Indexes for Health Technology Assessment Two Case Studies: Computer Tomography Scan and Linear Accelerator

L. Guzmán-Canizales, J. A. Lozano-Suárez, and M. R. Ortiz-Posadas(✉)

Electrical Engineering Department, Universidad Autónoma Metropolitana-Iztapalapa, CP 09340 Mexico City, Mexico
posa@xanum.uam.mx

Abstract. The Computed Tomography Service (CTS) of the National Institute of Pediatrics from Mexico, currently has a 64-slice CT-scan acquired in 2010. The equipment will be soon obsolete since the supplier will no longer provide technical support. In 2020 the CT-scan was evaluated, as well as the productivity of the CTS. Likewise, the Pediatric Radiotherapy Service (SRP) has a linear accelerator old than ten years and is also closed to becoming obsolete due to lack of technical support from the supplier. In 2019, the productivity of the SRP was evaluated as part of an investment project to acquire a new linear accelerator. In both studies, a set of variables and indicators was defined to evaluate different aspects of these two medical equipment. Therefore, the objective of this work was to show that the subset of variables and indicators defined for two devices with different purposes: diagnostic (CT-scan) and therapeutic (linear accelerator), are useful to evaluate any type of medical device. It was defined eight variables and a technical indicator (I_T). The I_T was applied in both medical equipment allowed knowing their technical state and suggesting a period to replace them. In both cases, it is observed that the results are consistent, since they are more than 10 years old, and during the year 2022 they will no longer have technical support from the provider. This scenario makes both the CT-scan and the linear accelerator obsolete equipment. Both equipment should be replaced in the short term.

Keywords: Health Technology Assessment · Computer Tomography Scan · Linear Accelerator

1 Introduction

Health Technology Assessment (HTA) is the systematic evaluation of properties, effects, and/or impacts of health care technology. It should include medical, social, ethical, and economic dimensions, and its main purpose is to inform decision-making in the health area [1]. The indicators are a very useful tool in the HTA. An indicator is an instrument to provide evidence of a particular condition, or measurement of certain specific results. Indicators may provide information on quantitative and qualitative aspects of a program or a project objective. To this effect, several HTA studies use indicators to prioritize the preventive maintenance [2]; prioritize the replacement of medical technology [3]; or estimate patient access to imaging services [4].

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The National Institute of Pediatrics from Mexico (INP, its Spanish acronym) is a tertiary public hospital with 243 beds. It has a total of 6165 medical equipment, 3699 are located in clinical and research laboratories, and 2466 in healthcare areas. About 1603 equipment is less than or equal to 10 years old, 1356 is between 11 to 20 years old, and 3206 is more than 20 years old [5]. In this sense, obsolescence is a characteristic related to the medical equipment antiquity. It implies the increasingly difficult to obtain spare parts, accessories, and consumables for its correct operation, with the consequence that the equipment will stop working. Therefore, it will be necessary to acquire a new one to continue providing healthcare services to patients.

The Computed Tomography Service (CTS) of the INP currently has a 64-slice CT-scan acquired in 2010. The equipment will be soon obsolete since the supplier will no longer provide technical support. In 2020 the CT-scan was evaluated considering three aspects: technical and economic performance, and the productivity of the CTA [6]. Likewise, the Pediatric Radiotherapy Service (PRS) has a linear accelerator old than ten years old and is also closed to becoming obsolete due to lack of technical support from the supplier. In 2019, the productivity of the SRP was evaluated as part of an investment project to acquire a new linear accelerator [7]. In both studies, a set of variables and indicators was defined to evaluate different aspects of the medical equipment. To evaluate the technical aspect and the productivity of the medical service where the medical equipment is located, a selection of the variables and indicators defined in each study was made. Therefore, the objective of this work was to show that the subset of variables and indicators defined for two medical equipment with different purposes: diagnostic (CT-scan) and therapeutic (linear accelerator), are useful to evaluate any type of medical device.

2 Methodology

2.1 Technical Evaluation of Medical Equipment

The technical evaluation of medical equipment was performed by applying a technical indicator (I_T) defined for eight variables (x_i) with a weight factor (ρ_i) through the Eq. (1) [6, 7]. Observe in Table 1 that the variable with the highest weight ($\rho_1 = 0.9$) is x_1 = Spare parts available next 5 years; and the lowest weight ($\rho_8 = 0.2$) is x_8 = Maintenance requirement, that describes the level and frequency of maintenance according to the manufacturer's indications, or accumulated experience of technical staff [8]. The variable x_4 = Equipment function, defines the application and environment in which the equipment item will operate, and it considers 10 functions [8].

$$I_T = \sum\nolimits_{i=1}^{n} \frac{\rho_i x_i}{4.4} \tag{1}$$

where:

x_i = variable, i = {1, …, 8} ρ_i = relevance factor for x_i.

N = 4.4 is the normalization factor for obtaining the I_T result into [0, 1].

For the interpretation of the quantitative result of I_T a qualitative scale was defined, divided into four intervals that correspond to a deadline for the equipment replacement:

[0,0.25) = long term (10 years)

Table 1. Variables of the technical indicator (I_T) and their weights [6].

x_i	Variable	ρ_i
x_1	Spare parts available next 5 years	0.9
x_2	Equipment age in operation	0.8
x_3	Days of the equipment out of service	0.7
x_4	Equipment function	0.6
x_5	Equipment failure frequency	0.5
x_6	Physical Risk	0.4
x_7	Consumables available next 5 years	0.3
x_8	Maintenance requirements	0.2

[0.25, 0.5) = medium term (6 years)
[0.5,0.75) = short term (3 years)
[0.75,1] = immediately (less than 3 years).

2.2 Epidemiological Analysis of the Medical Service

Epidemiological information was collected from the medical services: number of patients treated, patient characteristics, type of study, and time spent in each study. For the Computed Tomography Service (CTS), the information was obtained from the RIS-PACS (Radiology Information System—Picture Archiving and Communication System) [9], and for the Pediatric Radiotherapy Service (PRS) from the monthly report [10].

2.3 Medical Service Attention Time

It refers to the real time that the medical service attend patients. To calculate this time it was necessary to define two parameters:

Total Operation Time (k_{OT}). It is a constant obtained with the multiplication of the attention daily hours of the medical service (H_D), with the days worked per week (D_W), the weeks worked per year (W_Y), and the number of work shifts (W_S), using Eq. (2).

$$k_{OT} = (H_D)(D_W)(W_Y)(W_s) \tag{2}$$

Equipment Out of Service Time (t_{OS}). There are factors as failures in medical equipment and/or interruptions in the electrical supply, which leave medical equipment out of service. In this sense, the t_{OS} is obtained by adding the time spent on work orders (t_{WO}), preventive maintenance (t_{PM}) and power supply interruptions (t_{PSI}), with Eq. (3).

$$t_{OS} = t_{WO} + t_{PM} + t_{PSI} \tag{3}$$

Therefore, Medical Service Attention Time, (t_{MS}) was calculated with (4)

$$t_{MS} = k_{OT} - t_{OS} \tag{4}$$

2.4 Patient Attention Time

The Patient Attention Time (t_P) is variable and depends on:

- Patient features. First time, regular, emergency or COVID-19, and if the patient needs to be anesthetized.
- Patient's provenance. Patients can come from any of the Institute's 30 medical specialties. Although emergency patients represent almost a third of the total: 1018 patients treated in 2018, 1050 in 2019, and 947 in 2020. On the other hand, there are patients called "referred" from other public hospitals in Mexico City (General Hospital Dr. Manuel Gea González, Women's Hospital, Moctezuma Pediatric Hospital and Federico Gómez Children's Hospital of Mexico, inter alia).
- Anatomical region studied.
- Study type. Simple or contrasted.

These aspects were considered in the estimation of Patient Attention Time in the two medical services considered in this study: Computed Tomography and Pediatric Radiotherapy.

Patient attention time (Computed Tomography) ($t_{P\text{-}CT}$). To calculate this time, three patient types were considered: regular, emergency, and COVID-19, as the attention times in each case are different. Additionally, it was necessary to know these parameters:

The CT study time ($t_{S\text{-}CT}$) of a *regular* patient is calculated with the Eq. (5):

$$t_{S-CT} = \sum\nolimits_{i,j=1}^{n} (n_{i,j})(t_{i,j})/60\text{min} \tag{5}$$

where:

n, is the number of studies per year,

t, is the study time,

i = {1, 2, …, 6} is the study type (Table 4).

j = {1, …, 4} is the nature of the study (simple, contrasted, with or without anesthesia).

The CT-study time of an *emergency* patient is calculated with the Eq. (6). Note this equation has 10 min factor, wich is the time it takes to prepare the patient.

$$t_E = (\text{Patients No. })(10\ \text{min})/60\ \text{min} \tag{6}$$

The CT-study time of a *COVID-19* patient is calculated with the Eq. (7). In this case, sanitizing the room after patient attention takes 80 min.

$$t_C = (\text{COVID19Patient})(80\text{min})/60\text{min} \tag{7}$$

The CT-study time $t_{P\text{-}CT}$ for 2018 y 2019 results on:

$$t_{P-CT} = t_{S-CT} + t_e \tag{8}$$

For the year 2020, it was necessary to add to Eq. (8) the attention time of a *COVID-19* patient as shown in (9):

$$t_{p-CT-2020} = t_{S-CT} + t_e + t_C \tag{9}$$

Patient attention time (Pediatric Radiotherapy) ($t_{P\text{-}PR}$). In this case, there are two types of patients: first time and regular. The parameters required for time calculation were:

The total number of patients of each type treated for a specific period (P_A).

First time patient (t_{FT}):

$$t_{FT} = \frac{(P_A)(S_I)(t_{SI})}{60\text{min}} \tag{10}$$

where: S_1 = number of initial radiotherapy sessions; t_{S1} = initial radiotherapy sessions time.

Regular time patient (t_{RT}):

$$t_{RT} = \frac{(P_A)(S_R)(t_{SR})}{60\text{min}} \tag{11}$$

Where: S_R = regular radiotherapy sessions per patient; t_{SR} = regular radiotherapy sessions time. Finally:

$$t_{P-PR} = t_{FT} + t_{RT} \tag{12}$$

Equation (12) calculates the time spent in the attention of all oncological patients treated at Pediatric Radiotherapy Service for a certain period.

2.5 Medical Service Productivity

Medical Service Productivity (P_{MS}) was calculated using the proportion between patient attention time (t_P) and medical service attention time (t_{MS}) as in Eq. (13).

$$P_{MS} = \frac{t_P}{t_{MS}} \tag{13}$$

3 Results

3.1 Technical Evaluation of CT-Scan

The technical evaluation of the CT-scan was made with the information of the last three years (2018–2020). The values of variables are shown in Table 2. Note that the variables receive a qualitative value (Qi) used by the technical staff of the Biomedical Engineering Department (BED). For example, x_4. Equipment function has a Diagnostic (D) value, this involve that Physic risk (x_6) from equipment is a Misdiagnosis (MD). The CT-scan have a high complex technology therefore, its Maintenance requirements (x_8) are Important (I), which means that it requires highly specialized personnel to carry out preventive/corrective maintenance. Furthermore, note that Equipment failure frequency (x_5), has doubled every year, which shows the deterioration of the CT-scan. Note also that the variables have a quantitative domain (M_i), which is the mapping of the qualitative value (Q_i) to a value in the interval [0, 1] and are the same in the 2018–2019, and change for the year 2020.

The quantitative values (M_i) of the year 2018 (Table 2) were substituted in Eq. (1), to ilustrate the aplicattion of IT.

$$I_{T2018} = \frac{\sum_{i=1}^{n} p_i x_i}{4.4} = \frac{\begin{array}{c}(0.9)(1)+(0.8)(0.4)+(0.7)(1)\\ +(0.6)(0.6)+(0.5)(0.4)\\ +(0.4)(0.6)+(0.3)(1)+(0.2)(1)\end{array}}{4.4} = 0.73$$

According to the qualitative scale, this result indicates that the CT-scan must be replaced in the short term, that is, in three years.

Table 2. Qualitative (Q_i) and quantitative (M_i) values of the variables from technical indicator I_T of 64-slice CT-scan

Variable	2018	2019	Mi	2020	Mi
x_1 Spare parts available next 5 years	No	No	1	No	1
x_2 Equipment age in operation	8	9	0.4	10	0.4
x_3 Days of the equipment out of service	14	11	1	21	1
x_4 Equipment function	D	D	0.6	D	0.6
x_5 Equipment failure frequency	2	4	0.4	8	0.8
x_6 Physical Risk	MD	MD	0.6	MD	0.6
x_7 Consumables available next 5 years	No	No	1	No	1
x_8 Maintenance requirements	I	I	1	I	1

I_T was applied for the three years data and showed that in 2018 and 2019 (I_T=0.73), the equipment must be replaced in the short term (three years), that is, for the year 2021. In the year 2022, due to the number of failures I_T =0.77 so the equipment should be replaced immediately, within a period of less than 3 years.

3.2 Technical Evaluation of Linear Accelerator

The technical evaluation of the Linear Accelerator was made with the information of 2019 (Table 3). As in the case of the CT-scan, the variables have a qualitative (Q_i) and a quantitative domain (M_i). The equipment has been operating for more than ten years without any failures. However, four days out of service were identified due to preventive maintenance, which were carried out four times a year. Therefore, it presents the maintenance requirement considered as Important (I). The equipment has a Function (x_4) of Treatment (T), and a Physical risk (x_6) of Possible Injury to the Patient or Operator (PIPO).

Table 3. Qualitative (Q_i) and quantitative (M_i) values of the variables from technical indicator I_T of Linear Accelerator

x_i	Variable	Q_i	M_i
x_1	Spare parts available next 5 years	no	1
x_2	Equipment age in operation	15	0.8
x_3	Days of the equipment out of service	4	0.4
x_4	Equipment function	T	0.8
x_5	Equipment failure frequency	0	0
x_6	Physical Risk	PIPO	0.8
x_7	Consumables available next 5 years	No	1
x_8	Maintenance requirements	I	1

The application of I_T is illustrated by substituting the quantitative values of 2019 in Eq. (1).

$$I_T = \sum_{i=1}^{n} \frac{\rho_i x_i}{4.4} = \frac{\begin{array}{c}(0.9)(1) + (0.8)(0.8) + (0.7)(0.4)+ \\ (0.6)(0.8) + (0.5)(0) + (0.4)(0.8) \\ +(0.3)(1) + (0.2)(1)\end{array}}{4.4} = 0.71$$

According to the qualitative scale, the result of the indicator suggests that the linear accelerator should be replaced in the short term, in a period of 3 years.

3.3 Epidemiological Analysis of Computed Tomography Service

Twenty-one types of tomographic studies were identified by anatomical region and three interventional procedures [11]. Based on the experience of radiology technicians, studies by anatomical region can be classified into short and long studies. Angiotomography (cardiac, neck, renal, abdominal) requires a longer preparation time, and are considered in another group. Interventional procedures are classified into punctures (biopsies and drainage), and stereotaxy, the latter also requiring more time. On the other hand, the canceled studies represent a constant time investment of 20 min each one. In addition to the type of studies, the time study (t_S) depends on whether the study is simple (S) or contrasted (C), or if the patient requires anesthesia (A). The times per study are shown in Table 4, and the information by type of study for each year of the 2018–2020 triennium is observed in Table 5. Note that in total, 4239 studies were carried out in 2018, 4115 studies in 2019, and 3284 studies in 2020.

3.4 Epidemiological Analysis of Pediatric Radiotherapy Serice

During 2019, the Pediatric Radiotherapy Service (PRS) treated 212 patients. The data relative to the radiation sessions times are shown in Table 6.

Table 4. Type CT-study time (i) in minutes (j)

Study time ($t_{i,j}$)	S ($t_{i,1}$)	S/A ($t_{i,2}$)	C ($t_{i,3}$)	C/A($t_{i,4}$)
1. Short study ($t_{1,j}$)	15	40	35	60
2. Long study ($t_{2,j}$)	35	60	55	80
3. Angiotomography ($t_{3,j}$)	–	–	65	90
4. Puncture ($t_{4,j}$)	–	–	100	125
5. Stereotaxy ($t_{5,j}$)	–	–	–	175
6. Canceled ($t_{,6j}$)	20	–	–	–

Table 5. Patient attention process data in the Pediatric Radiotherapy Service

Parameter description	Value
Treated patients in 2019 (P_A)	212
Initial radiotherapy sesión per patient (S_I)	1
Regular radiotherapy sessions per patient (S_R)	25
Initial radiotherapy sessions time (TS_I)	45 min
Regular radiotherapy sessions time (TS_R)	15 min

3.5 Computed Tomography Service Attention Time

Total Operation Time (k_{CT}). Constant that was calculated by substituting the values of the parameters in Eq. (2):

$$k_{CT} = (51 \text{ weeks})(5 \text{ days})(8 \text{ h})(2 \text{ shift}) = 4080 \text{ h}$$

Equipment Out of Service Time ($t_{OS\text{-}TC}$). It is illustrated by calculating the time for 2018. In this year the CT-scan presented three faults with this number of hours out of service: gantry (168 h), UPS (88 h), electrical supply (72). Substituting these values in (6), the total number of hours out of service for the CT-scan in 2018 was:

$$t_{OS-CT-2018} = (168) + (88) + (72) = 328 \text{ h}$$

Tomography Computed Service Attention Time (t_{TC}). Substituting the data for the year 2018 in Eq. (4):

$$t_{CT-2018} = k - t_{OS-CT-2018} = 4080 - 328 = 3,752\text{h}$$

3.6 Patient Attention Time (Computed Tomography)

Study Time ($t_{S\text{-}CT}$). The time for each type of study was calculated. For example, for short studies time of the year 2018, we substituted the corresponding data (Table 5) in

Table 6. CT-studies annually per type

Study type	S	S/A	C	C c/A	Total
2018					
1. Short study	1,953	343	504	125	2,925
2. Long study	580	167	244	76	1,067
3. Angiotomography	–	–	84	140	224
4. Puncture	–	–	10	10	20
5. Stereotaxy	–	–	–	3	3
6. Canceled	30	–	–	–	30
Total	2,563	510	842	354	4,239
2019					
1. Short study	1,959	256	432	100	2,747
2. Long study	661	145	212	74	1,092
3. Angiotomography	–	–	113	128	241
4. Puncture	–	–	7	8	15
5. Stereotaxy	–	–	–	4	4
6. Canceled	16	–	–	–	16
Total	2,636	401	764	314	4,115
2020					
1. Short study	1,500	173	330	94	2,097
2. Long study	569	111	232	72	984
3. Angiotomography	–	–	91	102	193
4. Puncture	–	–	3	3	6
5. Stereotaxy	–	–	–	4	4
6. Canceled	14	–	–	–	14
Total	2,083	284	656	275	3,284

the Eq. (5):

$$t_{S-2018-\text{short}} = \frac{\begin{array}{c}(1,953)(15) + (343)(40)\\ +(504)(35) + 125(60)\end{array}}{60\text{min}} = 1,136\text{hrs}$$

We do the same in each study type and later the sum was made to obtain the global $t_{\text{S-TC}}$ with Eq. (5).

$$t_{S-2018-\text{long}} = 830\text{h}$$

$$t_{S-2018-\text{angio}} = 301\text{h}$$

$$t_{S-2018-\text{puncture}} = 38\text{h}$$

$$t_{S-2018-\text{stereotaxy}} = 9\text{h}$$

$$t_{S-2018-\text{canceled}} = 10\text{h}$$

$$t_{S\text{-CT-}2018=}(1136+830+301+38+9+10)=2324 \text{ h}$$

Emergency patient time (t_E). During 2018, 1018 emergency patients were treated. It was 1050 in 2019, and 1000 in 2020. To illustrate the use of Eq. (6), data from 2018 were substituted.

$$t_{E-2018}=(1018)(10 \text{ min})/60 \text{ min}=170 \text{ h}$$

Patient attention time (t_P). Applying Eq. (8), for 2018 and 2019 it was obtained:

$$t_{P-2018}=2324+170=2{,}494$$

$$t_{P-2019}=2190+175=2{,}365$$

Patient Covid-19 attention time (t_C). 76 Covid-19 patients were treated in 2020, and in each case, an average of 80 min was spent on their attention. Applying Eq. (7) it was obtained:

$$t_C = \frac{76(80\text{min})}{60} = 101\text{h}$$

Then, the t_P for 2020, was calculated by substituting the information in Eq. (12)

$$t_{p-2020} = 1802 + 167 + 101 = 2,070\text{h}$$

3.7 Computed Tomography Service Productivity

Substituting the service attention time (t_{CT}) and the patient attention time ($t_{P\text{-}CT}$) for the year 2018, in Eq. (13) it is obtained that the productivity in that year was:

$$P_{CT-2018} = \frac{t_P}{t_{CT}} = \frac{2494\text{h}}{3752\text{h}} = 0.66 = 66\%$$

Over the next two years, 2019 and 2020, productivity stood at 62% and 58%, respectively. In 2019 there was a decrease of 4%, and in 2020 it decreased by 4% more. The latter, as mentioned, was due to the fact that the CTS did not attend outpatients for three months and also the service time was reduced due to the COVID-19 pandemic.

3.8 Pediatric Radiotherapy Service Attention Time

The total operation time of the Pediatric Radiotherapy Service (k_{PR}) was calculated by substituting the corresponding values in Eq. (2):

$$k_{PR} = (8\text{h})(5\text{days})(48\text{weeks})(1\text{shift}) = 1920\text{h}$$

Linear Acelerator Out of Service Timel ($t_{OS\text{-}LA}$). Due to the four preventive maintenance interventions carried out, the equipment was out of service four days (32 h) during 2019. Substituting this value in expression (3) obtained: $t_{OS\text{-}LA} = 32$ h.

The attention time of the Pediatric Radiotherapy Service (PRS) was calculated with Eq. (4) and the data of the year 2019:

$$t_{P-RP} = 1920\text{h} - 32\text{h} = 1888\text{h}$$

3.9 Pattient Attention Time (Pediatric Radiotherapy)

First time patient (t_{FT}). The time for patients starting their radiotherapy treatment was calculated by substituting the data for the year 2019 (Table 6) in Eq. (10):

$$t_{FT} = \frac{(212)(1)(45)}{60} = 159\text{h}$$

Regular patient time (t_{RT}). The attention time for patients who continue their radiotherapy treatment was calculated by substituting the data for the year 2019 (Table 6) in Eq. (11):

$$t_{RT} = \frac{(212)(25)(15)}{60} = 1325\text{h}$$

Once t_{FT} y t_{RT} were estimated the patient attention time ($t_{P\text{-}RP}$) was obtained by adding these two times, using Eq. (11):

$$t_{P-RP} = 159\text{h} + 1325\text{h} = 1484\text{h}$$

3.10 Pediatric Radiotherapy Service Productivity

The Pediatric Radiotherapy Service productivity (P_{PR}), as for CTS, was calculated using the proportion between the time invested in patient attention (t_P), and the service patient attention time (t_{PR}) through the Eq. (12):

$$P_{PR-2019} = \frac{t_P}{t_{RP}} = \frac{1484\text{h}}{1888\text{h}} = 0.79 = 79\%$$

This result indicates that the PRS had a productivity of 79% during 2019.

4 Conclusions

The technical indicator (I_T) application in both medical equipment allowed knowing their technical state and suggesting a period to replace them. In the case of the CT-scan, a deterioration was observed due to the increase in the frequency of annual failures, so it must be replaced within a period not exceeding 3 years. The same way, the linear accelerator must also be replaced in the short term (three years). In both cases, it is observed that the results are consistent, since they are more than 10 years old, and during the year 2022 they will no longer have technical support from the provider. This scenario makes both the CT-scan and the linear accelerator obsolete equipment.

The importance of acquiring the two new medical equipment lies in providing safe and effective medical care to the patients attended by the National Institute of Pediatrics, as well as increasing the supply of care and, consequently, increasing the productivity of both Medical Services.

Finally, it was shown that the same set of indicators to evaluate the technical aspect of the medical equipment and the productivity of the medical service where it is located, are useful for the evaluation of medical equipment with different purposes, as were the two study cases presented in this work, since one equipment was for diagnosis (tomograph) and other for therapy (linear accelerator).

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