dimensions are analyzed below:

Processes. The processes classify technological development (to generate value for the HEI), organizational system (information flow), economic capacity (for technological renewal, maintenance and scaling), human resources (technical knowledge), impact (effect within the HEI), and feasibility (necessary knowledge, resources and authorizations).

An important part of the implementation of infrastructure processes in HEI is that they are derived from the pressure of the productive world, that is, the technological revolution and the information and knowledge societies have forced technological equipment in institutions to become more of a reality. This means that the design of plans and programs for the implementation of technologies acquires greater relevance in terms of time for the incorporation of the institution, so that it becomes a strong selection alternative by students (Torres Velandia, Barona Ríos, & García Ponce de León, 2010), who assert that infrastructure and modern equipment are different units in university environments.

These processes force the institution to move from traditional education to being an organization focused on learning. Increasingly, public institutions take on the challenge of incorporating ICT in all their areas to revalue and enhance the teaching function within the university. The competitive world forces the HEI to have an adequate infrastructure to support global and regional conferences.

Finally, it is pointed out that to the extent that the installation and implementation processes of the technological infrastructure within the institutions will strengthen both the internal operation of the same as well as the establishment of the future bases of institutional growth, which includes the number of users (internal and external), connected devices (internal and external), bandwidth (with possibilities of expansion), increase in university campuses, increase in educational quality and adding competitive advantages to the institution.

Policies. Definition of policies on how to display the services offered by the organization, a list of alerts and responses to them, performance measures (Key Performance Indicators, KPI), safeguards, failure management, change management, management of users, privilege management, among others. Another way of classifying the technological infrastructure in HEI is the one they offer (Torres Velandia, Barona Ríos, & García Ponce de León, 2010) and which is summarized in Table 3.

Table 3. ICT Infrastructure in HEI

Element	Examples
Hardware	Laptops, PC, printers
Connectivity	Existing ports, optical links, and connected laboratories
Technical support	Telecommunications, computer security, and Internet departments
Bills	Specification of IT expenses for the HEI
Digital resources	Licenses, virtual campuses (if applicable)

In this post COVID era, the use of online educational platforms was promoted globally, as well as the proliferation and/or creation of virtual universities. For this type of virtual HEI, (Cordero Guzmán & Ramón Poma, 2021) propose the preparation of ICT structure provider files, which can be summarized in Table 4 with the objective of carrying out quick checks at the time of selecting a supplier.

Table 4. Provider file

Product/Service	Characteristics
Connectivity (main campuses and/or headquarters)	Advanced network with surge capacity, extended LAN VPN, institutional cloud
Connectivity solutions	Rack, network cabling

e-mail. Institutional email within the HEI plays a predominant role in its operation. Through it, documents are issued quickly and securely, and it often constitutes the official channel of communication between the personnel that constitutes the institution.

The providers of this ICT service, according to (Almaguer Pérez & Hernández Yeja, 2021), must have appropriate measures for the elimination and/or control of attacks on the mail service, which are listed in Table 5.

Table 5. Email attacks

Attack	Description
Malware	Attack on device functionality or data corruption
Spam	Spam emails
Phishing	Email forgery
Human modification	Prevent staff from accessing emails for manipulation
Social engineering	Psychological manipulation to reveal information
Open relay	Allows users to send emails that come from any third-party email

It is also important to consider when selecting the email provider that offers cloud services (CSP, Cloud Service Provider) and includes the three layers proposed by the previously mentioned author.

Software as a service (SaaS), that is, the Institution buys or pays for access to applications on shared infrastructures. Rent infrastructure as a service (IaaS) for data storage. Rent platforms as a service (Platform as a Service, PaaS), to develop applications without updating your equipment. Consider that some providers, such as Microsoft Exchange Online, only offer SaaS services.

In line with the above, (Kumari, Agrawal, & Lilhore, 2017) make a list of possible attacks on email services, such as: Directory Harvest Attack, in which key information is collected from directory services, giving valid email names. Knowing the correct names of the institution, spammers could send messages to legitimate accounts without any problem. This problem spreads by sending many emails with little content to institutions.

Considering the Exchange Server as an example, it is known that one of its characteristics is that it specifically fights against directory harvesting attacks and this process is called tarpitting, which is defined as a practice that involves delaying the response back to a connected SMTP server. Tarpitting forces a delay between the moment a recipient is sent for acceptance to the SMTP server and the moment the response is sent back.

This is why it is desirable for the latency variable discussed earlier in this work to have values close to zero, which would greatly help this process. These authors also identify the problem of Non-Delivery Report (NDR), which is the reliance on address spoofing to achieve their goal. These are emails generated by a messaging system indicating that the recipient's address does not exist and therefore the email cannot be sent. Mail Relay Attacks are also detected, which allow mail servers to be used to send mail traffic originating from some other location, which usually consists of spam and other unwanted, unsolicited, or even illegal mail.

Finally, Mass Mailing Attacks are mentioned, where POP3 and IMAP4 protocols are used to access email; the services are aware of the clients' connections, which makes them viable targets for attacks such as denial of service (DoS) or buffer overflow attacks. Mail service providers should be aware of these problems to develop firewalls or alternative solutions, and these new services could be implemented in the initial configuration of institutional mail.

2.3 TOPSIS

Decision analysis is the best procedure for choosing a superlative alternative from all feasible alternatives. That is, there may be multiple feasible solutions to a problem. This means that different solutions to a problem can coexist that meet the requirements specified in the mathematical model proposed as a representation of the problem to be solved, but there will only be one optimal solution (the best of all of them).

This is one of the objectives pursued by decision analysis methods with many criteria (MCDM), and, in this research work, one of them, called TOPSIS, will be selected since it is responsible for measuring or weighing different preferences and is a useful tool to select the best alternative from a set of them.

TOPSIS is a MCDM decision analysis method and according to (Vega Falcón, Sánchez Martínez, Estupiñán Ricardo, & Leyva Vázquez, 2021) it is based on the concept of searching for an alternative with the shortest distance from an ideal solution that represents the best (positive ideal) and the most distant from the negative ideal or anti-ideal solution. The alternatives are classified with the use of a global index calculated based on the distances to the ideal solutions. These authors applied TOPSIS to rank universities in Ecuador.

Different mathematical models can be applied to measure the variables corresponding to the selected technological infrastructure; for this study, the characteristics of the TOPSIS method are used because this method calculates the distances, both ideal and anti-ideal, existing between the best possible solution, known as the optimal solution and the ideal and anti-ideal distances, respectively. The TOPSIS model allows the entry of different variables, and its main objective is to offer an order of the different selection alternatives according to prioritization. It is mainly based on finding the shortest Euclidean distance to an alternative considered ideal and at the same time, as far away as possible from another alternative called anti-ideal (Villanueva Ponce & García Alcaraz, 2013), who claim that TOPSIS method should be improved by incorporating Mahalanobis distances.

3 Methodology and results

The methodology used in this study covers the application of the seven stages of the traditional TOPSIS method to each of the four ICT resources specified above (Internet, educational platforms, infrastructure and email) with the purpose of determining an order of importance of the providers that offer each of these resources. Figure 1 shows the seven steps of the TOPSIS method applied to each of the technologies described above.

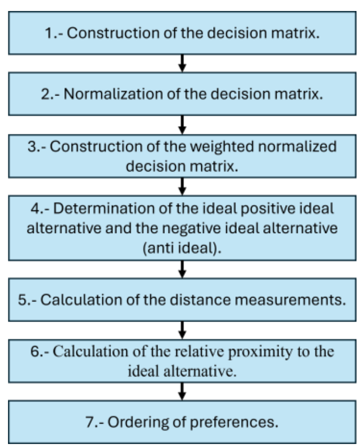

Figure 1. TOPSIS method steps.

The coefficients in the decision matrices for each of the evaluated technologies were obtained according to DM criteria, which prioritized speed of operation with higher percentages because real-time information flow is required, especially for online education, which is becoming increasingly common in educational settings. Regarding the specific weight of the number of users and cost, similar percentage weights were sought because it is understood that cost increases proportionally to the number of users served simultaneously.

We collected the data for each provider from technical and commercial information available on their institutional websites, technical sheets, quotations, and internal reports from the Information Technology Department of the Polytechnic University of Altamira. When official information was not accessible, we used average estimates based on previous studies about the performance and costs of ICT services in higher education institutions. We then organized these values into decision matrices according to the criteria defined by the DM and analyzed them using the TOPSIS method.

3.1 Internet

The calculation of the Internet resources is carried out below with the help of the TOPSIS method. The coefficients of 70% for speed and 30% for cost were determined. This is because HEI prioritizes speed over the cost of the service. A maximization function is also established for speed and a minimization function for costs. Table 6 shows the application of the TOPSIS method to Internet providers and their corresponding ranking.

Table 6. Application of the TOPSIS method to Internet providers

Decision matrix			Normalized matrix	decision	Weighted normalized decision matrix				
	Velocity (Mbps)	Cost	1,135.87	1,674.06					
Provider	MAX	MIN					Ideal distance	Anti- ideal	Proximity
A3	1,000	1,200	0.880	0.716	0.616	0.215	0.143	0.610	0.809
A2	500	800	0.440	0.477	0.308	0.143	0.316	0.310	0.495
A1	200	600	0.176	0.358	0.123	0.107	0.494	0.158	0.243
T2	10	400	0.008	0.238	0.006	0.071	0.610	0.143	0.190
T1	10	450	0.008	0.268	0.006	0.080	0.610	0.134	0.180
	0.7	0.3		Ideal	0.616	0.071			
				Anti-ideal	0.006	0.215			

3.2 Network infrastructure

For the network infrastructure, different commercial brands of switches, routers, access points and bridges were considered. For the switch suppliers, the percentages of 10%, 40%, 30% and 20% were determined for the characteristics of reach, velocity, users and cost, respectively. The maximization functions are established for the characteristics of range, speed and number of users, while the minimization function is established for the cost criterion. Table 7 shows the application of the TOPSIS method to switch suppliers and their corresponding ranking.

Table 7. Application of TOPSIS method to switches providers

	Decision matrix				Normalized decision matrix			
	Reach (m)	Velocity	Users	Cost	10004.9	208,016.25	2,003.07	25003.99
Provider	MAX	MAX	MAX	MIN				
C	300	208,000	2,000	25,000	0.029	0.999	0.998	0.999
T	10,000	1,000	100	400	0.999	0.004	0.049	0.015
H	100	2,400	48	200	0.009	0.011	0.023	0.007
	0.1	0.4	0.3	0.2				

	Weighted normalized decision matrix						
	Reach (m)	Velocity	Users	Cost	Ideal distance	Anti-ideal distance	Proximity
Provider	MAX	MAX	MAX	MIN			
C	0.002	0.399	0.299	0.199	0.220	0.493	0.691
T	0.099	0.001	0.014	0.003	0.489	0.220	0.310
H	0.00009	0.004	0.007	0.001	0.501	0.198	0.283
	0.1	0.4	0.3	0.2			

The same method was applied to the information obtained from router suppliers, with weights of 10%, 40%, 30% and 20% to the characteristics of range, speed, users and costs, respectively. The maximization functions are established for the criteria of reach, speed and number of users, while the minimization function is assigned to the cost criterion. Table 8 shows us the application of TOPSIS to the information obtained from router suppliers.

Table 8. TOPSIS application to routers providers

	Decision matrix				Normalized decision matrix			
	Reach (m)	Velocity	Users	Cost	374.16	18,870.34	2,027.93	2,040.22
Provider	MAX	MAX	MAX	MIN				
C	200	10,000	2,000	2,000	0.534	0.529	0.986	0.980
T	300	16,000	300	350	0.801	0.847	0.147	0.171
H	100	300	150	200	0.267	0.015	0.73	0.098
	0.1	0.4	0.3	0.2				

	Weighted normalized decision matrix						
	Reach (m)	Velocity	Users	Cost	Ideal distance	Anti-ideal distance	Proximity
Provider	MAX	MAX	MAX	MIN			
C	0.053	0.211	0.295	0.196	0.219	0.334	0.610
T	0.080	0.339	0.044	0.034	0.251	0.374	0.597
H	0.026	0.006	0.022	0.019	0.434	0.176	0.288
	0.1	0.4	0.3	0.2			

For the access points, the weights of 10%, 40%, 30% and 10% were again considered to measure the characteristics of range, speed, users and costs, respectively. On the other hand, the maximization functions are established for the criteria of reach, speed and number of users, while the minimization function is assigned to the cost criterion. Table 9 shows us the application of the TOPSIS method to the information obtained from access point providers and their corresponding ranking.

Table 9. Application of TOPSIS method to access point providers

	Decision matrix				Normalized decision matrix			
	Reach (m)	Velocity	Users	Cost	331.66	11,562.54	657.37	1,624.80
Provider	MAX	MAX	MAX	MIN				
C	100	11,000	400	14,00	0.301	0.951	0.608	0.861
T	300	3,550	100	200	0.904	0.307	0.152	0.123
H	100	300	512	800	0.301	0.025	0.778	0.492
	0.1	0.4	0.3	0.2				

	Weighted normalized decision matrix						
	Reach (m)	Velocity	Users	Cost	Ideal distance	Anti-ideal distance	Proximity
Provider	MAX	MAX	MAX	MIN			
C	0.030	0.380	0.182	0.172	0.167	0.394	0.702
T	0.090	0.122	0.045	0.024	0.319	0.195	0.379
H	0.030	0.010	0.233	0.098	0.382	0.202	0.345
	0.1	0.4	0.3	0.2			

Finally, for the bridges, the weights of 10%, 40%, 30% and 10% were again considered to measure the characteristics of range, speed, users and costs, respectively. On the other hand, the maximization functions are established for the criteria of reach, speed and number of users, while the minimization function is assigned to the cost criterion. Table 10 shows the application of the TOPSIS method to bridge providers according to the information found.

Table 10. TOPSIS application to bridge providers

	Decision matrix				Normalized decision matrix			
	Reach (m)	Velocity	Users	Cost				
Provider	MAX	MAX	MAX	MIN	7,071.77	881.53	191.30	1,211.12
T	5,000	867	100	160	0.707	0.983	0.522	0.132
H	100	150	150	35	0.014	0.170	0.784	0.028
C	5,000	54	64	1,200	0.707	0.061	0.334	0.990
	0.1	0.4	0.3	0.2				

	Weighted normalized decision matrix						
	Reach (m)	Velocity	Users	Cost	Ideal distance	Anti-ideal distance	Proximity
Provider	MAX	MAX	MAX	MIN			
T	0.070	0.393	0.156	0.026	0.081	0.416	0.837
H	0.001	0.068	0.235	0.005	0.332	0.238	0.418
C	0.070	0.024	0.100	0.198	0.437	0.069	0.136
	0.1	0.4	0.3	0.2			

3.3 e-mail

Considering the email providers, five of them were found, which, according to their characteristics and applying the TOPSIS method, the results shown in Table 11 were obtained. The weights of 60%, 20%, 10% and 10% to storage characteristics, speed, number of users and costs. The maximization function was also assigned to the criteria of storage, speed and number of users, while the minimization function was applied to the cost criterion.

Table 11. Application of TOPSIS method to email providers

	Decision matrix				Normalized decision matrix			
	Storage (GB)	Velocity (Mbps)	Users	Cost				
Provider	MAX	MAX	MAX	MIN	2,247.22	8	2	218.17
G2000	2,000	4	1	180	0.889	0.5	0.5	0.825
Y	1,000	4	1	100	0.444	0.5	0.5	0.458
G200	200	4	1	60	0.088	0.5	0.5	0.275
G100	100	4	1	40	0.044	0.5	0.5	0.183
	0.6	0.2	0.1	0.1				

	Weighted normalized decision matrix						
	Storage (GB)	Velocity (Mbps)	Users	Cost	Ideal distance	Anti-ideal distance	Proximity
Provider	MAX	MAX	MAX	MIN			
G2000	0.533	0.1	0.5	0.082	0.064	0.507	0.8877
Y	0.266	0.1	0.5	0.045	0.268	0.243	0.4752
G200	0.053	0.1	0.5	0.027	0.480	0.061	0.1128
G100	0.026	0.1	0.5	0.018	0.507	0.064	0.1122
	0.6	0.2	0.1	0.1			

3.4 Educational platforms

Regarding the educational platforms, data from five providers was found and based on that information, the TOPSIS method was applied to prioritize the surroundings of these providers.

The percentages of 30%, 10%, 30% and 30% were adjusted to the characteristics of storage, speed, users and costs, respectively. On the other hand, the maximization function was assigned to the criteria of storage, speed and number of users, while the minimization function was assigned to the cost criterion. Table 12 shows the application of the TOPSIS method to educational platform providers.

Table 12. TOPSIS application to educational platforms

	Decision matrix				Normalized decision matrix			
	Storage (TB)	Velocity (Mbps)	Users	Cost	1414214	707106781	229.13	8,996.42
Provider	MAX	MAX	MAX	MIN				
CE	1	1	1	1,100	0.7071	0.141	0.004	0.122
CP	1	1	1	1,210	0.7071	0.141	0.004	0.134
MSM	0.001	4	200	7,881	0.0007	0.565	0.872	0.876
MM	0.0005	4	100	3,408	0.00035	0.565	0.436	0.378
MS	0.00025	4	50	2,130	0.00017	0.565	0.218	0.236
	0.3	0.1	0.3	0.3				

	Weighted normalized decision matrix						
	Storage (GB)	Velocity (Mbps)	Users	Cost	Ideal distance	Anti-ideal distance	Proximity
Provider	MAX	MAX	MAX	MIN			
CE	0.212	0.014	0.001	0.036	0.263	0.310	0.540
CP	0.212	0.014	0.001	0.040	0.264	0.307	0.537
MSM	0.00021	0.056	0.261	0.262	0.309	0.263	0.459
MM	0.00010	0.056	0.130	0.113	0.260	0.202	0.436
MS	0.000053	0.056	0.065	0.065	0.291	0.206	0.415
	0.3	0.1	0.3	0.3			

Finally, Table 13 summarizes the best rated ICT providers considered in the study with the best proximity values according to the TOPSIS method.

Table 13. Summary of best evaluated providers

TIC	Provider	Ideal distance	Anti-ideal distance	**Proximity**
Internet	A3	0.143	0.610	**0.809**
Switches	C	0.220	0.493	**0.691**
Routers	C	0.219	0.334	**0.610**
Access points	C	0.167	0.394	**0.702**
Bridges	T	0.081	0.416	**0.837**
e-mail	G2000	0.064	0.507	**0.887**
Educational platforms	CE	0.263	0.310	**0.540**

4 Conclusions

The ranking of Internet providers generated by the TOPSIS method, shown in Table 6, generates Figure 2, which shows said ranking where it is highlighted that the best positioned provider is A3 with a proximity value of 0.809, while the least favored is supplier T1 (0.1805). It is also observed that the proximity line has a greater affinity with the anti-ideal line, showing a decline in choice preferences for suppliers A1, T2 and T1, respectively.

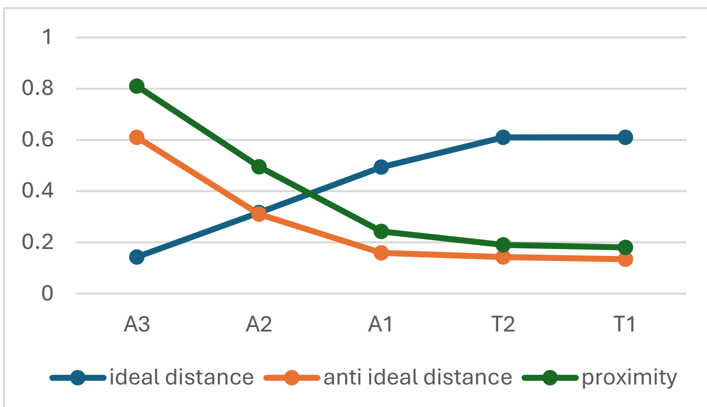

Figure 2. Ranking of Internet providers. Provider A3 is the best rated (proximity)

Figure 3 is generated from Table 7 and shows the ranking of the suppliers of the ICT resources of the switches. In conclusion, it is highlighted that supplier C is the best weighted with a proximity value of 0.691, while the worst weighted is supplier H with a proximity value of 0.283. It is observed that the proximity line shows a relative parallelism with the anti-ideal distance line, which offers us a perspective that suppliers T and H, respectively, do not satisfy the demands of the HEI, favoring themselves in this way the choice of supplier C.

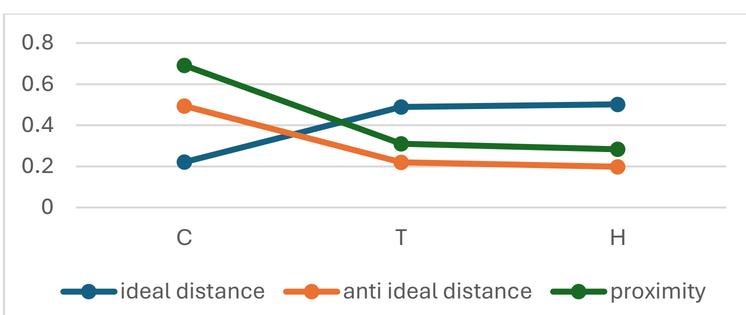

Figure 3. Ranking of switch providers. Provider C is the best rated (proximity)

From Table 8, Figure 4 is generated, which shows the ranking of the router suppliers, and where it can be seen that suppliers C and T obtained very similar proximity values (0.61 and 0.597, respectively), which means that it would be indistinct to choose one over the other. The proximity line is very far from the ideal and anti-ideal distance lines, which gives us an acceptable degree of confidence that this range of suppliers is appropriate.

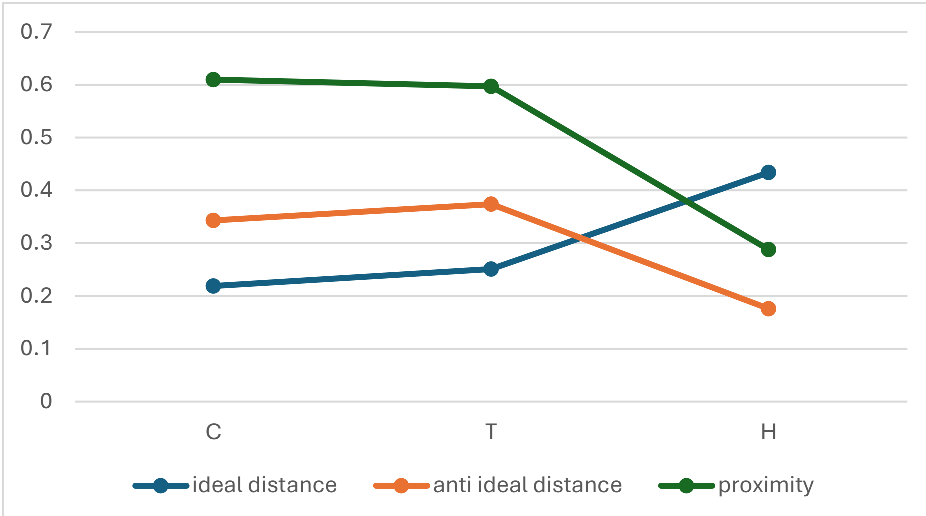

Figure 4. Ranking of routers providers. Provides C and T are the best rated (proximity)

Regarding the access point providers, Figure 5, whose origin is Table 9, concludes that the best provider is C (proximity 0.702), while providers T and H showed very similar proximities to each other as the least favored. A convergence is observed between the proximity line and the ideal distance line, which indicates that although suppliers T and H are not the best positioned, they can meet the requirements of the HEI adequately.

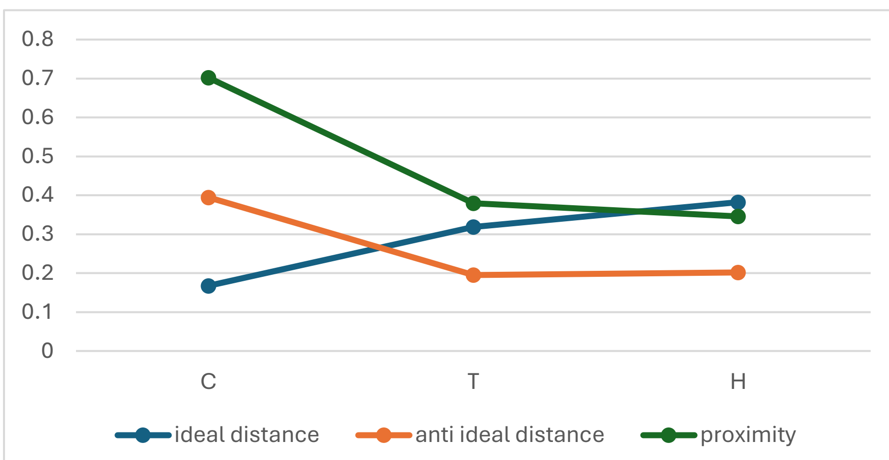

Figure 5. Ranking of access point providers. Provider C is the best rated (proximity)

Likewise, regarding ICT bridge providers, Figure 6 suggests that the best positioned provider is T with a proximity value of 0.837, while the worst positioned was provider C (proximity of 0.1367). The ideal distance line and the anti-ideal distance line are inversely proportional to each other and mutually exclusive, which indicates that the proximity line should be the basis of this choice of this ICT resource for the HEI.

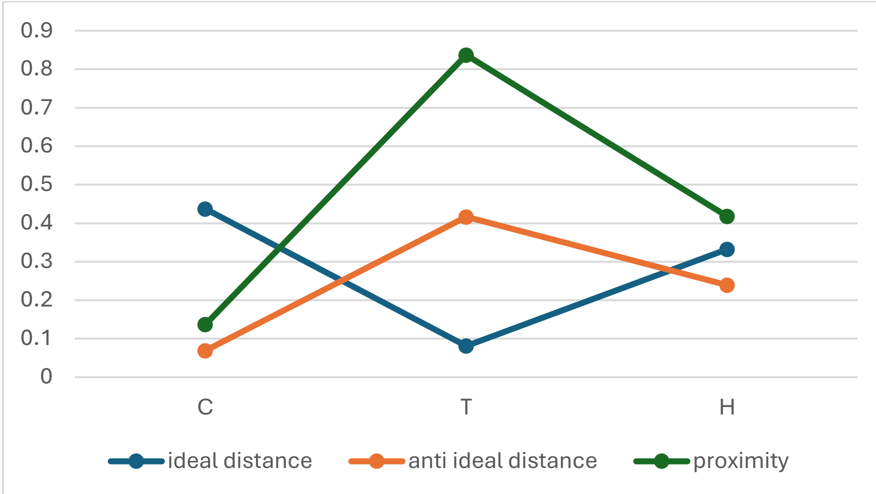

Figure 6. Ranking of bridges providers. Provider T is the best rated (proximity)

The email providers were also ranked by the TOPSIS method, and the result is shown in Figure 7, where it can be concluded that the G2000 provider was the best evaluated with a proximity value of 0.8877 while the worst positioned were the suppliers G200 and G100 with values of 0.1128 and 0.1122, respectively, which implies that they are under equal circumstances. On the other hand, it is highlighted that the proximity line bears a certain similarity to the anti-ideal line in the final part of the lines, which confirms that it would be desirable not to consider the worst positioned suppliers.

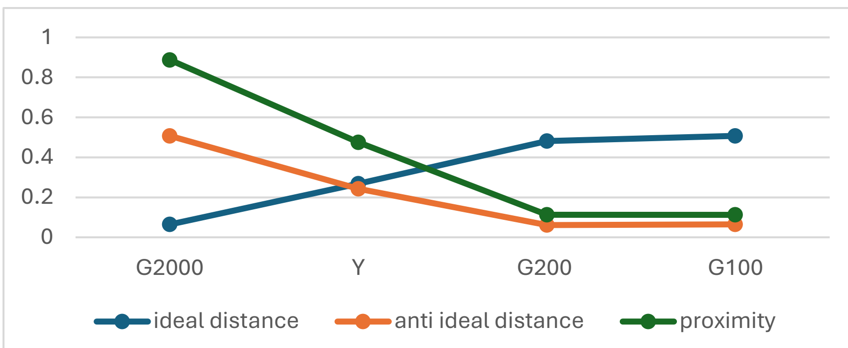

Figure 7. Ranking of e-mail providers. Provider G2000 is the best rated (proximity)

Finally, regarding the ranking of educational platform providers, Figure 8 indicates that the providers with the best proximity value are CE and CP with values of 0.5401 and 0.5379, respectively, which indicates that both could be considered for the final choice, however, it is highlighted that the other providers are not very far from them, so the final choice of this ICT resource could be inconclusive, above all, because the ideal and anti-ideal distance lines are very similar each other.

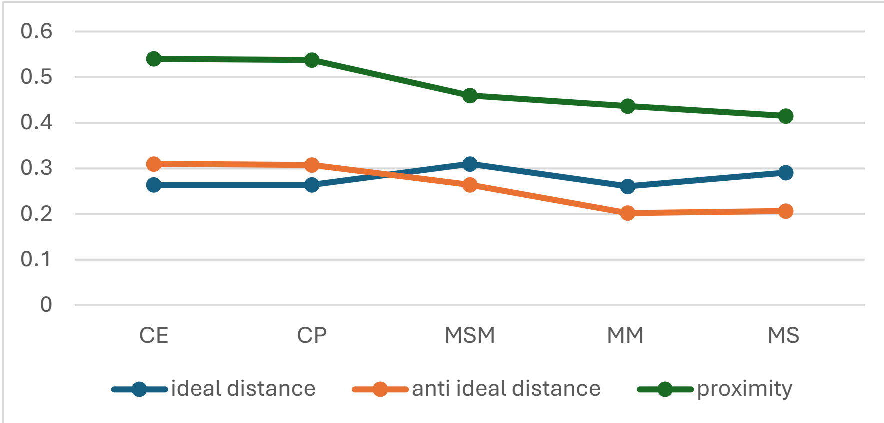

Figure 8. Ranking of educational platforms providers. Providers CE and CP are the best rated (proximity)

In the cases of router providers (Figure 4) and educational platforms (Figure 8) where the differences between the best rated providers are very small ("technical ties", although there is a "winner" provider) a second tie breaking criterion is recommended considering the highest values of the ideal distances; if the tie still persists, a third criterion would be used consisting of considering the lowest values of the anti-ideal distances to provide greater clarity in the decision making process.

The need for the integration of DM groups in HEIs is observed in order to evaluate some of the decision alternatives inherent in the institution's strategic operations, such as the acquisition of innovative technology aimed at increasing educational quality and thus gaining a competitive advantage; on the other hand, HEIs should capitalize on the calculated values since these quantitative values offer real alternatives for deciding, eliminating subjective tendencies in the decision.

Future research

As future work, it is highly recommended to identify different characteristics of ICT resources, such as those mentioned in this study (Internet, educational platforms, infrastructure and email) and another more, and assign a weight to each of them so that they can be subjected to the same TOPSIS method or to another of the many existing ones (fuzzy TOPSIS, AHP, ELECTRE, PROMETHEE) with the purpose of ranking ICT resources within the HEI.

TOPSIS was chosen over AHP primarily because it uses real values while AHP relies on pairwise comparisons; furthermore, TOPSIS offers a ranking of all alternatives while ELECTRE sometimes does not allow comparisons; and finally, TOPSIS was selected over PROMETHEE because it is less complex and therefore handles fewer intermediate decisions.

Parameterization is proposed in the calculations of the TOPSIS method. In this case, the percentages of application of the method used in each of the ICT infrastructures considered in the study vary according to the characteristics of the measurement variables of each of them. It is desirable that these percentages be captured by whoever carries out the research to have different scenarios with different values in each of the tests applied, with the aim of making more specific comparisons and thus achieving the best possible selection. This parameterization can be carried out through prerecorded formulas in the Excel file or using a programming language such as C, Python, or Java.

As mentioned above, the TOPSIS method is based on the calculation of Euclidean distances. It could be interesting to apply the Mahalanobis distances method in a next work to obtain results under this new scheme and in the same circumstances, to obtain results and to be able to make the corresponding comparison between the Euclidean and Mahalanobis distances and thus strengthen the criterion of most appropriate selection for the ranking of the technologies and their characteristics mentioned in this study.

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