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Sigma Level Performance of the Innovated Process in the Imaging Department at a Mexican Health Institute

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Abstract The National Institute of Respiratory Diseases is a third level public hospital in Mexico City, which in 2007 acquired an RIS-PACS to be implemented at its Imaging Department (ID), with the objective to enhance its service. This department attends an average of 3,500 patients per month developing different image modalities. The objective of this work was to determine the overall sigma level performance of four processes of the ID: reception, X-ray, computed tomography, and radiologist diagnosis, considering process analysis and innovation through Six Sigma methodology, measuring the innovation effectiveness by means of indicators and learning curves. Initially, a first measurement (M_1) of the original processes was determined; once 13 innovations were implemented in a pilot program, two more measurements were done, 15 days after (M_2) and 30 days after (M_3), in order to know the impact of the innovations in the ID processes. The initial sigma level of the ID before innovations was σ_1=2.0, which means that there were 36 patients per day with a process defect during their stay at the ID. In the two following measurements, σ_2= 2.2 which means that there were 28 patients per day with a process defect, and σ_3=2.3 with 24 patients per day with a process defect. These results demonstrate that the percentage of performance enhancement between the original process and 15 days later was 23 % and 30 days later an enhancement of 15 %. In total, an overall enhancement of 38 % was obtained at the ID of the institute.

Keywords Imaging Department performance · Process innovation · Six Sigma methodology · Sigma level

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Background

The National Institute of Respiratory Diseases (INER for its Spanish acronym) is a third level public hospital in Mexico City, which in 2007 acquired a picture archiving communication system–radiology information system (RIS-PACS) to be implemented at its Imaging Department (ID), with the objective to enhance its service. This department attends an average of 3,500 patients per month [1] developing different modalities of studies, such as X-ray, computed tomography, nuclear medicine, and ultrasound. The first steps to analyze the processes at the ID were to understand and document the ID's current workflow of the related work areas where the RIS-PACS was first implemented: Reception, X-ray, computed tomography, and radiologist diagnosis. Therefore, they were defined in a total of four processes.

Although it has been demonstrated that the integration of a RIS-PACS to imaging services falls into clinical effectiveness and productivity at different organization levels including reception personnel, technicians, and radiologists, the ID has been having workflow issues in handling this new technology due to some human, economic, and physical factors. This fact leads to inefficient processes where different kinds of waste were found, going through reception personnel's rework, studies' diagnosis delays, and ending with the patient's dissatisfaction.

In such a critical area as healthcare, it is imperative to provide quality with a reliable method that provides a snapshot of the current state of the healthcare services, metrics to characterize processes, and a control method that can be applied at any time. Quality of service is and has been a subjective term that may be qualified as good or bad, but we need evidence (metrics, indicators, and data) that can guide us towards the best performance. Other methods such as total quality management or continuous quality improvement give solutions to the quality concerns in processes,

but the main difference is that Six Sigma focuses in customer satisfaction, in this case, the patient, and reduces waste according to its Lean tools. The Six Sigma methodology and its Lean tools [2] are a proven and reliable method that reduce costs and waste, enhance processes, and optimize organizations.

The Six Sigma method was chosen for this work to reduce the variance of processes at the ID, measure the efficiency of processes, and therefore characterize the quality of healthcare service measured by a sigma level. Obtaining a sigma level gives us the objective metric that we need to measure the performance of the ID and a mechanism of control to monitor the sigma level in further measurements, when the proposed methodology is followed. It is expected that wastes as inefficient manual re-keying of critical patient data, unnecessary printing of imaging studies, usage of inappropriate RIS applications, delays on data or images' display, or increased patient's wait time are avoided and acquire benefits as increased personnel productivity, decreased cycle times, diagnosis accuracy, and matching patient's needs through value-added services.

The objective of this work was to determine an overall sigma level performance of the innovated processes of the Imaging Department at the INER, presenting a strategy that considers process analysis and innovation through the Six Sigma methodology, and measurement of the innovation effectiveness by means of indicators and learning curves. This strategy improved and standardized the ID's performance.

Methods

The method presented in this work follows the Six Sigma steps, aided with Lean as the perspective and Lean tools [2] as the principal work guidelines to propose a process innovation. This methodology is described as follows.

Process Analysis

The ID's overall process starts when the patient arrives to the department and ends when the study is available to the radiologist. To understand the overall process better, there were identified and delimited four processes considering work, personnel, and information flows. The first process identified was reception, through which every patient has to go to get their studies done. The primary activity done here is the demographic and study data input to the RIS. The second process identified is X-ray, in which the correspondent study is taken, printed if necessary, and the resulting study image is sent to the PACS, so that it is available for the radiologist. The third process refers to computed tomography, and it basically differs from the X-ray process in the study modality. The fourth process is radiologist diagnosis, in which all the activities are described. The radiologist develops to generate a diagnosis from the study previously taken; this diagnosis is ideally generated and saved in the PACS.

For each process, a flux diagram was done describing the work and people flow, identifying non-added value activities and opportunity areas. Non-added value activities are usually problems within a process that increase costs by using time and resources without directly satisfying the needs of the customer and represent a waste by definition (there are seven categories of waste in healthcare [3]). Removing or reducing wastes and knowing what types exist, which ones are there on purpose and which ones are not, are important because waste consumes resources and extends the study time. On the other hand, opportunity areas represent an activity that can be modified having a positive impact to the process and are not a waste by definition.

Innovation Proposals

An innovation proposal was developed for each activity to make the overall process more efficient, to utilize the actual resources in a balanced way, and to reduce wait times. Variables regarding the activity such as: time percentage, responsible areas, personnel involved, and elimination feasibility were evaluated to perform each innovation proposal, always following the guidelines of several Lean Six Sigma tools such as: *Kanban*, which is a method for managing inventory; *5S* (*sort*, *store*, *shine*, *standardize*, and *sustain*), which is a method for organizing workplaces to reduce waste time and motion for employees and making problems more readily apparent; *visual management* (*VM*), which is a method that makes problems visible to provide a fast response and problem solving [2]; and *standardized work instructions* (SWI), which are specific instructions that allow processes to be completed in a consistent, timely, and repeatable manner. By implementing the SWI, employees will increase production, improve quality, and enjoy a safer, predictable working environment [4].

Process Measurement

To measure the performance of each process, a group of variables was defined related with the RIS-PACS information flows and another group related with wait times related with human factor. With these variables, a group of normalized indicators was defined within a [0, 1] interval, associated with a relevance factor according to the feasibility of the innovation realization and the impact in the process [2].

To measure the time variables, a sample of 50 patients was calculated from the standardized value of 3,500 patients attended in average per month at the ID [1]. The sample was divided in 25 X-ray patients and 25 computed tomography patients, randomly selected during 4 days. The time of each

patient was measured from the patient's arrival to the ID until the corresponding study was available in the RIS-PACS, and/or the printed study was delivered. The measurements related with the information flow variables were obtained from the RIS-PACS, analyzing the total registered work per shift, during the measurement period.

To measure the impact of the proposals, a reference start point was needed. Because of this, the strategy was to determine a first measurement (M_1) of the original processes. With the objective to have a model of the innovated overall process, the proposals were implemented in a pilot program in which the four processes and all the ID's personnel were involved. Two more subsequent measurement periods, 15 days after (M_2) and 30 days after (M_3), were established to know the real effects of the innovations.

Impact of the Innovated Processes

It is expected that the personnel's individual learning, efficiency, skills, or practice improves each time the innovated process is repeated; this effect is represented by a learning curve. A learning curve is a function that shows the relation between the time (or cost) of production per unit and the number of consecutive units produced. The learning curves are based on the premise that the organizations, as well as people, have a better performance each time a process is repeated in a systematic way because of the skills and experience gained [5].

Mathematical Analysis The learning curve is a function $P(t)$ that represents the performance of someone who gains a skill as a time function, where N is the maximum learning level. Equation (1) describes a saturation-type exponential function, and to obtain the value of k coefficient, it is necessary to apply a linear transformation [5].

$$P(t) = N - e^{-kt} = 1 - e^{-(\mathrm{mt}+b)} \tag{1}$$

For the linear transformation (LT), Eq. (2) was used where the straight line equation is represented by k coefficient from Eq. (1) [6]. Once k is obtained, Eq. (1) can be drawn and a time estimate may be obtained with the evaluation of the variable t when $P(t)$=0.8, which represents the 80 % of the maximum level learned. This level was considered an adequate learning considering human factor for the process execution.

$$\mathrm{LT} = \log_{10}\left(\frac{1}{(1-P)}\right) \tag{2}$$

In this work, two learning curves were developed for each process, one for information flows and another one for wait time. Having M_1, M_2, and M_3 allows a more precise slope and estimate for the learning curve. It is important to say that the learning level was delimited into the interval [0, 1], where 1 represents 100 % learning**.** Once having the correspondent learning curves, an *overall* learning curve can be developed with a slope equal to the average of the previous; this represents a more precise estimate of the overall process improvement within a period of time. It is important to mention also that having these learning curves allows the ID to have a long-term projection of their personnel's effectiveness, in terms of the indicator results.

Sigma Level for the Process

The sigma level is a representation of the number of defects per million (DPM) in a manufacturing process or service delivery [7]. In the service delivery area, a sigma level between 1 and 2 is considered [8], which represents between 691,500 and 308,508 DPM. In particular, it is reported that the hospitals are currently working between three and four sigma levels, with 66,807 and 6,210 DPM, respectively [9]. To calculate the sigma level of the ID, it was determined that a production is equal to each patient attended. The procedure is shown as follows:

1. Having the global learning curve of the ID, the three learning levels N_1, N_2, and N_3 are taken and the probability of defect (d) is calculated using Eq. (3).

$$P(d) = 1 - N_j \tag{3}$$

2. Then, the probability of defect is projected on the normal distribution curve with two tails and the value z is obtained [10]. The area under the curve between $-z$ and z represents the number of correct productions per million. In this case, it represents a patient that concludes the complete process (reception–study take–study delivery) without any defect. What is outside this area represents the patients that had a defect during the process.
3. By knowing the z, the σ value is calculated using Eq. (4), where 1.5 is the normal adjustment for long- and middle-term variations (more than 15 days) in services [11].

$$\sigma = z + 1.5 \tag{4}$$

4. By knowing the σ, the DPMs were calculated, using the Six Sigma Conversion Table [12]. As it was said before, the defects correspond to the patients that had defects during the process.
5. Finally, the number of patients was calculated (Eq. 5) with defect per month at the ID, where 3,500 monthly average patient's demand at the ID [1].

$$\mathrm{Patients} = \frac{3,500(\mathrm{DPM})}{1 \times 10^6} \tag{5}$$

Table 1 Variables and indicators of information flows at the ID

Process	V_i	Variable description	I_i	P_i	M_1	M_2	M_3
Reception	V_1	Number of applications without error	$B_R=V_1/50$	0.75	0.38	0.86	0.84
	V_2	Number of patients with payment	$C_R=V_2/50$	1.00	0.42	0.94	1
	V_3	Measure of subsequent patient attention	$D_R=V_3/50$	1.00	0.36	0.66	0.7
	V_4	Printer installation in reception	$E_R=V_4$	1.00	0	1	1
	V_5 V_6	Number of CT studies in the RIS agenda Number of CT studies taken per shift	$I_R=V_5/V_6$	0.63	0	0	0.37
	V_7 V_8	Number of programmed studies in RIS Number of X-ray studies taken per shift	$II_R=V_7/V_8$	0.63	0	0	0
	V_9 V_{10}	Number of incorrect patient data registers Number of patients who attended in one shift	$III_R=V_9/V_{10}$	0.50	0.51	0.10	0.30
	V_{11}	Number of inconsistent registers	$IV_R=V_{11}/V_{10}$	0.38	0.14	0.00	0.25
X-ray	V_{12} V_{12}'	Number of incorrect registers between CR and RIS Number of correct registers between CR and RIS	$I_X=V_{12}'/V_{12}$	0.75	0.28	0.60	0.55
	V_{13} V_{14}	Number of X-ray studies concluded in one shift Number of X-ray studies completed in one shift	$II_X=V_{13}/V_{14}$	1.00	0	0.43	0.96
CT	V_5 V_6	Number of CT studies in the RIS agenda Number of CT studies taken per shift	$A_{CT}=V_5/V_6$	0.63	0	0	0.04
	V_{15} V_6	Number of CT studies concluded in one shift Number of CT studies taken in one shift	$B_{CT}=V_{15}/V_6$	1.00	0	0.77	0.95
Diagnosis	V_{16} V_{17}	Hiring of an RIS administrator Number of studies diagnosed in PACS	$A_D=V_{16}$	0.63	0	1	1
	V_{18}	Number of studies diagnosed in one shift	$B_D=V_{17}/V_{18}$	1.00	0	0	0.33

Results

Process Analysis

There were analyzed four processes: reception (R), X-ray (X), computed tomography (CT), and diagnosis (D). For each one, there was generated a flux diagram [13], and in total, there were 17 non-added value activities identified related with five defects, wait time, inventory, people movement, over-processing, and transportation, and ten opportunity areas. To know the processes performance, there were 25 variables (V_i) and 19 indicators (I_i) defined related with the information flow through the RIS-PACS (Table 1) or wait times (Table 2). It is important to clarify that not all the indicators have the same impact in the process; because of this, it was assigned a weigh (P_i) according to its relevance. Note that in Table 1 the indicators C_R, D_R, E_R, II_X, C_{TC}, and I_D have the major relevance (P_i=1) and the rest of the indicators have a value between 0.38 and 0.75. In the case of the wait time indicators (Table 2), three have the relevance (P_i=1) and the two remaining have the minimum relevance (P_i=0.25).

Innovation Proposals

There were generated 13 innovations related with personnel training, workflow changes, and workload distribution

Table 2 Variables and indicators of wait time at the ID

Process	V_i	Variable description	I_i	M_1	M_2	M_3
Reception	V_{19} V_{20}	Patient's arrival time Patient's attending time	$A'_R=V_{20}-V_{19}$	04:01	00:48	00:32
	V_{20} V_{21}	Patient's attending time Availability time of data in RIS	$B'_R=V_{21}-V_{20}$	24:29	10:16	17:28
	V_{22} V_{23}	Patient's calling time Study availability time in RIS	$C'_R=V_{23}-V_{22}$	23:00	16:18	17:28
X	V_{22} V_{24}	Patient's calling time Application arrival time to X-ray area	$A'_X=V_{22}-V_{24}$	14:08	05:31	04:34
CT	V_{22} V_{25}	Patient's calling time Application arrival time to CT area	$A_{CT}=V_{22}-V_{25}$	17:29	17:25	05:16

Table 3 Innovation proposals for the four processes of the ID

Process	Innovation	Lean tool
Reception	Patient's attention sign	VM
	Study payment sign	VM
	Personnel's activities blackboard	VM
	Study application	Kanban
X and CT	Radiologists' reminder sign	VM
	Radiologist's activities blackboard	VM
	Control technician assignment	5S (sustain)
	Trays to place the printed studies	5S (sort)
Diagnosis	Hiring of an RIS-PACS administrator	SWI and 5S (sustain)
Imaging department	RIS training (receptionist, technician, and radiologist)	SWI
	Log book (one per area: R, X/CT, and D)	VM

(Table 3). These innovations were evaluated and approved by the Imaging Department and the Biomedical Engineering Department, which depended on the available resources at the institute for their implementation.

For the reception process, there were four innovations generated: three visual aids (two for the patients and one for the technicians) using the VM tool, and there was a new study application form proposed using the Kanban tool.

Because the technician RIS profile is the same in the X-ray and computed tomography processes, there were four innovation proposals generated in common that have an impact in the reduction of wait times in the two processes. Two innovation proposals are based on visual aids (VM), and two are related with the consecutive order the study is taken with, the study conclusion, and the study printing order. These last two were developed based on sustain and sort from the 5S's Lean tool. For the diagnostic process, the *SWI* tool was used and it was proposed that an RIS-PACS administrator be hired to help the radiologists to view the studies' images or insert the studies' diagnosis in the system.

For the general ID process, in all the areas, many innovations were implemented, such as: three log books (reception personnel, technician, and radiologist directed) as a VM to document the problems encountered in the RIS-PACS; and the training for each one of the professional profiles found at the ID (receptionist, technician, and radiologist) on the use of the system and avoid the sub-use of technology that was present at that time. In this case, the SWI tool was also used.

Measurement of the Process

The first measurement (M_1) was performed to know the original process performance, and the result of the information flow indicators is shown in Table 1. Note that some indicators have a value of zero. This is because the RIS-PACS at that time was not fully utilized because the reception personnel did not program patients in the agenda, the technicians did not conclude studies, and the radiologists did not diagnose the studies. In the case of the indicator E_R that is related with the installation of a study printer in reception, the value of zero represents that at that time, this resource was not available. For the time indicators, the M_1 corresponding values (Table 2) represent the initial reference of wait time for the related activities. What is expected in the subsequent measurements is that the wait times are reduced.

To implement the innovations in the process, a pilot program was held at the INER's ID for 5 weeks (October–November 2010). The pilot program started with the placing of the visual aids in their corresponding places and areas and the log books to document the RIS-PACS-encountered problems at the reception, X-ray, computed tomography, and diagnosis areas. The trays were also placed to ensure the order of the printed studies for their delivery. Later, the training for 20 users was programmed: four receptionists; four technicians in the morning shift and seven in the afternoon shift; three radiologists in the morning shift; and two in the special

Table 4 Product (Ii)(Pi) of the indicators I_X and II_X in the three measurement periods

Indicador	P_i	M_1	$M_1(P_i)$	M_2	$M_2(P_i)$	M_3	$M_3(P_i)$
I_X	0.75	0.28	0.21	0.60	0.45	0.55	0.41
II_X	1.00	0.00	0.00	0.43	0.43	0.96	0.96
Σ	1.75		0.21		0.88		1.37

Table 5 Indicators change Δ_j and linear transformation LT for the X-ray sub-process

	Information flows		Wait time	
Time [days]	Δ_j	LT	Δ_j	LT
0	0.118	0.055	0.686	0.503
15	0.494	0.296	0.877	0.910
30	0.785	0.668	0.911	0.051

shift. Each one of the trainings lasted 30 min and was delivered in a theoretical–practical way by using the RIS-PACS.

Once the innovations are implemented, two more measurements were performed, in t=15 days (M_2) and in t= 30 days (M_3). The result of the information flow indicators is presented in Table 1. Note that the II_R indicator obtained a value of zero in the three time frames because it was not possible to launch the RIS agenda to program the patients' appointments; however, in the rest of the indicators, there was an increase in the subsequent measurements, which means that there was an enhancement in the performance of the sub-processes of the ID. In the case of the wait time indicators, the result is shown in Table 2. Note that in general, the wait times decreased, but in the B'_R and C'_R indicators, there was no increase probably because the usage of the RIS is related and it was not possible to launch the system's agenda to automate the studies programming.

Impact of the Innovated Processes

For each process, two learning curve types were generated: one for information flows and another one for wait times [14, 15]. In both cases, the expected function (1) has the maximum learning value in 1 (N=1) on the y axis and is equal to 100 %. Later, a global learning curve for each case was generated that integrates the four processes in order to show the impact of the innovations in the ID. To obtain this learning curve, the information that was acquired in the three measurement periods was used (M_1, M_2, and M_3) and the calculated learning levels were defined as N_1, N_2, and N_3, respectively. These learning levels represent the level of the process performance in percentage notation.

Global Learning Curves for the ID

Next, the procedure to calculate the global learning curves is illustrated.

1. Calculate the indicators' change Δ_j for each measurement period using Eq. (6).

$$\Delta_j = \frac{\sum_{i=1}^{n}(I_i)(P_i)}{\sum_{i=1}^{n} P_i}, j \rightarrow \{1, ..., 3\}. \quad (6)$$

This operation is illustrated with the two information flow indicators for the X-ray process. The product of each indicator (I_i) by its corresponding weigh (P_i) in each measurement period (M_1, M_2, and M_3) and the sum, respectively, are shown in Table 4.

Later, using Eq. (6), the indicators' change Δ_j in each period was calculated, obtaining the following results:

$$\Delta_1 = \frac{0.21}{1.75} \simeq 0.118 \quad \Delta_2 = \frac{0.88}{1.75} \simeq 0.494 \quad \Delta_3 = \frac{1.37}{1.75} \simeq 0.785$$

2. Apply the linear transformation LT (Eq. (2)) to the indicators' change Δ_j. The example for Δ_1=0.118 is shown, corresponding to the indicators' change of X-ray process in the first measurement (t=0 days). The total of calculations is shown in Table 5.

$$\mathrm{LT} = \log_{10}\left(\frac{1}{(1-0.118)}\right)0.055$$

The same procedure was done for the other three processes (reception, computed tomography, and diagnosis). The indicators' change Δ_j for each process in each measurement period as well as their linear transformation is shown in Table 6. To develop the global learning curve of the ID, the average of the result of the indicators' change $\overline{\Delta_j}$ was considered in each measurement period for each sub-process; for both information flow and wait times using Eq. (2), the linear transformation was performed (Table 6). It was graphed t vs LT (Fig. 1) and the straight line equations $Y(t)_{IF}$ and $Y(t)_{WT}$ were obtained.

3. Obtain the equation of the global learning curve of for information flow $P(t)_{IF}$ and wait time $P(t)_{WT}$ of the X-

Table 6 Indicators' change and their average $\overline{\Delta_j}$ in each measurement period for each process

	Information flows						Wait time				
Days	X	R	CT	D	$\overline{\Delta_j}$	LT	RX	R	CT	$\overline{\Delta_j}$	LT
0	0.118	0.233	0	0	0.090	0.025	0.686	0.807	0.783	0.741	0.587
15	0.494	0.561	0.473	0.263	0.448	0.258	0.877	0.896	0.790	0.854	0.835
30	0.785	0.613	0.597	0.509	0.626	0.427	0.911	0.903	0.940	0.918	1.086

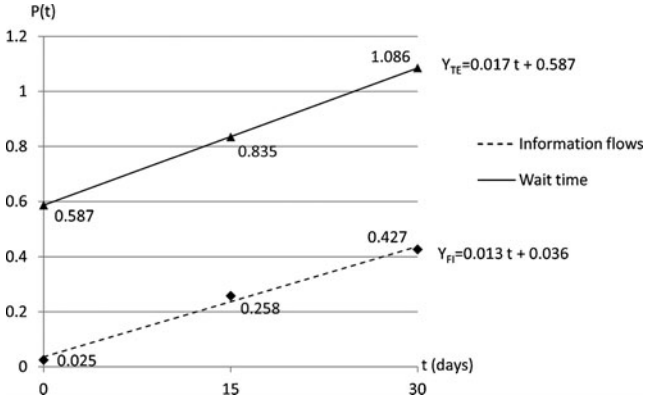

Fig. 1 Linear transformation for both type of indicators at the ID

ray sub-process using Eq. (1) and the slope (m) and the origin coordinate (b) from the equations $Y(t)_{IF}$ and $Y(t)_{WT}$ obtained in the preceding step (Fig. 1) and graph (Fig. 2).

$$P(t)_{FI} = 1 - e^{-(0.013t+0.036)} \tag{7}$$

$$P(t)_{TE} = 1 - e^{-(0.017t+0.587)} \tag{8}$$

The overall learning increase for the global ID process is clearly shown in both curves (Fig. 2). Note that for wait times, 66 % was reached in 30 days with an overall increase of 22 %. For information flow, a 34 % learning level with an overall increase of 31 % was reached because the initial learning level was practically null (3.5 %). The increase in the learning level was due to the correct RIS-PACS usage by the ID personnel, after the training was done in the pilot program.

4. Calculate the time in which it is prognosticated that the process will reach 80 % of the maximum learning, for information flow and wait times using Eqs. (7) and (8), respectively.

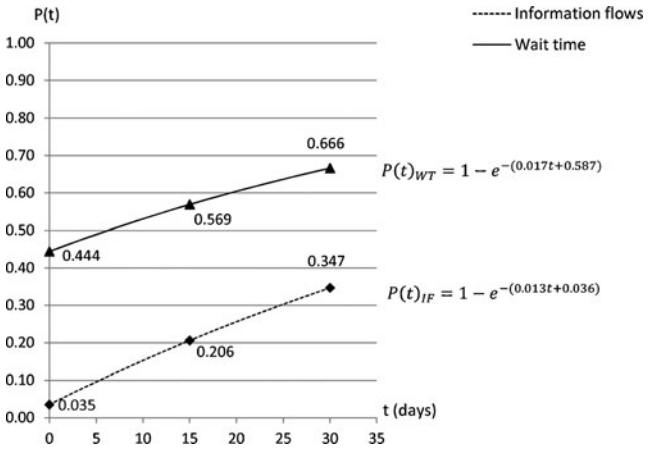

Fig. 2 Learning curves of the ID

Information flows: $P(t)_{IF} = 1 - e^{-(0.013t+0.036)} = 0.80$
Finding t value: $t = \frac{\ln(0.2)+b}{-m} = \frac{\ln(0.2)+0.036}{-0.013} \simeq 121$ days
Wait time: $P(t)_{TE} = 1 - e^{-(0.014t+0.66)} = 0.80$
Finding t value: $t \simeq 60$ days

It is prognosticated that in 121 days, an 80 % of learning level will be reached in the global ID process; for wait times, there are 60 days with a growing positive tendency in both cases.

Sigma Level of the Imaging Department

The procedure for calculating the sigma level of the ID process is described as follows:

1. Calculate the global learning level for information flow and wait time with the average of the three levels N_1, N_2, and N_3 shown in Fig. 2 and the defect probability P (d) using Eq. (3). The results are shown in Table 7.

$$P_1(d) = 1 - 0.239 = 0.761$$
$$P_2(d) = 1 - 0.388 = 0.612$$
$$P_3(d) = 1 - 0.507 = 0.493$$

2. Calculate z_j value finding the defect probability $P_j(d)$ in the two-tailed normal distribution table [10].

$$z_1 = 0.305, \quad z_2 = 0.510, \quad z_3 = 0.690$$

3. Calculate the sigma level σ_k using Eq. (4) and the z_j value.

$$\sigma_1 = 0.305 + 1.5 = 1.8, \quad \sigma_2 = 2.0, \quad \sigma_3 = 2.2$$

4. Calculate the DPM, using the Six Sigma Conversion Table [12].

$$\mathrm{DPM}_1 = 401,300, \quad \mathrm{DPM}_2 = 308,500, \quad \mathrm{DPM}_3 = 226,600$$

The defects in this work correspond to the patients that experienced a defect during the process at the ID.

5. Calculate the number of attended patients with defect per month using Eq. (5).

$$\mathrm{Patients}(N_1) = \frac{3{,}500(401{,}300)}{1\times10^6} = 1{,}405,$$
$$\mathrm{patients}(N_2) = 1{,}080, \mathrm{patients}(N_3) = 793$$

The initial sigma level of the ID (before the innovations) was σ_1=1.8 which means 1,405 patients with defect per

Table 7 Average learning level of the ID in the three measurement times

	N_1	N_2	N_3
Information flow	0.035	0.206	0.347
Wait time	0.444	0.569	0.666
Average	0.239	0.388	0.507

month, this means, 47 daily patients with defect during their stay at the ID. During M_2 and M_3, the number of patients with defect was 1,080 per month (σ_2=2.0), which means 36 patients with defect per day; and 793(σ_3=2.2), with 27 patients with defect per day. On the other hand, considering that in the ID there are 3,500 patients attended in average per month, the percentage of patients with defect is relatively low: 1.3, 1.0, and 0.7 %, respectively.

Conclusions

Parting from the installation of an RIS-PACS at the ID in the INER the innovation of four processes was performed: reception, X-ray, computed tomography, and diagnosis. There were 25 defined variables and 19 indicators related with the information flow through the RIS-PACS and the wait time associated with the human factor during the process. There were 13 innovation proposals generated directed to three different topics: (a) personnel training, (b) changes in the workflow, and (c) workloads that were implemented at the ID in a pilot program.

With the objective to know the impact of the innovated processes at the ID, there were two learning curves generated (Fig. 2): one for information flows and another one for wait times. These curves show how the overall learning for the global ID process was increased because if the curve is a positive saturation-type exponential function (which is the case), it means that there is learning gain because a learning curve represents the performance of someone who gains a skill as a time function. Observe that the three learning levels obtained in the three measurement periods (0, 15, and 30 days) were N_1= 0.239, N_2=0.388, and N_3=0.507, respectively (Table 6), which clearly show an improvement in the process performance.

To complete the Six Sigma methodology and obtain a control method for the processes, the sigma level (σ) of the ID was determined, which before the innovations was σ_1=1.8 with 47 patients with defect per day. The two subsequent measurements were: σ_2=2.0 with 36 patients with defect per day and σ_3=2.2 with 27 patients with defect per day. It is important to note that although these values are located within the standard values established for the services delivery, σ_1=[1.0, 2.0] [8], these values are still under the performance levels reported for hospitals: σ_1=[3.0, 4.0] [9]. However, the enhancement percentage between the original process and 15 days after the innovations implementation was 10 %, and after 30 days, the process enhancement was 10 % more; it is concluded that the general ID process had a general improvement of 20 %. This clearly demonstrates that the innovations had a positive impact in the performance of the process at the ID in the INER during the first 30 days when the pilot program was implemented. In the same manner that the innovations are held within the process execution, the personnel will become more able (will continue learning), and therefore, the sigma level will continue to grow. The Six Sigma methodology represented a good tool to detect the defects in the ID process, propose innovations, and evaluate the innovated process. In this sense, although the use of this methodology in this work is presented at an imaging department, it is clear that this methodology may be applied to any process within a health institute.

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