Analyzing the Business Case for UV-LED Curing Part II: Executing Calculations

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This article is the second installment in a three-part series designed to illustrate the process of conducting a business case analysis on UV-curing systems. If you have not yet read "Part I—Identifying Cash Flows" (which appeared in the RadTech Report's *December 2013 issue), you may want to do so before continuing with Part II. The article can be found at* www.radtech.org.

Many existing users of UV-curing equipment are contemplating whether to replace aging conventional systems with UV-LED alternatives. Others are evaluating UV-LED technology as a possible curing solution for new lines. When both conventional and UV-LED curing are equally viable options for a given application, the decision on which technology to use for a new line or the decision on whether to proceed with a retrofit predominantly rests on the business case.

In order to illustrate examples of decision-making methodology, a real-world example will be used to calculate the Return on Investment (ROI), Payback Period (PB) and Life-Cycle Cost Analysis (LCCA) for the purchase, integration, operation and maintenance of both a UV-arc and a UV-LED curing system. Equations for ROI, PB and LCCA were introduced and discussed in Part I as well as an explanation of how to identify the cash flow variables needed to conduct such an analysis.

For the sake of brevity, the ROI and PB examples in this paper will use *simple* methods of analysis, while the LCCA will be a *discounted* analysis. The reader can always apply the discounted methods covered in the LCCA example to the ROI and PB examples in order to improve the accuracy of the analysis. The concept of discounting and the justification

Table 1

Assumptions

Single-color screen press with 50-feet-per-minute maximum line speed
38-inch wide press cures 36-inch wide substrates and less
Plant makeup air is conditioned all 12 months
General maintenance of arc and LED systems for non-key issues is similar
Storage, handling and maintenance with respect to arc and LED inks are the same
Plant is located in a suburb of Chicago, Illinois
8-hour day, 5-day week, 50-week year with 15% downtime
Ink usage is approximately 3-5 pounds per day; 750-1,250 pounds per year
$30 per hour internal labor rate; $100 per hour contract labor rate
$0.08/kWh electricity rate (cost and transmission); Plant PF is 0.95; Target PF is 0.90
$7.79/1,000 ft^3 delivered natural gas commercial rate
State and local utility sales taxes are a combined 6%
UV systems purchased and not financed; Resale values are $0
Time value of money is not factored into the ROI and Payback Period calculations
Installation costs include labor, travel expenses and parts not mentioned elsewhere
All costs and calculations in U.S. dollars with an annual inflation of 3%
Useful life of UV systems is eight years based on case study daily operating demand

Figure 1

38-inch, flat-bed screen press

for incorporating it into an economic analysis were presented in Part I and will be further expanded upon in this paper.

The first variation of the case study considers a completely brand new line which could be equipped with either conventional UV or UV-LED. The second demonstrates an analysis on an existing line that is being evaluated for a possible LED retrofit. The case study is a relatively basic example; however, the exercise steps through the entire process and provides the foundation for applying the methodology to more complicated scenarios. Even though actual values are used, they are solely for illustrative purposes as some have been estimated and others rounded to protect the confidentiality of the vendors. This is acceptable since it is the analytical process being demonstrated in this paper and not a justification for or against a particular type of curing system.

It is important to understand that purchase, installation and running costs; electricity rates; energy demand of components; and the need for conditioned plant makeup air, among other costs, vary significantly between facilities and geographic locations. As a result, values for a specific application and installation site should be used instead of those presented here. In doing so, readers will likely discover that investment opportunities that may be justifiable and appropriate for one project or location may not make sense for another.

Screen Printing Example

Consider the flat-bed screen press shown in Figure 1. It is an existing press fitted with a single 38-inch, air-cooled arc lamp that does not incorporate a shutter mechanism. The maximum line speed is 50 feet per minute, and the maximum substrate width is 36 inches. The UV system is negatively cooled with heat and ozone exhausted through the building's roof. The corresponding makeup air is heated in the winter and cooled in the summer. The UV-power supply is interlocked so that the conveyor belt

Figure 2

UV-arc lamphead

Figure 3

UV-LED array

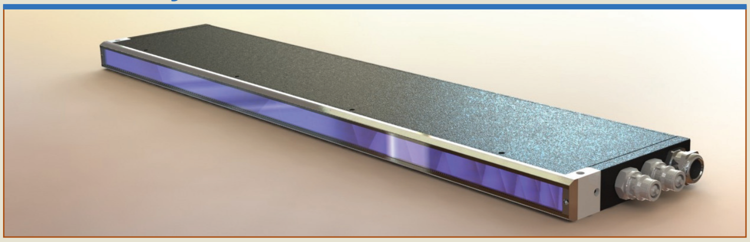

Table 2

UV-curing system specifications

Spec	UV-Arc Lamp	UV-LED
Length	38 inches	37 inches
Cooling	Air, negatively extracted	Refrigerated liquid
Shutter	None	None
Peak Irradiance	2 Watts/cm^2	5 Watts/cm^2
Nominal Power	125, 200, 300 Watts/inch	125 Watts/inch
AC Supply	11.5 kW, 480 Volt, 3 Phase	4.5 kW, 480 Volt, 3 Phase
Running Current	14.6 amps per phase	5.7 amps per phase
Bulb or Diode Type	1 x Mercury 'H' Bulb	395 nm
Bulb or Diode Life	1,000-2,000 hours	10,000-20,000 hours
Bulb Cost	$160 each	Not Applicable
Reflector Qty./Life	2/1 year	Not Applicable
Reflector Cost	$85 each	$0
Warm-up/ Cooldown	5 minutes/ 5 minutes	0 seconds/ 0 seconds
System Cooling and Exhaust	1.6 kW, 1,140 cfm, 230 Volt fan, 30 feet duct	4.2 kW, 230 Volt refrigerated circulation chiller

is always running when the UV system is ON. If the belt stops, the UV source switches OFF since there is no shutter.

A complete list of underlying assumptions and known operating factors for the UV system, press and manufacturing facility are detailed in Table 1. Images of the existing arc lamp as well as a viable UV-LED replacement array are provided in Figures 2 and 3, respectively. The technical specifications for both curing systems are summarized in Table 2.

Since the maximum substrate width is only 36 inches, it is feasible to use a 37-inch UV-LED array even though the original arc lamp system is 38 inches long. With both arc and UV-LED, it is advantageous to use a curing system that is slightly longer than the substrate width in order to ensure proper curing up to the edges of the cure surface.

While the irradiance of the UV-LED system is much greater than that of the arc lamp system (5 Watts/cm^2 compared to 2 Watts/cm^2), the total energy required to power the LED system is less than half of that required by the arc system (11.5 kW compared to 4.5 kW). This is quite typical of UV-LED technology and is one of its benefits. That said, if one UV-LED array delivers insufficient energy density (Joules/cm^2) to cure the ink at the desired line speed of 50 fpm and a second UV-LED array is needed to make the technology viable, then the combined energy for the two LED arrays doubles from 4.5 kW to 9 kW. This illustrates the importance of ensuring that the business case analysis is conducted on curing equipment that is proven suitable for the application.

Cash Flow Summary

Using the cash flow identification guidelines from Part I, the list of assumptions in Table 1 and the curing system specifications of Table 2, 16 different cash flow values can be identified. The cash flows are itemized in Tables 3, 4 and 5 and reflect purchasing, installing, operating and maintaining both an arc and an LED curing system as well as purchasing the corresponding UV-curable screen inks. All operating costs are based on an eight-hour day, five-day week, and 50-week year. No labor for setting up

Table 3

Purchase and installation cash flows (including labor)

	Cost Component	UV-Arc Lamp	UV-LED
1	UV system	$28,000	$42,000
2	UV cooling	Exhaust Fan: $1,250	Chiller: $5,500
3	Mounting bracket, shielding, safety interlocks, communication to host machine	$1,500	$1,500
4	Duct, stack and roof penetration	$1,500	$0
5	Makeup air system (for heating and cooling)	$7,000	$0
6	One-day UV and chiller installation	$1,500	$1,500
7	Two-day exhaust and makeup air installation	$2,500	$0
		TOTAL: $43,250	**TOTAL: $50,500**

TABLE 4

Annual electrical and natural gas operating cash flows

	Cost Component	UV-Arc Lamp	UV-LED
8	Full power UV operation *= Wattage · (Target PF / Existing PF) · On Time · Electricity Rate · Tax Rate*	*11.5 kW · 8 hours · 5 days · 50 weeks · 0.85 uptime · $0.08 kW/h · 1.06 =* $1,658	*4.5 kW · 7.8 hours · 5 days · 50 weeks · 0.85 uptime · $0.08 kW/h · 1.06 =* $633
9	Exhaust fan operation *= Wattage · (Target PF / Existing PF) · On Time · Electricity Rate · Tax Rate*	*1.6 kW · 8 hours · 5 days · 50 weeks · 0.85 uptime · $0.08 kW/h · 1.06 =* $231	$0
10	Heat makeup air in winter	$3,000	$0
11	Cool makeup air in summer	$1,500	$0
12	Liquid chiller operation *= Wattage · (Target PF / Existing PF) · On Time · Electricity Rate · Tax Rate*	$0	*4.2 kW · 7.8 hours · 5 days · 50 weeks · 0.85 uptime · $0.08 kW/h · 1.06 =* $590
		TOTAL: $6,389	**TOTAL: $1,223**

or running the printing line is included in the cash flows as it is assumed to be the same for both types of UV systems.

Each of the cash flows listed in the three tables will increase or decrease based on the facility's geographic location as well as choices made by the buyer and the facility's engineering team. For example, a new makeup air unit will cost considerably more than a used unit or may be unnecessary if an existing makeup air system has additional capacity. The installation of the makeup air unit will cost more if the unit needs to be hoisted up to the roof or if a concrete resting pad needs to be poured next to the building. If a liquid chiller is installed outside a facility that experiences freezing temperatures, the unit will need to filled with a glycol coolant and be capable of withstanding outdoor environmental conditions. Finally, the availability and functional characteristics of the ink, coating or adhesive will vary by process, application and supplier—all of which factor into the material's price structure. More unique and lower volume formulation purchases will typically be more expensive, especially if what is required is not currently available and must be developed.

The purchase and installation costs of makeup air systems, exhaust fans, chillers, mounting brackets, controls interface and duct lengths can vary significantly among suppliers and models. There are always cheaper or more expensive options. The installation location with respect to the UV system will also dictate duct and cable lengths, as well as the capacity requirements for the fans and chillers. As a result, it is critical that the intended equipment user do the calculations themselves and not base any decisions on calculations performed for another facility or for a completely different curing application.

The energy consumption costs in Table 4 assume an eight-hour day for the arc system and a 7.8-hour day for the LED system. This is because UV-LED curing systems are instant ON and instant OFF; whereas, arc lamp and microwave curing systems have warm-up and cooldown cycles. The case study calculations assume that the UV systems are each turned

TABLE 5

Annual consumable cash flows

	Cost Component	UV-Arc Lamp	UV-LED
13	Annual bulb / diode / array replacement	*2 bulbs x $160 each, $40 shipping each, $30 labor each, $25 disposal each =* $510	$0
14	Annual reflector replacement	*2 reflectors x $85 each and $40 shipping per pair, $30 labor per pair =* $240	$0
15	Annual filter replacements (cost & labor for lamphead, exhaust fan, makeup fan, chiller, control cabinet)	$400	$60
16	Annual increase in UV-LED ink costs over conventional ink costs (approximately 1,250 pounds @ $3 per pound average)	$0	$3,750
		TOTAL: $1,150	**TOTAL: $3,810**

ON and OFF once a day and that the arc lamp total cycle time is 10 to 12 minutes (approximately 0.2 hours). In order to ensure a fair comparison, both systems were evaluated equally in terms of productive manufacturing time. Alternatively, the calculations could have assumed that the LED system was ON for the full eight hours, but, in order to do so, it would have been necessary to know how much additional annual profit would have been generated by the increased throughput of the LED line during the additional 0.2 hours of daily production. Remember, it is cash flow that is being analyzed, and it is important to capture everything on equal footing so that the results are not compromised.

Adjusting for Inflation

Whenever estimating costs that occur in future years, it is generally accepted to use a constant rate of inflation. Inflation rates for all countries are widely published and available online. The inflation rate in the United States and Europe has hovered around 2% or less for several years, while certain Asian and South American countries have experienced much higher rates. A conservative analysis for a facility operating in the U.S. or Europe might employ a 3-4% annual inflation rate.

A simple formula can be used to project future costs adjusted for inflation. In general, cash flows are often represented by the letter C. The cash flow in actual dollars after n years (C_n) is the cash flow at present day (C_0) multiplied by one plus the inflation rate raised to the n^{th} power. As inflation is generally positive, an item's actual cost in n years is typically greater than its actual cost in year zero unless there are significant technological advances or efficacy gains in manufacturing. The mathematical formula is:

$$C_n = C_0 \ (1 + \text{inflation rate})^n$$

Actual and Real Dollars

Actual or nominal dollars (A$) are the quantity of dollars associated with a cash flow at the time at which it occurs. It is effectively the price that appears on the price tag at the time the purchase is made. Most business case analysis deals in actual dollars; however, calculations can also be executed using real dollars. Real dollars (R$) are the number of dollars adjusted to reflect true purchasing power relative to a defined point in time. Only at the present time are the two ever equivalent. Whether one is using actual or real dollars, all cash flow values in the analysis should be exclusively one or the other.

The following two examples highlight the difference between actual and real dollars. While often disregarded, there have been incredibly significant gains in the production, processing and distribution of food over the previous 80 years. Even though the actual dollars spent on food items today is much greater than in years past (A$), the real cost of the items adjusted to another base period in time is far less (R$). In general, it is much cheaper to feed oneself or one's family today than at any other time in history (R$), even though the actual quantity of dollars (A$) spent to purchase food items is greater today. Alternatively, highly demanded luxury items such as famous paintings, homes in older more desirable neighborhoods, or certain automobile models that may have been much more affordable at the time of production often become more valuable in future years resulting in both higher actual costs (A$) as well as a higher real costs adjusted to any other base period in time (R$).

The equation to convert actual dollars into real dollars, assuming a constant rate of inflation, is:

$$R\$_k = A\$_k \left(\frac{1}{1 + \text{inflation rate}}\right)^{k-b}$$

where k is the point in time at which the actual cost occurs, and b is the base time to which all of the actual costs are adjusted.

Simple and Discounted Analysis

In order to sum costs that occur in different years of the evaluation period, it is more accurate to adjust the cash flows to a common point in time, typically year zero. This is referred to as the *Net Present Value (NPV)*. With either actual or real dollars, discounting the cash flow values from the future to the present day using a nominal or real discount rate respectively will make the calculations more accurate. As long as the appropriate discount rate is used, both actual and real dollars will yield the same result. When discounting is not used, the analysis is referred to as Simple ROI, Simple PB and Simple LCCA. When discounting is used, it is called Discounted ROI, Discounted PB and Discounted LCCA.

The NPV of each cash flow can be determined by dividing the respective cash flow (C) by one plus the company's discount rate (r) raised to the power of the year in which it falls (n). C_0 represents the initial investment at the start of the time period. The formula for discounting all cash flows over the length of the evaluation period is:

$$NPV = C_0 + \sum_{n=1}^{n} \frac{C_n}{(1+r)^n}$$

NPV requires knowledge of a company's discount rate (r). The discount rate is an interest rate that takes into account the time value of money. There is a discount rate for use with actual dollars and a separate discount rate for use with real dollars. Both discount rates are different for each company and are based on a company's cost of equity, a company's cost of debt and the type of project. For

Table 6

Discount rate examples

Category	Discount Rate
Speculative venture	30%
New products	20%
Expansion of existing business @ company cost of capital	15%
Process improvement using known technology	10%

example, one particular company might structure their nominal discount rates as shown in Table 6, while another might use completely different values.

Determining a company's cost of capital and discount rate is a bit more involved than the other calculations presented in this paper and so will not be covered. If the reader does not know the appropriate discount rate for his or her operation, it is recommended that he or she consult with the company's financial business analyst or accountant. For the purposes of the discounted LCCA calculations in this paper, a nominal rate of 8% will be used.

Calculating Return on Investment

The ROI is a measure of an investment's efficiency. It is calculated by dividing the benefit of the investment by its total cost. The ROI can either be expressed as a ratio or as a percentage. From a financial perspective, an investment should only be pursued if it has a positive ROI and there are no other competing investment opportunities yielding a higher value. (See Equation 1)

When an ROI is applied to a completely new curing line, the *Gain from Investment* in the numerator of the equation is the expected incremental increase in the facility's profits driven exclusively by the new line. The *Cost of Investment* in both the numerator and denominator represents all costs associated with purchasing and installing the line. With respect to the case study, the ROI equation can be rewritten as shown in Equation 2.

The profit potential includes only the revenue and operating costs resulting directly from the new line. It is calculated by deducting all projected operating costs from expected revenue. (See Equation 3)

The profit potential is highly dependent on the evaluation time period, industry, facility and economic climate. In fact, the attractiveness of the ROI can almost always be strengthened by extending the evaluation period since this produces more profit and increases the value of the numerator. The further into the future the profits are estimated, however, the more unreliable the estimates become. The appropriate length of evaluation is unique to each facility and should be based on the useful life of the equipment, nature of the business and general economic climate.

The UV-curing system and printing line investment costs are a one-time cash flow occurring at the end of year zero; whereas, the profit cash flows occur in each year of the evaluation period. If the annual profits are totaled without discounting to the net present value, the result is a *simple ROI*. If the annual profits are separately discounted to the present, then the resulting value is a *discounted ROI*. Since the profit potential is the only cash flow occurring over multiple years, it is the only value that needs discounted.

Analyzing the profit potential as well as evaluating the purchase, installation and maintenance costs of the printing equipment is not the focus of this paper. As a result, the case study will only address the cash flows related to curing. Plug the

Equations 1-5

1. $$\text{ROI} = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}}$$

2. $$\text{ROI} = \frac{\text{Profit Potential} - (\text{UV System Cost} + \text{Printing Line Cost})}{(\text{UV System Cost} + \text{Printing Line Cost})}$$

3. $$\text{Profit Potential} = \text{Potential Revenue} - \text{Potential Operating Costs}$$

4. $$\text{ROI}_{\text{LED New Line}} = \frac{\text{Profit Potential} - (\$50{,}500 + \text{Printing Line Cost})}{(\$50{,}500 + \text{Printing Line Cost})}$$

5. $$\text{ROI}_{\text{Arc New Line}} = \frac{\text{Profit Potential} - (\$43{,}250 + \text{Printing Line Cost})}{(\$43{,}250 + \text{Printing Line Cost})}$$

total UV-curing system purchase and installation costs presented in Table 3 into the ROI equation. (See Equations 4 and 5)

In order for ROI to justify the new line, the profit potential has to exceed the total investment costs, including the UV system and the printing line. As previously stated, the profit potential is incredibly dependent on the length of time the line will operate. In general, a greater profit and lower overall investment cost result in a greater ROI. Based on this analysis alone, the opportunity with the greatest ROI is the one that should be pursued.

For the case study, ROI values for a new line with either an arc or an LED system will be positive as long as the profit potential is greater than the sum of the curing system and the printing line costs. The ROI values will likely be similar enough that one could justify using either technology for this particular case based solely on the ROI. The results will be discussed in more detail in Part III.

When an ROI is applied to an existing line as a means of evaluating a potential retrofit from UV-arc to UV-LED, the gains from investment are reduced to only the incremental business over what the line currently yields with conventional UV. An increase in profit might be due to (1) the ability to better process heat-sensitive materials; (2) reduced product damage and scrap resulting from less heat transfer to the substrate; (3) possible increased throughput created by less downtime due to instant ON/OFF or potentially—*but not guaranteed*—faster line speeds; (4) any gains in business from marketing manufacturing processes using UV-LED curing equipment; or (5) the ability to produce a value-added capability with UV-LED curing that was not possible with the conventional curing system. Alternatively, if no additional profits are generated by switching curing systems or if profits are actually decreased due to insufficient color gamut necessary for full production, then the gain from investment in a new UV-curing system is zero or even negative.

For any retrofit scenario, the line investment costs are effectively zero since the material handling and printing system already exists in the facility. If the expected gains in business or expected gains due to reduced scrap are sufficient to offset the investment costs of the LED system, then the ROI will be a positive number. Otherwise, it will be negative and the investment should not be pursued according to ROI.

$$ROI_{\text{LED Retrofit}} = \frac{\text{Profit Potential} - (\$50{,}500 + \$0)}{(\$50{,}500 + \$0)}$$

If the existing curing system is viable and currently generates profit for the line, then the ROI for a retrofit is less attractive than if the existing UV system is spent and must be replaced. The same retrofit formula can be used for a replacement arc system if the existing arc system has reached the end of its useful life. Comparing the ROI for the LED and the ROI for an arc (or microwave system) would help indicate the better capital investment path for retrofitting the line and keeping it running.

Calculating Payback Period

The payback period is the length of time required to recover the cost of an investment. It is calculated by dividing the total project costs by the annual cash inflows. In general, only short-term payback periods of a few years are desirable; however, the acceptable length of time is subjective and varies by industry and project.

$$PB = \frac{\text{Cost of Investment}}{\text{Annual Cash Inflows}}$$

When analyzing the acquisition of an entirely new line, the *Cost of Investment* includes all purchase and installation costs associated with the material handling and application equipment as well as the curing system. The *Annual Cash Inflows* include all the incremental profits (revenue less operating costs) or savings directly resulting from installing and running the new line.

As with the ROI calculations, the purpose of this paper is not to dwell on the earnings potential of the opportunity. This is because earnings are highly dependent on the industry, facility and economic climate in which the equipment operates as well as the length of the evaluation period. Instead, the purpose of this paper is to focus on the cash flows specifically related to the curing equipment and evaluate them in isolation.

For the case study example, it is the comparison of UV-arc to UV-LED that is the goal. As a result, the PB analysis will determine how long it will take the annual operating savings of a UV-LED curing system to offset its greater purchase cost. In doing so, the *Cost of Investment* is the difference in the purchase and installation costs of the arc and LED systems. The savings in operating and maintenance costs generated by UV-LED in comparison to UV-arc constitute the *Annual Cash Inflows*. The resulting payback period equation becomes:

$$PB = \frac{\Delta \text{ Cost of Curing Systems}}{\Delta \text{ Annual Operating Costs}}$$

The case study analysis assumes that either an arc or an LED system could be installed on the printing line and the UV-LED system and corresponding LED ink set have a higher purchase price and a lower overall operating cost than their conventional counterparts. The same formula can be applied to a new line or to an existing line where the current

Equations 6-8

$$6.\quad PB_{\text{LED New Line}} = \frac{\$50{,}500 - \$43{,}250}{(\$6{,}389 + \$1{,}150) - (\$1{,}223 + \$3{,}810)} = 2.9 \text{ years}$$

$$7.\quad PB_{\text{LED Retrofit}} = \frac{\$50{,}500 - \$0}{(\$6{,}389 + \$1{,}150) - (\$1{,}223 + \$3{,}810)} = 20.2 \text{ years}$$

$$8.\quad PB_{\text{LED Retrofit}} = \frac{\$50{,}500 - \$5{,}000}{(\$6{,}389 + \$1{,}150) - (\$1{,}223 + \$3{,}810)} = 18.2 \text{ years}$$

UV system has reached the end of its useful life and must be replaced.

Plug the purchase, installation, operating and maintenance costs presented in Tables 3, 4 and 5 into the Payback Period equation. (See Equations 6 and 7)

The results indicate that if it is viable to install either an arc or LED system on a new printing line similar to the one shown in Figure 1, then it would take approximately three years for the savings in daily LED operating expense to recover the increased investment costs of the LED system over the arc system. However, if the printing line already exists and is equipped with an arc lamp system that still has remaining life, then it would take approximately 20 years to recover the purchase and installation costs of the LED curing system—assuming there are no incremental gains in profit from switching to LED. If there are potential gains such as savings due to reduced scrap, then the increase in profit is added to the denominator and the payback period is reduced.

It is relatively easy to argue both for and against installing an LED system on a new printing line for this particular case study. The payback of three years is right on the edge of what would be acceptable. Trying to justify an LED system as a retrofit for this particular line and facility, however, would be nearly impossible, but that would also be the case if one was trying to retrofit the existing arc lamp system with a different arc or microwave system. It is not so much an issue of LED versus arc as it is scrapping a viable piece of equipment just to install newer technology. As a result, many retrofits only make sense if they result in additional capabilities that are not possible with the current curing system or if the current curing system has reached the end of its useful life.

The Payback Period example used for the retrofit assumes that the existing UV-curing system has no remaining useful life as stated in the list of assumptions in Table 1. If it is possible to sell the UV system, then the gains from the sale could be used to offset the initial costs in the numerator. For example, if it is possible to sell the conventional UV system for $5,000, then the equation changes. (See Equation 8)

For even greater accuracy, each year's operating costs could be adjusted for inflation and the cash flows occurring in each future year as well as any potential salvage value could be discounted to the net present value for year zero. Since the investment costs already occur in year zero, no discounting is required. The LCCA analysis that follows provides an example of discounting and inflation adjustment that could be extended to the payback period example.

Calculating Life-Cycle Cost Analysis

The LCCA is a method of determining the most cost-effective investment by calculating the total system costs over the expected life of the equipment less any salvage value. The formula should be applied to each equally desirable opportunity. The venture with the lowest LCCA is typically the one that is pursued. As long as the cash flows are discounted to the NPV, the LCCA accounts for the time value of money and forces the consideration of all costs related to an investment above and beyond the initial financial outlay. As previously presented, the mathematical formula for NPV is:

$$NPV = C_0 + \sum_{n=1}^{n} \frac{C_n}{(1+r)^n}$$

An LCCA is always performed over the entire life of the venture (n); however, expected life is subjective and is entirely up to the person performing the calculations. The expected life may be up to the point where the equipment is projected to no longer work, becomes obsolete or is too expensive to maintain or operate; the product the equipment is being used to produce is expected to no longer have sufficient demand; the equipment is scheduled to be liquidated; or the equipment is planned to be idled in order to pursue another more profitable opportunity.

It is important to note that the investment opportunities being compared may not have the same useful life and the useful life may not always be clear. If one UV-curing system is expected to last eight years and another one is expected to last 12 years, then the latter will yield four additional years of profit-producing potential. However, if the line will only be used for a manufacturing operation meant to last six years, then the increased life of one product over the other is negligible aside from the potential impact on salvage value.

Table 7

Annual cash flows for a UV-arc curing line and discounted LCCA

UV-Arc Cost Component	Y_0	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Purchase / installation	$43,250	$0	$0	$0	$0	$0	$0	$0	$0
Energy for Operation	$0	$6,581	$6,778	$6,981	$7,191	$7,407	$7,629	$7,858	$8,093
Spare parts / maintenance	$0	$1,185	$1,220	$1,257	$1,294	$1,333	$1,373	$1,414	$1,457
Unplanned repair @ 15% of investment	$0	$0	$0	$0	$0	$6,488	$0	$0	$0
Annual Total	**$43,250**	**$7,766**	**$7,998**	**$8,238**	**$8,485**	**$15,228**	**$9,002**	**$9,272**	**$9,550**

For the purpose of the case study, the useful life of the venture is arbitrarily eight years for both arc and LED, and the discount rate is 8%. The facility in which the printer runs operates on an eight-hour day, five-day week and 50-week year. The line runs continuously with an average of 15% downtime. An annual inflation rate of 3% applies to all operating costs and expenses. Coolant for the chiller is typically replaced every two years, so it is assumed that the replacement will take place in years three, five and seven. As a result, an actual coolant cost of $250 at time zero with a 3% inflation rate results in projected costs of $273, $290 and $307, respectively. In addition, a non-planned maintenance repair for both the arc and LED systems has been forecasted for year five at a value of 15% of the original system prices.

Since the technology is still relatively new, the cost of the LED inks is assumed to be $3 more expensive per pound than the conventional counterpart. In addition, since the consumable volume for this particular line is low at 750-1,250 pounds per year, any decrease in ink pricing is not likely to occur over the selected evaluation period. As a result, the increase in LED ink costs over conventional ink costs is assumed to be constant at $3 x 1,250 pounds or $3,750 annually. Because inflation will apply to both conventional and LED inks equally and since the cash flow being used is the difference between the two, an adjustment for inflation will not be factored into the ink analysis. Inflation, however, will be used for all other items.

All relevant cash flows are summarized in Tables 7 and 8. The values are based on the initial costs presented in Tables 3, 4 and 5 as well as the preceding paragraphs. The initial cash flows are assumed to be actual costs estimated at year zero. As a result, a 3% inflation rate is applied for each year following year zero.

Plugging the annual totals from Tables 7 and 8 into the NPV equation reveals that while the initial investment cost of the LED system is greater than that of the arc system ($50,500 > $43,250), the LED system costs $10,540 less than the arc system over its estimated eight-year life ($96,680-$86,140). This will not necessarily be the case for every application. Some installations will yield even greater savings for LED while others may prove that an arc system is cheaper to operate over the respective life cycle. (See Equations 9 through 12)

As was the case with ROI and PB, a retrofit scenario results in

Table 8

Annual cash flows for a UV-LED curing line and discounted LCCA

UV-LED Cost Component	Y_0	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Purchase / installation	$50,500	$0	$0	$0	$0	$0	$0	$0	$0
Energy for Operation	$0	$1,260	$1,297	$1,336	$1,376	$1,418	$1,460	$1,504	$1,549
Chiller filter replacement	$0	$62	$64	$66	$68	$70	$72	$74	$76
Coolant	$0	$0	$0	$273	$0	$290	$0	$307	$0
Unplanned repair @ 15% of investment	$0	$0	$0	$0	$0	$7,575	$0	$0	$0
Increase in ink costs over arc	$0	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750	$3,750
Annual Total	**$50,500**	**$5,072**	**$5,111**	**$5,425**	**$5,194**	**$13,103**	**$5,282**	**$5,635**	**$5,375**

EQUATIONS 9-15

$$\text{9. } LCCA_{Arc} = \$43{,}250 + \frac{\$7{,}766}{1.08^1} + \frac{\$7{,}998}{1.08^2} + \frac{\$8{,}238}{1.08^3} + \frac{\$8{,}485}{1.08^4} + \frac{\$15{,}228}{1.08^5} + \frac{\$9{,}002}{1.08^6} + \frac{\$9{,}272}{1.08^7} + \frac{\$9{,}550}{1.08^8}$$

$$\text{10. } LCCA_{Arc} = \$96{,}680$$

$$\text{11. } LCCA_{LED} = \$50{,}500 + \frac{\$5{,}072}{1.08^1} + \frac{\$5{,}111}{1.08^2} + \frac{\$5{,}425}{1.08^3} + \frac{\$5{,}194}{1.08^4} + \frac{\$13{,}103}{1.08^5} + \frac{\$5{,}282}{1.08^6} + \frac{\$5{,}635}{1.08^7} + \frac{\$5{,}375}{1.08^8}$$

$$\text{12. } LCCA_{LED} = \$86{,}140$$

$$\text{13. } LCCA_{Arc} = \overset{\$0}{\cancel{\$43{,}250}} + \frac{\$7{,}766}{1.08^1} + \frac{\$7{,}998}{1.08^2} + \frac{\$8{,}238}{1.08^3} + \frac{\$8{,}485}{1.08^4} + \frac{\$15{,}228}{1.08^5} + \frac{\$9{,}002}{1.08^6} + \frac{\$9{,}272}{1.08^7} + \frac{\$9{,}550}{1.08^8}$$

$$\text{14. } LCCA_{Arc} = \$53{,}430$$

$$\text{15. } LCCA = \sum \text{NPV All Costs} - \text{NPV Salvage Value}$$

the elimination of the arc system investment cost in year zero. Consequently, the LED system for the retrofit scenario costs $32,720 more than the arc system over the estimated eight-year life ($86,140 - $53,430). This makes the investment in an LED retrofit difficult to justify unless the LED-curing system provides technical capabilities or additional profit not possible with the existing arc-lamp system. If this proves to be the case, then an ROI and PB should be used to further determine whether the investment is viable since they will account for any increase in profitability. (See Equations 13 and 14)

The case study assumes that neither curing system has any salvage value. If either piece of equipment is saleable after its expected life of eight years, then the value of the sale would enter the LCCA calculations as a cost offsetting cash flow in year nine. The salvage value(s) would need to be discounted back to year zero just like each of the other cash flows; however, it would be a negative number. (See Equation 15)

Determining a reasonable salvage value can be difficult, especially for new technology that is still evolving and for technology that is so specific to a given application such as UV curing. In addition, estimating anything so far into the future is always a gamble. A conservative approach is to assume that the equipment has no salvage value.

Final Comments

ROI , PB and LCCA are three distinct methods of evaluating the merit of investment opportunities. ROI reflects the profitability of a project. PB is a measure of liquidity and LCCA determines the total cost impact over the investment's useful life. All three equations are designed to be tailored to discrete opportunities, and the person conducting the analysis has great liberty regarding what is included in the analysis and what is not.

The numerical results of ROI, PB and LCCA are meant to be interpreted with respect to other opportunities, including the option of doing nothing. They are decision-making tools designed to reduce investment risk and guide the overall selection process. While the calculations themselves are not terribly difficult, the challenge lies in determining the input variables and collecting the actual data. Since no two UV-curing applications or installations are completely identical, the data and factors used for analysis will always be different. As a result, it is important to make sure that the input data always reflects the intended application and geographic location of the investment opportunity.

When used correctly and together, ROI, PB and LCCA can greatly increase one's understanding of the investment being considered as well as illustrate where possible risks may lie. The accuracy and relevancy of all calculations can be improved by adjusting for inflation; using reasonable evaluation periods; and discounting future cash flows to the net present value. The results of any calculation, however, are only as good as the input data and are easily manipulated by altering or omitting certain variables. As a result, utmost caution should be used when assessing calculations done by someone else. It is strongly recommended that the intended user and purchaser of the technology personally perform the calculations and perform a sensitivity analysis—as will be demonstrated in the third and final installment of this series—whenever the results will be used for making actual investment decisions.

Finally, ROI, PB and LCCA are only tools of analysis and the results are always subject to interpretation. Common sense must also play a role. If UV-LED curing offers new capabilities that cannot be achieved with conventional curing technology, then there may be very strong reasons for moving forward even if the financial argument is not that appealing. Likewise, if UV-LED curing is not technically viable for a given formulation at the desired process speeds and under the constraints of the installation, then it should not be pursued even if the financial business argument is strong.

References

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