

A Filmless Radiology Department in a Full Digital Regional Hospital: Quantitative Evaluation of the Increased Quality and Efficiency

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Reggio Emilia hospital installed Picture Archiving and Communications Systems (PACS) as the final step towards a completely digital clinical environment completing the HIS/EMR and 1,400 web/terminals for patient information access. Financial benefits throughout the hospital were assessed upfront and measured periodically. Key indicators (radiology exam turnaround time, number of radiology procedures performed, inpatients length of stay before and after the PACS implementation, etc.) were analyzed and values were statistically tested to assess workflow and productivity improvements. The hospital went “filmless” in 28 weeks. Between the half of 2004 and the respective period in 2003, overall Radiology Department productivity increased by 12%, TAT improved by more than 60%. Timelier patient care resulted in decreased lengths of stay. Neurology alone experienced a 12% improvement in average patient stay. To quantify the impact of PACS on the average hospital stays and the expected productivity benefits to inpatient productivity were used a “high level” and a “detailed” business model. Annual financial upsides have exceeded \$1.9 millions/year. A well-planned PACS deployment simplifies imaging workflow and improves patient care throughout the hospital while delivering substantial financial benefits. Staff buy-in was the key in this process and on-going training and process monitoring are a must.

KEY WORDS: PACS, cost savings, cost-effectiveness, efficiency, PACS system, performance, patient stay

BACKGROUND

Hospital Transition to Full Digital Imaging

Reggio Emilia’ Arcispedale Santa Maria Nuova is a 900-bed public regional acute care hospital. Major investments in medical

equipment and health care information systems have been made in recent years. The hospital invests more than 2% of its global budget in Information Technology (IT, Picture Archiving and Communications Systems (PACS) excluded) annually. Approximately 180,000 imaging examinations are performed every year by the Radiology Department, with a large outpatient population of 40%. Emergency department represents 31% of the workload, while inpatient and day patients account for the remaining 29%.

Transition to Full Digital Imaging

A joint multifunctional management project team for PACS was formed during initial project phase and continues to provide guidance in ongoing PACS operations. The team set clear criteria to monitor the implementation and measure the clinical and busi-

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Table 1. Schedule of the Implementation of PACS

Date	Main Activity
April 15, 2003	PACS go live. CT and MR examination archived on PACS. Filmless start in Radiology Department
June 15, 2003	Starts test web images distribution in Neurology
July 21, 2003	No more film printed for CT/MR examinations of inpatient requested by pilot departments
August 4, 2003	No more film printed for CT/MR examinations for outpatient (referral and paper print of key images)
October 1, 2003	Hospital filmless transition completed (images web distribution extended to all departments)
May 5, 2004	100% digital radiological procedures ordering completed on HIS
June 14, 2004	Referral and images CD for all outpatients

ness outcomes,¹⁻³ providing solutions for specific clinical departmental requirements such as digital orthopedic preoperative planning for the operating room. A medical representative from each of the 37 hospital wards is on the team. Specifications for the system included full PACS/RIS/HIS and modality integration, load balancing mutual take-over PACS server configuration, "Everything on Line (EOL)" architecture in the form of Kodak DirectView PACS 5.2,⁴⁻⁶ automatic speech recognition systems (ASRS), and web-based full-depth 12-bit image ward distribution via an intranet PACS web access on any of the hospital's 1,400 personal computers.

The deployment was performed in a multistep approach (Table 1). Extensive user training on the PACS web module involved more than 400 medical and nursing professionals.⁷ To facilitate and accelerate the use of the IT process, a portion of the clinical staff's incentive plan was tied to the Electronic Patient Record (EPR) component deployment. As an example, during the first half of 2004, 50% of the bonuses were tied to the transition from paper to electronic radiology examination orders.

Measuring PACS Benefits

Peer experience indicates that PACS enables increased productivity in imaging procedures, as well as improved patient care and patient satisfaction.^{1,2} Three key areas were measured over time

(both pre- and post-PACS), analyzed, and documented⁷⁻⁹: film consumption; number and charges billed for outpatient procedures; and inpatient productivity. The number of inpatient procedures were not analyzed per se as in Italy type and number of imaging procedures performed for inpatients do not influence inpatient reimbursements, tied only to DRG reimbursements (business benefits can be related on hospital stay that can be shortened by increased productivity, limiting patient discharge delay due to reports and images unavailability).

Number and Charges Billed for Outpatient Procedures

A set of queries was created to automatically extract the pre and post-PACS information (respectively from October 15th 2002 to April 15th 2003 and from October 15th 2003 to April 15th 2004) from the HIS/RIS data for type and number of outpatient procedures and average ordering waiting time (in days) necessary to have a nonurgent procedure performed. The latter can be a good proxy for recaptured reimbursements from the private sector.^{8,9}

Inpatient Hospital Productivity

Even if the patient stay involves multiple factors, it is reasonable to assume that faster availability of reports can produce quicker clinical

Table 2. Total Reimbursements Invoiced by the Radiology Department

	Number of Exams	Equivalent Reimbursement	Average Exams Cost	Radiology Department Working Staff (No. eq. full time)	Productivity (per full time)
Pre-PACS (10/15/02-4/15/03)	78,904	\$3,716,368	\$47.1	92.5	\$40,177
With PACS (10/15/03-4/15/04)	84,532	\$4,197,242	\$49.7	88.5	\$47,426
Differences	7.1%	12.9%	5.4%	-4 FTEs	18.0%

Table 3. p Values Obtained by Student t test on Different Acquisition Modality Execution Time (ET), Referral Time (RT) and Turn Around Time (TAT) between Execution Time, Referral Time and Turn Around Time Pre- and Post-PACS

Modality	ET	RT	TAT
General X-ray	0.385	4.60E-07	1.32E-05
CT	0.608	1.57E-04	1.72E-04
MRI	0.732	3.46E-05	3.6E-04
US	0.561	1.81E-15	2.85E-12
Mammography	0.592	6.83E-06	2.51E-05

treatment. The corresponding improved patient discharge rate may be providing timely and hopefully improved patient care. A set of queries was created to automatically extract the information from the HIS/RIS data for the turnaround time (TAT) and hospital stay measurements. The data before and after the PACS implementation was measured using the same metrics and during the same time of year, thereby eliminating any seasonality effect. Patients who had at least one imaging examination during their hospital stay were compared to patients who had no imaging

examination during their hospital stay. Imaging order comparisons were made as well, measuring the average number of examinations per patient.

To assess each clinical department’s reaction to the PACS implementation, each finding was validated by the ward supervisors and staffs via a predetermined form. Evaluation included time required to complete radiological procedures, time to image and report availability, as well as accessibility of previous examinations.

Two different methods were used to quantify the PACS’ impact on the length of average

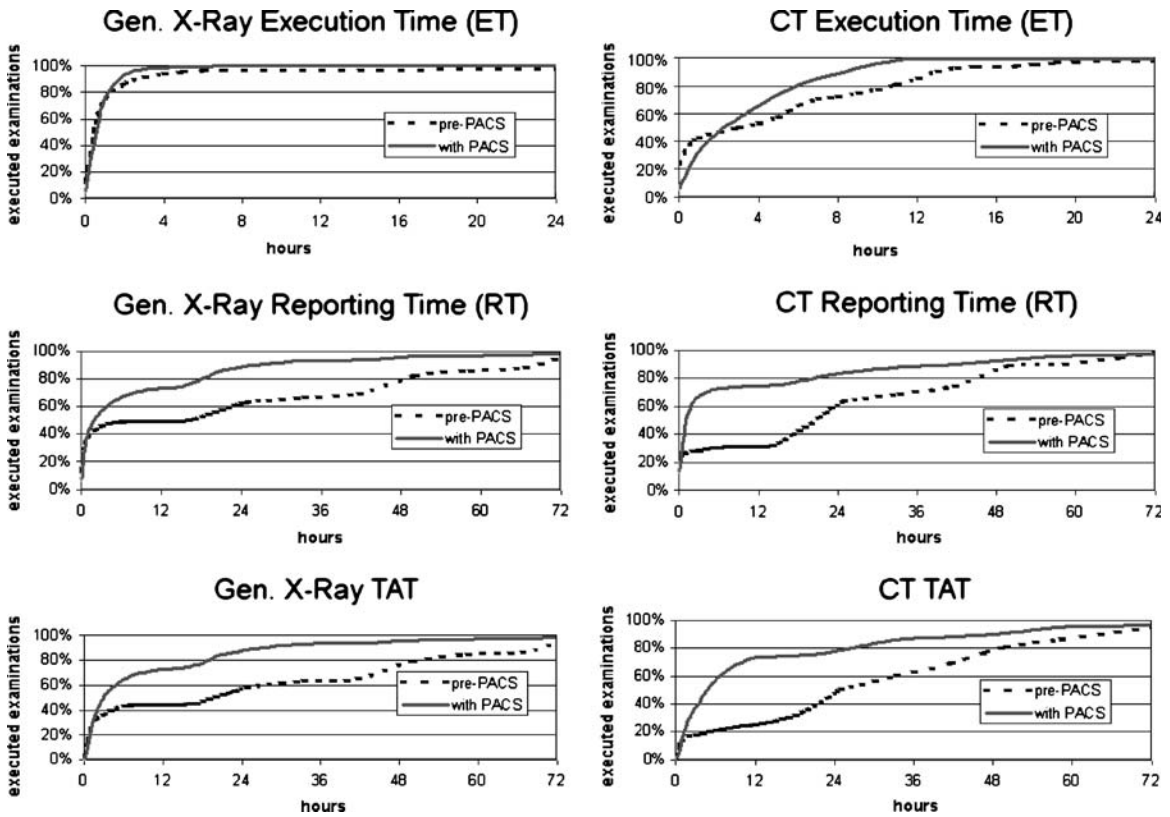


Fig 1. Percentage of executed, referred, and completed examination as a function of the time for general X-ray and CT examinations in pre-PACS (dotted line—from 10/15/2002 to 04/15/2003) and with PACS (continuous line—from 10/15/2003 to 04/15/2004) condition.

Table 4. Pre- and Post-PACS Average TAT (hours) for Different Acquisition Modality

Modality	Pre-PACS	Post-PACS	Difference	Variability
General X-ray	42.1	15.4	-64 %	Statistically reduced >3 times
CT	40.5	20.0	-52%	Statistically reduced 8 times
MRI	44.5	32.6	-28%	Variability statistically not changed
Mammography	41.1	16.2	-61%	Variability statistically reduced >3 times

hospital stay and the corresponding inpatient productivity. The first method, called “high level business model approach”, was developed during the initial phase of this study to predict the impact of an integrated PACS/RIS/HIS system.⁴ This is based on the concept that image and report availability influences the length of the patient’s hospital stay, either by enabling earlier treatment or earlier discharge. The second method, called “detailed business model approach”, considers each hospital department’s performance, and measures each performance improvement. Seventeen clinical and surgical departments were analyzed, ensuring no significant change in the clinical or surgical protocols, nor any unit organizational change. The key variables that the project team chose to analyze and validate were Radiology “turnaround time” and inpatient hospital stay. TAT is defined as the sum of the time that elapses between the moment an imaging exam is ordered, its execution time (ET), and the reporting time (RT), which is the time lapse between the image execution time and the availability of the imaging exam’s report. Turnaround time is the input and inpatient hospital stay is the output used to calculate the resulting hospital productivity. Sta-

tistical analysis was performed on the means, median, and variances to validate the results relative to TAT and “hospital stay by unit” both before and after PACS implementation, using Minitab (Minitab release 14, Minitab Inc., PA, USA). Distribution always tested for normality, and none proved to be modeled statistically by a normal curve. Therefore, for variance statistical analysis, Levene test was used; and for median, mood median test was used. *F* test and ANOVA one-way *t* tests were used for means analysis. The team checked to ensure that no significant clinical treatment protocol change or staffing change had occurred in the considered timeframes. The “hospital stay” was analyzed for consistency against department flow (chronic versus “regular” patients), use of radiology services, and diagnose related grouping (DRG and/or ICD9 codes), whenever possible. The 17 units that were analyzed were those that ordered the greatest number of radiology procedures for inpatients being prioritized; in this respect, neurology was the first. To quantify economical improvement, media differences were used when the central values had changed. If the variance analysis had also changed, a P95 approach was used.

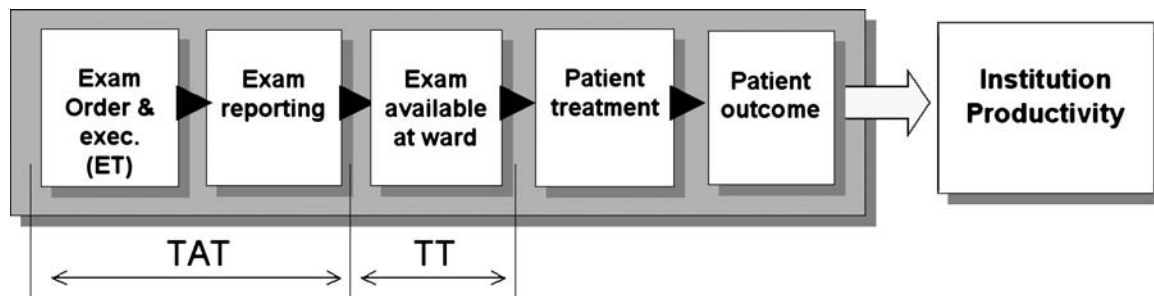


Fig 2. Workflow of radiology procedures process. The turnaround time, TAT, is defined as the sum of the time that elapses between an imaging examination is ordered and executed. The transfer time, TT, is the time to deliver images and referral to the clinical units. In a fully integrated digital environment images and referrals are immediately available to the ward (TT = 0). In an analogue one, film and paper printed reports need to be physically carried from Radiology to the ordering clinical or surgical unit.

Table 5. Pre- and Post-PACS Inpatient MRI Procedures' TAT

MRI scans TAT	Number of Exams	Mean (hours)	Standard Deviation (hours)	Median (hours)	Q3-Q1 (hours)
Pre-PACS (1/1/03–30/4/03)	481	38.35	28.5	29.1	42.2
With PACS (1/1/04–30/4/04)	496	24.90	31.6	11.0	28.2
Improvement		13.4		18.1	14.0

RESULTS

Film Savings

Film savings during the period immediately following system installation, April to October, 2003, were 15%, and grew to 90% as soon as the workflow became filmless 28 weeks after go live. Only mammography remained film-based. All of the studies' images were available on intranet PACS web distribution. Outpatients' key images are automatically burned on CD. Patients who require iconography film prints pay an additional fee. Film savings correspond to \$0.84 million per year versus pre-PACS.

Outpatient Productivity

Data analysis measured a 7% increase in the number of radiology department imaging procedures year over year during the same 6-month period (October 15 to April 15) with no increase in the number of technologists or radiologists,¹³ thanks to the combined PACS and CR/DR implementation. The first year's period (10/15/02–4/15/03) was pre-PACS implementation; the second year's period (10/15/03–4/15/04) was postimplementation. Before the PACS implementation, outpatient examination reports were delivered in 5 days. After the introduction of PACS, this time was reduced to 3 days. Urgent examination responses were delivered immediately and the report delivery process did not change during this time.

The elimination of the off-line reports typing has freed up staff resources for other tasks:

reminders to outpatients regarding scheduled procedures and filling slots made available by cancellation or reschedule requests. This process enhancement decreased average waitlists for outpatients from 90 to 40 days for nonurgent CT exams and from 90–180 down to 30–60 days for nonurgent ultrasound scans. Shorter waitlists enabled increased outpatient business. Total reimbursements invoiced by the Radiology Department rose 12.9% to \$4.2 million during the post-PACS implementation period referenced in Table 2 (line 2). This far exceeds the average annual increase of the preceding 2 years, 2001 and 2002, at 4.7% and 5.2%, respectively. The economical benefit corresponding to the increased number and the higher complexity (average cost per exams rose by more than 5%) of outpatient examinations directly reimbursed to the Hospital, was estimated in more than \$0.55 million for the year 2004 (with PACS) with respect to the 2003 (pre-PACS).

Radiology Department Turnaround Time

Effects of PACS and ASRS on Execution and Reporting Time

Assuming the different percentages of examinations referred/executed/completed as a function of time could be adopted as workflow indicators, a detailed statistical analysis on the TAT data demonstrated that the sample populations corresponded to pre- and post-PACS situations belonged to two different distributions with a 5% confidence level (*t* test groups). For CT, MRI, general X-ray, or mammography examinations,

Table 6. Pre- and Post-PACS Inpatient CT Procedures' TAT

CT scans TAT	Number of Exams	Mean (hours)	Standard Deviation (hours)
Pre-PACS (1/1/03–30/4/03)	2,093	29.6	32.36
With PACS (1/1/04–30/4/04)	1,954	13.5	24.75
Improvement		16.1	

Table 7. Pre- and Post-PACS Inpatient Chest Radiography Exams' TAT

Chest exams TAT	Number of Exams	Mean (hours)	Standard Deviation (hours)	Median (hours)	Q3-Q1 (hours)
Pre-PACS (1/1/03–30/4/03)	6,754	33.9	56.25	19.1	44.2
With PACS (1/1/04–30/4/04)	7,456	9.62	26.09	2.6	5.5
Improvement		24.3	–	16.5	39.3

the percentage of executed examinations in function of time failed to show statistical difference in the image acquisition process: the introduction of digital radiographic image acquisition systems did not produce a statistically significant reduction of the average execution time. Greater productivity is a result of improved workflow (scheduling ability and the resulting reduction of the “idle time”).

The *t* test for a difference between the percentages of referred examination in function of time showed statistically significant difference in the reporting process with and without PACS.^{10–12} ASRS in radiologist reporting process permitted greatly diminished average report times for mammography and ultrasound examinations also (Table 3).

In general, execution time almost never exceeded the daily work time of 12 hours. On the other hand, referral time before PACS and ASRS was typist-dependent, assuming a characteristically step trend (clearly visible in Fig. 1). Please note that 12-hour continuums correspond to the two daily 6-hour work shifts and 12-hour plateaus correspond to night breaks. This is, of course, less evident after introduction of PACS and ASRS (Table 4).

Inpatient Workflow

Figure 2 describes the workflow for inpatients requiring radiology procedures and demonstrates how radiology performance influences the length of hospital stay.^{8–10, 14} As stated before, TAT

decreased with PACS introduction over 60%, even without adding benefits from eliminating transmission time (TT). MRI, CT, and radiography exams were studied. In all cases, the sample size was statistically significant and large in absolute terms. It is important to note that the transmission time (TT) from the radiology department to the ward was not taken into account. Before PACS, TT was estimated to be between 8–12 hours range, unless the department sent someone to pick up the study (films and report). After PACS implementation, the TT is a matter of seconds.¹⁵

Inpatient MRI Scans

For MRI scans, the mean TAT decreased from 38.4 to 24.9 hours; the median decreased from 29.1 to 11.0 hours, with an improvement of 18.1 hours or 62% ($p < 0.001$); the “(Q3–Q1)” indicator, used as a proxy for variance and spread, decreased from 42.2 to 28.2 hours (Table 5). Mean and median distributions were statistically different, showing a *p*-value equal to zero in both cases (note: variance *p*-value Levene's test, for nonnormal distributions, is equal to 0.220). Execution time (ET) did not change much; the mean moved from 2.6 to 2.5 hours, and the median increased from 0.6 to 1.4 hours.

Inpatient CT Scans

For CT scans, the mean TAT decreased from 29.6 to 13.5 hours. The median decreased from

Table 8. High-level Business Model Approach Expected Benefit. The Percentage of Significant Exams is Assumed as the Percentage of Examination Performed 24 Hours Before Patient Discharge

Type of procedure	Number of Inpatient Exams per Year	Average Hospital Patient Daily Cost	Significant Exams	Expected Benefit
MRI	1,740		44%	\$328,556
CT	5,376	\$415	26%	\$483,982
Radiography	22,443		16%	\$1,487,890
Total				\$2,300,428

Table 9. Patient Stay, Neurology. Pre- and Post-PACS Comparison

Neurology patients	Patients Treated	Patients Treated with Rad. Exam.	Mean (days)	Standard Deviation (days)	Median (days)	Q3-Q1 (days)
Pre-PACS (1/1/03–30/6/03)	541	454	10.8	7.9	9.0	9.6
With PACS (1/1/04–30/6/04)	589	499	10.2	8.1	7.9	8.6
Improvement	+ 9%	+ 10%	6%	–2%	12%	11%
<i>P</i> = value			0.197	0.589 (<i>F</i> -test)	0.042	0.916 (Levene)

21.1 to 3.1 hours ($p < 0.001$), a sevenfold improvement. The “(Q3–Q1)” criteria, used as a proxy for variance and spread, decreased from 42.2 to 8.2 hours, an eightfold improvement (Table 6). Mean, median, and variance distributions were statistically different, showing a *p*-value equal to zero in all cases. Analysis on ET and RT displayed findings similar to those of the MRI studies.

Inpatient Radiography Exams—Chest

To understand the improvement of traditional radiography exams, the chest x-ray examination was analyzed as one of the most common and standardized procedure. The mean TAT decreased from 36.0 to 8.9 hours ($p < 0.001$) and the median decreased from 20.6 to 2.5 hours, an improvement of 18.0 hours or an eightfold improvement. The “(Q3–Q1)” criteria, used as a proxy for variance and spread, decreased from 44.5 to 4.9 hours, a ninefold improvement. Mean, median, and variance distributions were statistically different, showing a *p*-value equal to zero in all cases (Table 7).

Reporting time decreased for the modalities. Even though dictation time is longer for the radiologist with the digital solution, the very nimble reporting process offsets this shortfall with a substantial gain.

Hospital Productivity Driven by Improved Radiology Workflow

The number of inpatients treated in the first half of 2004 versus the first half 2003 did not change: 16,207 versus 16,362.

Inpatient Hospital Productivity Assessment—High-level Business Model Approach

The improved Radiology performance contributes to hospital workflow by enabling the clinical and surgical wards to begin earlier treatment and/or to safely discharge the patient due to the immediate availability of the necessary images and reports according to the relevant clinical protocols.

By extracting the data from the RIS, and assuming savings of a full day in the length of patient stay for each exam performed in the 24-hour period before patient discharge, the hospital anticipates a \$2.3 million benefit a year (Table 8). The contribution of earlier treatment decision was not evaluated because the examinations are generally performed before scheduled admissions (day surgery or day hospital admissions are usually preferred over longer and more expensive treatments).

Inpatient Hospital Productivity Assessment—Detailed Business Model Approach

The four most important departments of the 17 that showed actual improvements during analysis, are documented in the following section.

Neurology

Neurology treated 589 patients during the first half of 2004, an increase of 9% over the previous year. While 13% did not require radiology

Table 10. Thoracic Surgery Patient with Radiological Procedures. Pre- and Post-PACS Patient Stay

Thoracic surgery patients	Patients Treated	Mean (days)	Standard Deviation (days)	Median (days)	Q3-Q1 (days)
Pre-PACS (1/1/03–30/6/03)	149	9.3	10.6	7.0	6.1
With PACS (1/1/04–30/6/04)	191	7.8	6.1	6.3	6.3
Improvement/change	+ 28%	16%	42%	11%	–3%
<i>P</i> = value		0.100	0.000 (<i>F</i> -test)	0.325	0.105 (Levene)

Table 11. Internal Medicine Patient with Radiological Procedures. Pre- and Post-PACS Patient Stay

Internal medicine patients	Patients Treated	Mean (days)	Standard Deviation (days)	Median (days)	Q3-Q1 (days)
Pre-PACS (1/1/03–30/6/03)	526	13.0	8.7	11.1	10.1
With PACS (1/1/04–30/6/04)	497	11.7	7.4	10.0	9.5
Improvement/change	–6%	10%	15%	10%	6%
<i>P</i> = value		0.011	0.000/ <i>F</i> -test)	0.047	0.045 (Levene)

procedures, the Chi-square analysis suggested that the “with/without radiological examinations” had not changed during the study period (p -value=0.276, Chi-square=1.888). The data from the first half of 2003 and 2004, respectively (Table 9) show a decrease in the mean of 6%, to 10.2 days, a statistically valid decrease for the median of 12% to 7.9 days. Variability decreases as well, but not in statistical terms. Results for the most frequent DRG (DRG014) showed similar patterns (Table 9). For a population of 174 patients, 159 with radiology procedures, length of patient stay with imaging procedures decreased statistically from 8.9 to 6.9 days, with variability increasing mathematically from 6.9 to 7.3 days. The total annual economic benefit is estimated at \$360,000, for approximately 1,100 patient bed/days saved, at \$331/day.

Thoracic Surgery

The unit treated 224 patients in the first half of 2004, an increase of 14% over the prior year, without altering the number of postsurgery beds available. The amount of “with/without radiological examinations during stay” had changed during the studied period (p -value=0.016, Chi-square=11.755). Fifteen percent of the patients in 2004 did not require radiology procedures during their stay, down from 24% the year before. If we study the patient population with radiology procedures during their stay, the data from the first half of 2003 and 2004 respectively show a mathematical decrease for the means of 16% to 7.8 days, with a decrease for the median of 11% to 6.3 days. Variability decreased 42% (F -test p <0.001, Levene’s p =0.105). In this case, the benefit is driven by planning the surgical procedures and patient discharges well, as well as the resulting new admissions. Referring physicians felt more comfortable about the greater perceived probability of getting the radiology images and reports within the required time (Table 10). The total

economical benefit for the year is estimated at \$480,000, for approximately 578 patient bed/days saved.

Internal Medicine

The Internal Medicine ward, specialized in hypertension disorder and diabetic patients, treated 874 patients in the first half of 2004, with a decrease of 2.6% versus the year before, reflecting somewhat the decrease of capacity (-6 patient beds). The unit did not change significantly its clinical protocols, as patients using radiology services shrank 6% to 497 (Chi-square p value=0.450). Overall stay for the department decreased mathematically 7% from 11 to 10.2 days (means) and 3% from 8.7 to 8.3 days (medians); F -test and Levene’s test p values for variance analysis are respectively less than 0.001 and equal to 0.079. While median stay for patients without radiology services did not change—means moved from 7.4 to 7.2 days, medians stable at 6.1 days, patient stay with radiology procedures diminished statistically 10% for both means and medians, from 13.0 to 11.7 days (means) and from 11.1 to 10.0 days (medians). Variability also decreased 6% (Table 11). The two most frequent DRGs show results in line with the general analysis. The total economical benefit for the year is estimated at \$193,000, for approx. 920 patient bed/days saved.

Other Wards

Other units positively benefited by PACS availability: Gastroenterology, Orthopaedics, Vascular Surgery, Neonatology, Children’s Neuropsychiatry, Pneumology, and Neurotrauma experienced a total savings of approximately \$870,000 and 1,500 patient bed/days.

The total outcome of the detailed business exceeds \$1.9 million per year.

High-level Versus Detailed Business Model Approach

The high-level and detailed business models deliver the same order of savings (\$2.3 million per year versus \$1.9 million per year, respectively). The high-level approach represents the “theoretical” saving limit achievable with the existing workflow. The detailed business model approach represents the actual (“real life”) estimate.

DISCUSSION

After 18 months, the business outcome upside is evaluated in excess of \$2.45 million per year (\$1.9 million TAT + \$0.55 million outpatient productivity), nearly three times the film savings of \$0.84 million per year. Financial criteria were not the driving factors in choosing to adopt a fully integrated PACS solution. Given the current workload of the imaging department, the latest digital imaging technologies cannot be incorporated without moving to a totally digital environment. Clinical quality has been increased due to the availability of tools to review complex multislice CT and MRI studies; the ability to compare a several studies of the same patient across different modalities and timeframes; and finally by enabling detailed simultaneous clinical discussions between the referring physicians and radiology teams.

CONCLUSION

While we are confident in the general conclusions that a PACS system can simplify and speed up an IT integrated hospital workflow, any quantitative aspects could vary due to local context, duration of the period of observation, or by the number of wards analyzed. In particular, the patient stay can vary due to different internal decisions. However, in our case, we ensured that no significant changes in patient treatment occurred during the study period. For these types of evaluation, strong cooperation with the referring physicians is necessary.

A well-planned, fully integrated digital Radiology Department can simplify workflow throughout the hospital. PACS technology, empowered with speech recognition systems and web distribution tools, can deliver significant benefits to a health care institution. Staff and interdepartmental cooperation is key to this process. Driving workflow

optimization and detailed continuous performance monitoring are a must, as well.

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