Successful Conversion to Digital X-Ray Detectors

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Abstract. Conversion of x-ray inspections from film to digital x-ray detectors has many benefits including increased detectability, higher productivity, and simplified operations. However, successful conversion requires consideration of both technical and financial factors. The imaging performance of DXR flat-panel detector products provides the necessary film-equivalent detectability of fine defect indications with reduced exposure requirements in many applications. To determine if a digital solution is economically justified, GE Inspection Technologies routinely provides total cost of ownership (TCO) projections for specific customer applications. These projections include factors such as productivity gains, detector wearout for applicable detector models, service contract options, and elimination of unnecessary chemical handling.

Introduction

Digital Radiography (with solid-state x-ray detectors) and Computed Radiography (with photostimulable phosphor imaging plates) technologies have been successfully used to replace film in a variety of industrial radiography applications. Current estimates of the installed base for such film-replacement applications are approaching 1000 worldwide. The purpose of this paper is to present some of the issues that can help a potential user of these new technologies successfully convert from film to a digital image receptor. In addition to the technical prerequisites for a successful conversion (e.g., sufficient "image quality" to reliably image indications of interest), there are typically financial considerations.

1. Total Cost of Ownership

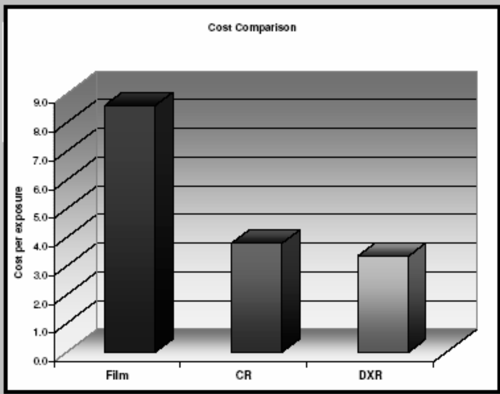
Radiographic inspections are typically performed for safety and quality reasons. However, there is usually motivation to control and even reduce the costs of performing these inspections. Thus one reason to consider a switch from film-based to digital radiography is to reduce overall expenditures. In this sense, a successful conversion is one that, when viewed as an investment, results in a measurable reduction in inspection costs.

Inspection costs include consumables such as film, chemicals, cassettes, leads, CR imaging plates, etc. Additional costs are required to perform the inspections, including logistics of moving parts to a radiography department, labour costs associated with acquiring, developing, and reviewing the films or images, and costs for archiving and reporting. There are also indirect costs, such as maintenance, inspection cycle time, addition inventory and work-in-process costs, etc. All together, these categories of cost can be combined to comprise the "total cost of ownership" for an inspection process. An example total cost calculation is shown in Figure 1, comparing film, CR, and DR options. Reducing the total cost is one measure of a successful conversion. But ordinarily the cost benefit must be compared to the up-front investment cost of making the conversion.

	Film	CR	DXR	
Exposures/year	84000	73043	69278	67200 films to be delivered to customer
Average % of retakes	20%	8%	3%	
wearout (images)			450000	
X-Ray time				
Set-up time (s)	60	60	60	
Exposure time(s)	45	15	9	
Processing time(s)	120	60	1	For film : take auto-feeder into account
Real resources time	120	75	70	
Down time	2%	3%	5%	
X-ray efficiency	90%	90%	90%	
labour cost/hr €	50	50	50	
Overlap correction factor	1	1	1	amount of units operated by 1 resource : should not exceed value in row 40
Needed man min/exp	2.3	1.4	1.4	
X-Ray cost/exp €	1.9	1.2	1.1	
X-Ray cost/year €	158730	87156	78777	
Man Day needed	397	218	197	
Inspection time				
Diagnose time/exp	30	30	30	
Documentation time/exp	30	30	30	
Archival time/exp	60	30	10	
Insp. Resource cost/hr	50	50	50	
Inspection efficiency	90%	90%	90%	
Needed insp.man min/exp	2.2	1.7	1.3	
Inspection cost/exp	1.9	1.4	1.1	
Inspection cost/year	155556	101449	74838	
Man Day needed	389	254	187	
Consumables				
Consumable cost/exp.	3	0.5	0.23333333	
Consumable cost/year	252000	36522	16165	
Hardware				
Base system cost	14000	98000	64000	
Write off period	5	5	5	
panel cost			105000	
panel replacement period			6	
Unit maintenance cost	3000	10000	8835.05155	
Working days/year	220	220	220	
Shifts	1	1	1	
Equipment capacity	46570	92189	77390	
Units needed	2	1	1	
Hardware purchase cost/ye	5600	19600	30300	
Maintenance cost/year	6000	10000	25000	
Hardware cost/year	11600	29600	55300	Check result with overlap correction factor
Total Cost	577886	254727	225079	
Cost/delivered exposure	9	4	3	
Cost saving / Exposure		5	5	

(shaded)	Application parameters. Fill out as appropriate
(light)	Referenced values. Change if needed
(dark)	Calculated value. Do not change

Summary	Film	CR	DXR
Needed resources for X-ray	1.8	1.0	0.9
Needed resources for diagnosis	1.8	1.2	0.9
Needed equipment	2	1	1
Yearly cost saving (Euro)			352806
%			61%
Cost per exposure	8.6	3.8	3.3



reference = delivered exposures

Figure 1. A typical inspection "total cost" calculation, for illustrative purposes only. In this example, the "total cost" per inspection is calculated for film, CR, and DR, including acquisition and review labor, consumables, and hardware costs including initial investment and maintenance.

1.1 Return on Investment Criteria

In most cases, the initial cost of adding a digital inspection capability or converting an existing film inspection to digital requires significant budget expenditure, so that the installed equipment is considered a capital investment. In industry, three criteria are commonly used to estimate expected return on investment for capital investments. These are Payback Period, Internal Rate of Return, and Net Present Value. Other types of organizations have different budget approval processes and metrics, but the concepts presented here may still be applicable in justifying budget expenditures.

1.2 Payback Period

This metric is the simplest to understand: it is simply the investment amount divided by the savings rate. For example, if the initial investment is 50,000 € and the resulting savings rate is 40,000 € per year, the payback period would be 1.25 years. Many organizations look for payback periods of 2 years or less to help justify capital investments.

1.3 Net Present Value

Net Present Value (NPV) is a more detailed way to view a multi-year investment. The calculation is straightforward, and most spreadsheet programs have a NPV() function to make it even easier. NPV can account for the effects of inflation. It is an estimate of the long-term impact of an investment decision expressed in current currency value (e.g., 2006€). The NPV of an investment should be positive, as a negative NPV indicates that the investment will not "pay off."

1.4 Internal Rate of Return

Internal Rate of Return (IRR) or Discounted Rate of Return is another detailed way to view a multi-year investment. Again the calculation is typically performed within a spreadsheet. The IRR gives the equivalent "interest rate" that an investment would earn. In order to look favourably on an investment decision, most organizations expect the IRR to be greater than some minimum value. Considering three factors typically sets this minimum value. These factors are: the current external investment rates available through financial instruments, the risk of investment failure, and an anticipated internal profit rate. Thus many businesses require a minimum IRR in the range of 10% to 15% in order to "go ahead" with a capital investment project.

2. Selection Factors

A number of factors influence which digital technology is preferred in any particular inspection application. To provide effective support, vendors ordinarily require a detailed understanding of each proposed application. Because digital involves relatively "new" technology, several questions are key to performing a successful conversion, including:

- What is the expected customer benefit?
- What is being inspected? How is it done today?
- What are the throughput requirements?
- What is the required return-on-investment?

Once the basic parameters of the application are understood, vendors should be able to assist in identification of appropriate technologies, and appropriate candidates can then be evaluated. It is critical that all key requirements (e.g., image quality, speed, throughput, etc.) be achievable simultaneously. For example, implementing a technology that achieves the required radiographic sensitivity only when operating at a "too slow" throughput will ensure ultimate disappointment.

2.1 General Guidelines

As shown in Table 1, there are several typical indicators that can quickly help steer a decision toward a particular digital technology. None of these indicators are absolute, but should always be evaluated in the context of a particular application. In particular, it is critical to consider both CR imaging plates and DR digital detectors as consumables. Both media will eventually require replacement. CR plates typically “wear out” from mechanical abrasion, resulting in fixed image artefacts. When the artefacts become objectionable (with careful handling, typically after many hundreds of scans), the plates must be replaced. DR detectors eventually degrade from stray x-ray dose that is not converted to image information. They “wear out” and similarly require replacement, typically after many hundreds of thousands exposures, because of objectionable noise levels in the resulting images.

Table 1. Typical indicators for CR vs. DR selection.

DR indicators:	CR indicators:
– Film or Image Intensifier replacement – Applications that benefit from automation – Applications requiring top image quality and fastest imaging speed – Applications below ~300 kV – Applications without complex access constraints	– Film replacement – Applications where DR precluded by portability or lack of electrical power – Rough handling or extreme environments – Applications requiring high kV – Wrap-around, cut-film, or “stick-it-in” jobs

Often the required kV for inspections is an important factor. The wearout rate of DR devices depends strongly on the x-ray absorption efficiency, and thus on the kV settings used to produce x-rays. The total cost per image begins to favour CR as the kV settings increase. A key point to recognize is that the optimum kV settings can change significantly between the different detection types. In particular, the optimum kV setting for DR is often lower than for CR or film, and this can effect the cost calculations.

A second important factor is the annual inspection volume (number of inspections per year). High-volume applications favour DR, while lower-volume applications favour CR or even film. The “crossover point” can vary significantly depending on annual inspection volume, but typically CR is favoured above 350 kV, while DR is favoured below 225 kV. The crossover point continues to increase as the technology in DR detectors is improved. For instance, the recently announced Endurance technology for DXR-500 devices reduces the wear out by a factor of 3 or more, significantly reducing the total cost of ownership, and making practical operation at significantly higher inspection energies.

2.2 Technical Factors

Table 2 shows additional technical considerations that can steer a conversion application in a particular direction. One key to throughput is simply the time required to acquire high-quality static images. Because of their excellent absorption efficiency, DR detectors with structured CsI scintillators have the very fast exposure times, and can collect high quality images with significantly less incident dose than other options. This efficiency allows for optimum inspection throughput, particularly when set-up and loading delays can be avoided. This class of DR detectors can exhibit small indication detectability that exceeds the performance of D4 film in many applications. CR and lower performance DR detectors typically perform more like D7 or D5, although the latest CR imaging plates (type IPS) are approaching D4 performance.

Another benefit of Digital Detectors is a much larger dynamic range than film. This typically reduces the number of re-shoots needed because of accidental over- or underexposures, and also allows wider latitude in thickness that can be effectively inspected in a single film view.

Because the improved dose sensitivity of DR allows quality images to be obtained with a lower kV and significantly reduced mA, the exclusion zone in field applications can be sometimes be decreased, significantly improving productivity.

One disadvantage of DR compared to CR or film is that the cost can preclude having a variety of sizes and resolutions available. Thus, an operation that has small volumes of a wide variety of inspection applications and that require a wide mix of film types and sizes may find it difficult to justify multiple DR systems. However, a mix of parts does not necessarily preclude DR as a digital conversion technology candidate, especially when the mix uses similar radiographic techniques.

Table 2. Typical Technical Characteristics of Film vs. CR or DR.

Current Properties	**Film**- with, w/o Pb intensifying screens	**CR**- with or w/o Pb Hard or soft cassette	**DR** – CCD, CMOS, a-Si
Speed	Slow	Medium	**Fast**
Spatial resolution	10 – 50 micron	50 –250 micron	**50** – 400 micron
SNR	50 - 250	100 – 250	**250 – 2000**
Dynamic Range	256:1, but multiple films	>4000:1	**>4000:1**
Cost of investment Cost of operation	Low High	Moderate Moderate	Moderate to High **Low**
Radiation Robustness	Excellent	Excellent	Application dependent System dependent
Mechanical robustness, environment tolerance	Excellent	Excellent	Application dependent
Ability to conform media about object	Yes	Yes	No
Portable media/equipment	High	High	Moderate; High for thin, light weight detectors
Thickness, for tight access	Very thin	Very thin to thin	Getting better
Reusability, media	1	1000-10,000	**10,000 – 1,000,000**
Field non-exclusion zone – impact on concurrent processes	Large area roped off	Moderate area roped	**Low area roped**
Sizes	Different sized film	Different sized IPs	Different sized detectors
Sensitivity to scatter	Low	Medium	Medium

Summary

Converting a radiographic inspection application from Film to CR or DR technology can make a significant reduction in the total cost of inspection. To analyze this benefit, the cost of conversion can be viewed as an investment. Standard financial metrics can be used to quantify the benefit from a “total cost” perspective.

Vendors that offer film, CR, and DR choices can help determine the most effective technology for a particular application if they understand the context and details of a particular inspection. There are simple guidelines that can quickly steer between CR and DR, but a detailed analysis of all relevant technical factors should also be performed prior to beginning a digital conversion project.