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Multicriteria Analysis for IoT Selection in a Telemetry System

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***Abstract*—The speed of technology evolution offers us more and better alternatives to solve problems and to increase the efficiency of processes. Such is the case of Communications networks and especially the Internet. Nowadays, Internet connection has become, to some extent, a necessity within societies; all kinds of devices can be connected through the Internet (IoT). In this sense, using the Internet for data transmissions at industrial levels (Industry 4.0) brings technical and economic advantages that allow improving the processes efficiency. It is possible to obtain good quality data in real-time and at a low cost using the Internet in Telemetry processes. This paper proposes a multicriteria analysis to find the most suitable IoT technology for a telemetry network of water meters in the city of Huacho, Peru. First, the types of IoT available in the area are established, then a balance is made accordingly to technical, social, and economic criteria; and finally, the most appropriate IoT technology is obtained for the case study.**

***Index Terms*—Internet, information technology and systems, network protocols, secision tables.**

1. Introduction

THERE is no doubt that technological evolution conditions the way we see the world and interact with it. This evolution is increasingly accelerated. The techniques and knowledge that arise in response to everyday problems acquire new applications in a short time. Such is the case with telemetry and the Internet.

The appearance of concepts such as the Internet of Things (IoT), which defines the possibility of connecting computers through the Internet, has resulted in the evolution of applications that explore the possibility of connecting industrial systems remotely through this communication network. It is at this point where telemetry systems acquire a new dimension.

This paper proposes a multicriteria analysis to find the most suitable IoT technology for a telemetry network of water meters in the city of Huacho, Peru. First, the available IoT platforms are described showing their most important characteristics. Then, in the third section, the methodology used for the multicriteria analysis is explained. This section presents the entire procedure and the equations applied to reach an objective decision. The fourth section contains the analysis carried out for the case study. Finally, in the fifth section, the result obtained in the previous one is discussed, and possible future applications of the methodology used are proposed.

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2. IoT Technologies

The term IoT encompasses everything connected to the Internet, but it is increasingly being used to define objects that "talk" to each other [1]. This technology has been being applied in different industrial areas, such as smart agriculture, smart health care, or smart manufacturing [2]. The evolution of technology has brought low-power consumption devices, more efficient communication protocols, and several link platforms. These important advantages for distance connection between devices make the application of the Internet in Telemetry systems almost an obligation.

IoT platforms have a central role within communications systems and allow the implementation of different applications accordingly to their own characteristics [3]. In this sense, to select an IoT platform for a Telemetry system, there are several criteria that should be established, then weighted accordingly to their importance, and finally evaluated.

There are several IoT technologies available around the world; they will be briefly described below.

2.1 DASH7

The DASH7 Alliance (D7A) is an open-source active RFID standard for WSAN protocol. D7A complies with the ISO/IEC 18000-7 standard. ISO/IEC 18000-7 is an open standard for the license-free 433 MHz ISM band air-interface for wireless communications. The 433 MHz frequency provides D7A with a long propagation distance and better penetration. A full OSI stack (7 OSI layers) known as D7A protocol (D7AP) is specified. It provides a long-range (up to 2 Km) and low latency with multi-year battery life to connect moving objects [4].

2.2 Nb-IoT

Narrow Band Internet of Things was set up by 3GPP in Cellular systems in support of ultra-low complexity and low throughput Internet of Things. It defines a new radio access technology that can be integrated into the LTE standard. NB-IoT is built from existing LTE functions, but many features have been removed to keep this standard as simple as possible to reduce device cost and minimize battery consumption. This optimization includes removing handover, carrier aggregation, measurements to monitor the channel quality, and dual connectivity. NB-IoT operates on the same licensed frequencies used by LTE and employs QPSK and BPSK modulations [4].

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2.3 LoRaWan

LoRaWAN is an open standard architecture developed by LoRa Alliance. LoRa is a physical layer technology that enables long-range, low data rate, and low power wireless communication. It is an unlicensed band technology that modulates the signals in the sub–GHz ISM band using the spread spectrum technique [4].

Like Sigfox, GPRS, and NB-IoT, the LoRaWAN protocol is based on a star protocol where each device communicates with a base station which relays the information to and from a central server via an IP-based protocol [5].

2.4 GPRS

In the past, most of the applications that required low data rates for a long-range were using cellular networks. This type of network provides the users with many services. Before the emergence of LPWAN technologies, cellular networks had been offering the GSM, GPRS, EDGE, 3G, and 4G technologies. Today, 3G/4G technologies aim to provide users with minimum latency and high data rates for multimedia applications. For this purpose, most of IoT applications were used in the GPRS networks. GPRS is a 2.5G mobile communication that provides a data rate of 56 to 114 kbps with a range up to 26 Km. The primary disadvantages of the GPRS network are the power consumption and high maintenance cost [4].

The GPRS systems have been deployed for many years and serve as the reference for LPWA technology in many markets today. GPRS is the packet radio service built on top of GSM and uses GMSK modulation. It requires a frequency reuse scheme of up to 12, providing an inefficient spectral density. GPRS and NB-IoT operate in the licensed bands and are therefore not restricted by duty cycle or listen before talking limitations [5].

2.5 Sigfox

SigFox uses Ultra-Narrow Band (UNB) modulation with Differential Binary Phase-Shift Keying (DBPSK) at 100 bps. In SigFox, the device initiates a transmission by sending three uplink packages in sequence on three random carrier frequencies. The base station will successfully receive the package even if two of the transmissions are lost due to, e.g., collision with other devices or interference from other systems using the same frequency. The duty cycle restrictions of the utilized sub-band in the 868 MHz EU ISM band is 1 %. Therefore, a SigFox device may only transmit 36 seconds per hour. The time on-air is 6 sec per package, and thus the maximum is six messages per hour with a payload of 4, 8, or 12 bytes. [5]

2.6 Weightless

Weightless is managed by the Weightless-Special Interest Group. Three standards have been proposed by the group, namely Weightless-N, Weightless-W, and Weightless-P. This section will focus on the most recent standard: Weightless-P.

Weightless-P is a non-proprietary physical layer technology. It uses GMSK and QPSK for modulating the signal. These modulating schemes are very well known and are used in various commercial products; hence the end devices do not require a proprietary chipset. Weightless-P divides the Sub-GHz ISM spectrum into 12.5KHz narrow channels, and each channel offers a data rate of 200 bps to 100 Kbps. The firmware of these devices can be upgraded by air using its own wireless link because the bidirectional communication is fully supported. [6].

2.7 RPMA

Formerly known as On-Ramp Wireless, it came up with Random Phase Multiple Access (RPMA), which is a spread-spectrum technology operating on the 2.4GHz ISM band instead of the sub 1GHz bands and leverages more relaxed regulations on the spectrum across different regions.

Like in LoRaWAN, a base station in RPMA's is also capable of receiving transmissions on all the spreading factors. Also, like LoRaWAN adaptive data rate (ADR) technique is employed by the devices, where devices can select optimum spreading factors based on the downlink signal strength.

RPMA uses a form of Viterbi algorithm that allows guaranteed message arrival at the base station even with the Packet Error Rate (PER) as high as 50%, and security is improved using encryption [6].

2.8 NB-Fi

NB-Fi is an LPWAN protocol that supports secure bidirectional communication for IoT, machine-to-machine (M2M), Smart Grid, Smart Utilities, Smart City, and industrial applications. NB-Fi is a protocol that was developed by WAVIoT and designed for secure wireless transmission of small volumes of data over long distances with low energy consumption. NB-Fi is an open standard with the disclosed format of NB-Fi messages and relevant technical data required for manufacturers to produce compatible end-devices.

NB-Fi standard supports up to 4.3 billion devices in a single network with a 32-bit ID for each device. NB-Fi does not use IP addressing (IPv4, IPv6) to optimize the size of the payload. IoT devices such as sensors and gauges can transmit tiny data packages, only a few bytes. As the minimum size of the IP header is 20 bytes, the Non-IP Data Delivery (NIDD) approach allows developing simpler and cheaper devices. Data exchange between devices and third-party applications is possible via the WAVIoT IoT platform's API [7].

2.9 LTE Cat-M1

As one of the advanced wide area network technologies, LTE is regarded as a promising candidate for accommodating a large amount of MTC devices. However, the current infrastructure of LTE networks is built mainly for broadband communication used by smartphones. To support MTC devices, 3GPP has been working on study items for MTC since 2011 [2] and has already undergone several amendments to include new MTC-oriented features based on the existing LTE

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architecture. By reusing most of the existing LTE technology, it requires only a software upgrade to provide MTC service. One critical enhancement is LTEeMTC (enhanced MTC) introduced in Release 13, which is mainly for low-cost, low-power, low-rate, and delay-insensitive MTC devices. Specifically, Release 13 defines a new user equipment (UE) category, namely CategoryM1 (Cat-M1), to achieve enhanced coverage in reduced bandwidth as low as 1.4MHz. Moreover, to further reduce the cost and complexity of these eMTC devices, Cat-M1 also supports operation with only one receive antenna. The need for low-complexity hardware design also makes coverage enhancement more challenging [8].

For the multicriteria analysis to select the most suitable IoT technology to be implemented in the Telemetry System, only four platforms were included: LoRaWAN, Sigfox, Gprs, Nb-IoT. The other platforms are not available in the country.

3. Methodology

As mentioned before, there are many IoT technologies in the market with different technical characteristics. The selection of one of them for project implementation is not a simple task. There are several factors that should be analyzed, and each factor has its own importance depending on the project's nature. Regarding this, a multicriteria analysis is carried out to select the best alternative.

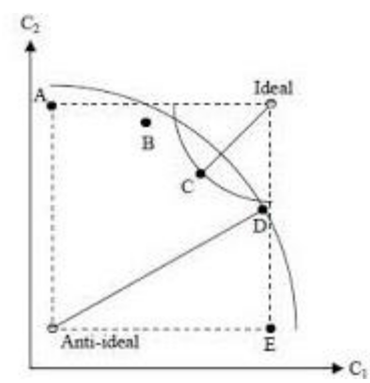

Fig 1. Ideal and Anti-Ideal points in TOPSIS method

Multicriteria analysis (MCA) provides a systematic methodology to integrate heterogeneous and uncertain information with cost-benefit information and stakeholders' views in an understandable framework to rank project alternatives. MCA is highly useful as a tool for project evaluation during the developed phase when decision makers do not have sufficient knowledge regarding details, but the importance of making the right decision is considerable [9].

A vast number of multicriteria decision-making methods have been developed to deal with the problem of ranking a set of alternatives evaluated in a multicriteria fashion. Very often, these methods assume that the evaluation among criteria is statistically independent. However, in actual problems, the observed data may comprise dependent criteria, which, among other problems, may result in biased rankings [10].

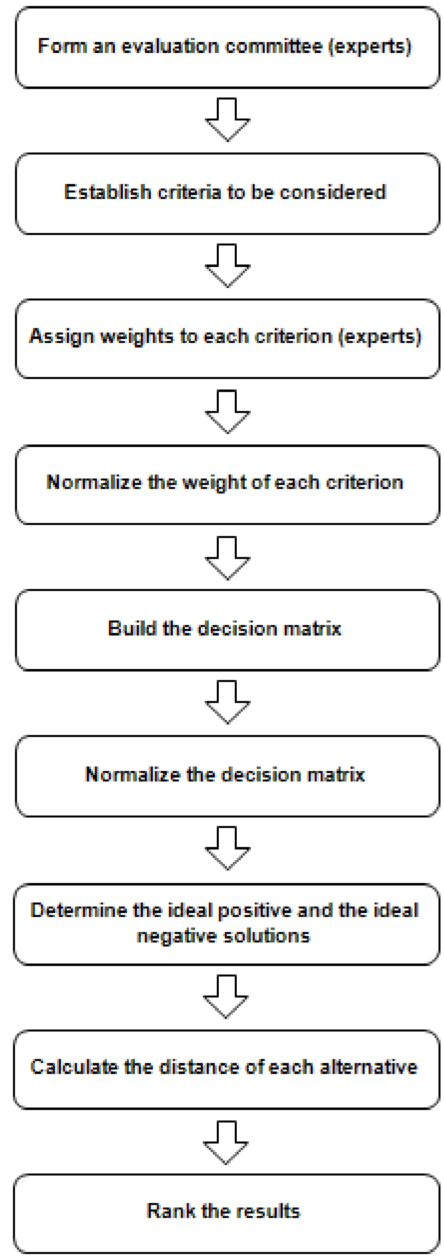

Fig. 2. TOPSIS method

To evaluate IoT technologies and choose the best option, a multicriteria analysis based on TOPSIS was used.

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is among the most popular MCDM (Multiple Criteria Decision Making) methods. Decision making is the process of selecting a possible course of action from all the available alternatives. In almost all such problems, the multiplicity of criteria for judging the alternatives is pervasive. That is, for many such problems, the decision maker wants to attain more than one objective or goal in selecting the course of action while satisfying the constraints dictated by environment, processes, and resources [11]. TOPSIS provides a broader principle of compromise for solving this kind of prob-

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lem [12]; it was originally developed by Hwang and Yoon [13]. Traditionally, this method is applied to ranking problems, where alternatives are evaluated based on Euclidean distances from an ideal and a non-ideal solution [14].

The basic concept of this method is that the selected alternative should have the shortest distance to the positive ideal solution as well as the farthest distance from the negative ideal solution [15].

As an example, Fig. 1 shows five alternatives, A, B, C, D, and E, with a choice of 2 criteria; it also shows the ideal and anti-ideal points. It is obvious that if the usual Euclidean distance (p = 2) is applied with equal weights, point C is the closest to the ideal, and D is the furthest. TOPSIS solves this dilemma in the choice between the ideal and the anti-ideal [16].

For applying the TOPSIS Method, steps could be resume as shown in Fig. 2.

To apply the multicriteria analysis based on TOPSIS, the criteria under which each alternative will be evaluated were first established. According to the expert's opinion, ten criteria were selected and divided into three groups, as shown in Table 1:

TABLE 1
CRITERIA

Number	Groups	Description
1	Technical	Availability. There are three values: "2" if this technology is available; 1 if the technology can be implemented; and 0 if it is not available
2	Technical	Maximum transmission speed (kbps)
3	Technical	Large of data frame per transmission (bytes)
4	Technical	Power consumption in years considering one transmission per day
5	Technical	Nodes per gateway (x1000)
6	Technical	Maximum transmission distance (km, with sightline)
7	Economic	Device cost (US$)
8	Economic	Service/Maintenance cost (US$/transmission/device)
9	Social	Local support (number of suppliers)
10	Social	Government permission (need government license 1, license not needed 0)

Each criterion has a value according to the IoT platform characteristics, as shown in Table 2.

Four experts were asked to assign weights to each criterion, according to their knowledge and experience in this kind of system. They were asked to consider the importance that each criterion has in Telemetry systems for the case study, especially the location. To set the appropriate weight, the Likert Scale was applied.

The Likert scale is widely used in social work research and is commonly constructed with four to seven points, but it can be increased to eleven, a common metric that ranges from 0 to 10. Also, it can be treated as a continuous measure, and hence arithmetic operations can be used [17].

In this research, a scale from 1 to 7 was used, where "7" represents the greatest weight in importance for the criterion. The result was a matrix $W_{4 \times 10}$ with w_{ij} elements, where i represents each expert and j represents the index of the criterion.

A unique weight for each criterion is obtained using the geometric mean [15]:

$$\mathrm{Gj} = \sqrt[4]{\mathrm{w}_{1\mathrm{j}} \times \mathrm{w}_{2\mathrm{j}} \times \mathrm{w}_{3\mathrm{j}} \times \mathrm{w}_{4\mathrm{j}}} \quad (1)$$

Then, the weights should be normalized in order to be compared with each other [15]. For this operation, the sum of all the weights is needed:

$$\mathrm{S} = \sum_{\mathrm{j}=1}^{10} \mathrm{G}_{\mathrm{j}} \quad (2)$$

The normalized weights of each criterion is calculated by:

$$Y_j = \frac{G_j}{S} \quad (3)$$

The idea of TOPSIS can be expressed in a series of steps [18]. The first task of the TOPSIS algorithm consists of creating a decision matrix. At this point, once the value of each criterion (j) corresponding to each alternative (k) is assigned, the result is the matrix X with elements x_{kj}. This is shown in Table 2.

To calculate de normalized decision matrix A, the normalized value a_{kj} is calculated as:

$$A = [a_{kj}]_{m \times n}$$

$$a_{kj} = \frac{x_{kj}}{\sqrt{\sum_{k=1}^{n} (x_{kj})^2}} \quad (4)$$

$$k = 1, 2, 3\ldots, m;\ \ j = 1, 2, 3, \ldots, n,$$

where x_{kj} represents the x value of alternative k corresponding to criterion j.

Then the Ideal Positive Value (a^+) and the Ideal Negative Value (a^-) should be calculated for each criterion. This is done with these expressions:

$$a^+_j = \max(\mathrm{a}_{\mathrm{kj}}) \text{ where } k = 1,2,3\ldots m \quad (5)$$

$$a^-_j = \min(\mathrm{a}_{\mathrm{kj}}) \text{ where } k = 1,2,3\ldots m \quad (6)$$

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TABLE 2
ASSIGNED VALUES FOR EACH IOT ALTERNATIVE

Ideal	**max**	**max**	**max**	**max**	**max**	**max**	**min**	**min**	**max**	**min**
Alternative\Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
LoraWan	1	50	243	15	100	5	2.38	0.39	1	0
GPRS	2	10000	10000	5	200	100	3	2	3	1
Sigfox	0	0.1	12	20	100	10	5.94	1.6	1	0
NB-IoT	0	1000	1600	10	200	1	23.8	0.6	0	1

TABLE 3
ASSIGNED WEIGHTS BY EXPERTS

E\C	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	7	5	5	4	5	3	4	6	2	4
2	7	6	1	3	2	2	3	6	3	2
3	7	7	2	6	4	5	3	6	4	3
4	7	5	1	5	2	4	4	5	3	1
G.M	7	5.692	1.778	4.356	2.991	3.31	3.464	5.733	2.913	2.213
N.W.	0.177	0.144	0.045	0.11	0.076	0.084	0.088	0.145	0.074	0.056

TABLE 4
NORMALIZED DECISION MATRIX

Ideal	**max**	**max**	**max**	**max**	**max**	**max**	**min**	**min**	**max**	**min**
Alternative\Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
LoraWan	0.45	0.00	0.02	0.55	0.32	0.05	0.10	0.15	0.30	0.00
GPRS	0.89	1.00	0.99	0.18	0.63	0.99	0.12	0.75	0.90	0.71
Sigfox	0.00	0.00	0.00	0.73	0.32	0.10	0.24	0.60	0.30	0.00
NB-IoT	0.00	0.10	0.16	0.37	0.63	0.01	0.96	0.23	0.00	0.71

Calculating the separation measures using the *n*-dimensional Euclidean distance. The separation of each alternative from the positive ideal solution is given as:

$$pa_j = Y_j \,.\, (a^+_j - a_j)^2 \tag{7}$$

$$D^+_k = \sqrt{\textstyle\sum_{j=1}^{m}(pa_j)} \tag{8}$$

Similarly, the separation from the negative ideal solution is given as:

$$na_j = Y_j \,.\, (a^-_j - a_j)^2 \tag{9}$$

$$D^-_k = \sqrt{\textstyle\sum_{j=1}^{m}(na_j)} \tag{10}$$

For each “distance,” D^+ and D^-, a_j represents the normalized value "a" for each criterion "j."

For each alternative, calculate the ratio R_k as:

$$R_k = D^-_k \,/\, (D^-_k + D^+_k) \tag{11}$$

Finally, alternatives should be ranked in increasing order according to the radio R_k.

4. RESULTS

For the case study, four experts assigned importance values (weights) for each criterion according to a 1-7 Likert Scale. The results are shown in Table 3.

Each row represents the expert's assigned values, and each column represents each criterion. GM row is the Geometric Mean, and NW row corresponds to the Normalized Weight according to equation 3.

The assigned values for each IoT alternative were shown before in Table 2.

Table 4 shows the normalized decision matrix A, according to equation 4 for each element of the matrix.

Table 5 shows the Positive Ideal and the Negative Ideal for each criterion.

To obtain D^+, the corresponding factors were calculated and are shown in Table 6:

In this sense, D^+ for each alternative is shown in Table 8:

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TABLE 5
POSITIVE IDEAL AND NEGATIVE IDEAL FOR EACH CRITERION

Ideal	**max**	**max**	**max**	**max**	**max**	**max**	**min**	**min**	**max**	**min**
Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Positive Ideal	0.89	1.00	0.99	0.73	0.63	0.99	0.10	0.15	0.90	0.00
Negative Ideal	0.00	0.00	0.00	0.18	0.32	0.01	0.96	0.75	0.00	0.71

TABLE 6
D+ FACTORS

Ideal	**max**	**max**	**max**	**max**	**max**	**max**	**min**	**min**	**max**	**min**
Alternative\Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
LoraWan	0.04	0.14	0.04	0.00	0.01	0.07	0.00	0.00	0.03	0.00
GPRS	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.05	0.00	0.03
Sigfox	0.14	0.14	0.04	0.00	0.01	0.07	0.00	0.03	0.03	0.00
NB-IoT	0.14	0.12	0.03	0.01	0.00	0.08	0.07	0.00	0.06	0.03

TABLE 7
D- FACTORS

Ideal	**max**	**max**	**max**	**max**	**max**	**max**	**min**	**min**	**max**	**min**
Alternative\Criteria	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
LoraWan	0.04	0.00	0.00	0.01	0.00	0.00	0.07	0.05	0.01	0.03
GPRS	0.14	0.14	0.04	0.00	0.01	0.08	0.06	0.00	0.06	0.00
Sigfox	0.00	0.00	0.00	0.03	0.00	0.00	0.05	0.00	0.01	0.03
NB-IoT	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00

TABLE 8
D+ FOR EACH IOT ALTERNATIVE

Alternative	D^+
LoraWan	0.5759
GPRS	0.3384
Sigfox	0.6798
NB-IoT	0.7344

TABLE 9
D- FOR EACH IOT ALTERNATIVE

Alternative	D^-
LoraWan	0.451396
GPRS	0.734482
Sigfox	0.342476
NB-IoT	0.232531

D^- is obtained in the same way. Table 7 shows the corresponding factors that were calculated according to equation 9.

Table 9 shows D^- for each IoT alternative.

Finally, R is calculated according to equation 11, and the results are shown in Table 10.

As shown, applying the TOPSIS method, the best alternative for the Telemetry System is GPRS which is the one that has more suppliers in Peru and is more developed around the country. The second one is LoraWan, which low-cost and low power consumption equipment make this platform a good alternative for smaller systems.

TABLE 10
R FOR EACH IOT ALTERNATIVE

Alternative	R	Rank
LoraWan	0.439414	2
GPRS	**0.684608**	**1**
Sigfox	0.335029	3
NB-IoT	0.240487	4

On the other hand, the worst alternative is NB-IoT, which despite its technical characteristics, it is still being developed in the country.

5. CONCLUSIONS

The selection of an IoT technology for a Telemetry System depends on many factors. The most important element is platform availability at the location of the system. Other important factors are the involved costs and the government permissions for communication networks.

A multicriteria analysis was done considering not only the criteria that could have an important impact on the system implementation but also the opinion of experts with experience in the case study (similar systems and locations).

Accordingly to the analysis, the suitable IoT technology for a Telemetry System in Huacho, Peru, is GPRS. This result is consistent with the "experts" previous thoughts, which selection was the same. They considered network availability, costs, and the number of suppliers to make their decision

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(supported by their experience). However, the TOPSIS method offers an objective analysis that supports this selection.

As shown before, one of the most important factors of this method is the “experts” opinion. It is necessary to build an “evaluation committee” with enough knowledge and experience to achieve good results.

It is demonstrated that this analytical method works and could be scalable to another kind of system or to solve decision problems considering multiple criteria. For future research, as soon as more IoT alternatives are available at the location, they could be evaluated using the same methodology. Furthermore, this kind of analysis could be done to other system problems like equipment maintenance, choice of suppliers, etc.

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