3
Engineering Systems and Engineering Economics of Loss Prevention

Joel M. Haight

3.1
Introduction

The topic of economics in a loss prevention engineering context can generate significant discussion among employees in the workplace and among professionals who practice loss prevention engineering. The discussion seems, at times, to center around the humanitarian problem of considering the economic value of a human life or even what the human cost of an injury is. The question of how much a human life is worth is a difficult (in fact, many would consider impossible) question to answer. Although insurance companies deal with this question every day, it seems to be a question with which many safety or loss prevention engineering professionals struggle. However, placing a value on a human life and determining the cost of an injury such that intervention or prevention decisions can be made are essential to meeting business objectives and also ensuring the fairest treatment of potential injury victims and the others affected by the potential injury (i.e., family, etc.). How could we say that we will not implement an injury prevention intervention because it is too expensive, if it would save a life? The humanitarian nature of many of us would dictate that we take the stance that we will save lives no matter what the cost. However; this has the potential for sending a company into bankruptcy. Unfortunately, almost any preventive action will cost money and in many cases cannot, with much certainty, assure anyone that it will in fact, prevent the incident. It is hard to buy into that option. Given these two needs (humanitarian and business), shall we say that a business approach with a touch of humanitarianism is most appropriate? It is proposed that most loss prevention engineers should adopt an integrated humanitarian–business approach that incorporates the concept of risk and the idea of risk tolerance.

To integrate the business needs properly into our natural humanitarian nature, the concept of risk will be discussed. Throughout this discussion, as an organization is developing its economic strategy towards loss prevention engineering, it is suggested that it consider concepts such as risk, risk management, direct costs, indirect costs, return on investment (ROI) versus cost reduction versus productivity improvement savings, and so on, as it considers loss prevention intervention

Handbook of Loss Prevention Engineering, First Edition. Edited by J. M. Haight.

strategy alternatives. A risk management approach is an approach that many of today's companies seem to have adopted. And in this approach, it is often the case that they use the direct cost (a quantifiable value) of injuries as one measure of the seriousness of the consequences of an accident (an injury or fatality) combined with a measure of the likelihood of the incident's occurrence (a quantifiable value). This resulting "semi-quantitative measure" or risk index is what is used as a basis for their loss prevention engineering-related business decisions (Clemens and Simmons, 1998).

The process is one in which the potential cost and the severity of an accident are identified, the likelihood of occurrence is estimated, and the integration of the two is indexed. Once this has been accomplished, risks can be relatively ranked by their risk index values and business decisions can be made to determine whether the cost of a prevention intervention, given its ability to minimize the severity or likelihood of occurrence of the accident, would be justified. From these cost, severity, and likelihood data, a determination can be made as to how much tolerance the business organization has for that level of severity and likelihood or, in other words, how much risk are they willing to accept? Is it too costly for the minimal reduction in risk it would afford? This is a question that an organization would have to ask itself. Making loss prevention engineering improvement decisions based on risk would probably be recognized as a risk management approach. This risk-based approach will be discussed in greater detail later in the chapter, however, with the intent of introducing it so that it can be taken in the proper engineering economic context; some additional discussion is included here in the Introduction. The combination of these severity and likelihood attributes of an incident are most often treated in many industries as risk. This combination takes many forms. Whereas some multiply these two values and the resultant product is considered the "risk," many combine them in a matrix format and artificially determine an index-like value (US Department of Defense, 1993; Clemens and Simmons, 1998). Although this value has no real mathematical significance, this process does allow a mechanism for relative comparison between incidents or between interventions. With this relative comparison, if one were comparing several risk or loss prevention interventions (e.g., considering between a prevention strategy that involves a less expensive option that provides less protection, but lasts longer, and a more expensive option that provides more protection, but has a shorter useful lifetime), one can make a business decision as to which prevention intervention is more cost-effective based on its equivalent cost and the amount by which it would be expected to lower the risk of a particular injury (OSHA, 2012). Once these comparative measures have been established, one can then rely on any of a multitude of cost comparison techniques available from the established field of engineering economics.

The scope of this chapter includes some discussion of measuring and analyzing risk and risk management; however, its main focus will be to present applications of various engineering economics techniques in a loss prevention engineering-related context. There will also be discussion of direct and indirect costs of injuries. Some opinions and also results from the published literature will be offered to explain how these values can be determined and used. Also, there is much in the literature about the ROI afforded by the implementation of a loss prevention intervention (Cecich, 2005; National Safety Council, 2005). This ROI topic will also be treated in this chapter. ROI will be argued against the more realistic consideration of cost savings or productivity improvement savings. First, we will have to establish a basis in this chapter for the financial considerations of loss prevention engineering.

3.2 Cost of Injuries

The National Safety Council publishes the direct cost of industrial injuries every year and, depending on what the data source is, one can see that industrial or occupational injuries alone cost industry in the neighborhood of US$160 billion dollars each year. That is roughly $30 000–40 000 per injury, depending on the numbers of injuries in any one year (National Safety Council, 2012). If one assumes an average cost per injury of $40 000, just using direct costs as a decision-making basis, would it be cost-effective to use a prevention intervention to reduce the numbers of injuries by one next year if the cost to implement an intervention is $41 000? The benefit:cost ratio would be $40 000/$41 000 or 0.975 (if one assumes that the entire investment is returned, the ratio would be 1). A ratio of <1 may not be considered cost-effective. To explain this cost further, it may cost $41 000 to purchase all the equipment, create storage and maintenance space, implement the training and the inspection process, and so on for a new fall protection system (belts, harnesses, clamps, constructing all the tie-off points, inspections, maintenance, etc.) and the saving for preventing one injury is $40 000. This is an important question that those charged with both economic and loss prevention responsibilities should ask themselves and the organization. Would this expense be justified if one injury could be prevented? And how would one know that the intervention is what prevented the one injury that did not occur anyway? If it is assumed that a decision could be made to *not* implement the intervention because it would be more costly than the injury it is expected to prevent, the organization should probably use *all* costs for the benefit–cost analysis, and ensure that the costs are accurate and that the service life of the intervention be considered in the decision. What about indirect costs? Will the intervention prevent at least one injury per year? How many years will the intervention last and when will a payout be realized? Does this meet the organization's project payout expectations or its minimum acceptable rate of return (MARR) (in terms of cost savings)? Is there a cost associated with operating or maintaining the intervention over the time of its useful life, and were these costs considered? Was the time value of money considered in the decision? Can other intervention options be compared? These are all important questions that must be asked and this chapter will attempt to define and address some of them.

Let us first deal more with this issue of direct and indirect costs. The easiest one to consider is direct cost. In the case of injuries, it is considered, in most of the literature, to be the hospital bill or other direct medical costs to treat the injury, ambulance costs, time lost by the injured employee, benefits costs associated with the time lost by the employee, and overtime costs paid to other employees to cover the injured employee's absence (Cecich, 2005). These are directly charged by the organizations that provide medical services and by the organization itself for employee time and benefits. These are relatively easy to book and are usually consistent across all injuries. The most valid cost comparisons are in and from this category.

The other important cost category is indirect costs. It is often reported in the literature that these costs can be anywhere from four to ten times the direct costs. If this potential amount is true, one can easily see why it is important to capture these costs when making any economic decisions around loss or injury prevention (Cecich, 2005). This time, when completing the benefit–cost analysis of a particular intervention (from the example above), if the direct injury cost is \$40 000 and by considering indirect costs ($\sim 4 \times$ direct), the total cost of one injury is now \$40 000 + (\$40 000 × 4) = \$200 000. The \$41 000 to implement the corrective measures or interventions now appears to be cost-effective in considering the benefit:cost ratio. Now the benefit:cost ratio is \$200 000/\$41 000 = 4.88, as compared with the 0.975 noted above when considering direct costs only. It appears to be much more justified to spend the money on the protection or prevention intervention. It is important to point out, however, that *saving* \$41 000 is not the same as *adding* \$41 000 in revenue. ROI will be treated next.

3.3
Return on Investment Versus Cost Savings Versus Productivity Savings

ROI means that a return of money is experienced as a result of an investment (Investopedia, 2012). It is often used to compare either the strength or the efficiency of a particular investment. A typical equation used for making this calculation is

$$\text{ROI} = \frac{\text{gain from investment} - \text{cost of investment}}{\text{cost of investment}} \tag{3.1}$$

For example, if one invests \$200 000 in a new piece of equipment and that equipment increases one's production such that \$500 000 in increased revenue is generated in the first year of operation, the investment is said to have produced a ROI of 1.5 or a 150% return (ROI = \$500 000 − \$200 000/\$200 000 = 1.5). This is a positive ROI and therefore it is likely to be viewed as a positive investment. It is a commonly used decision-making tool because of its effectiveness and its simplicity. If someone is deciding to make a particular investment, they would consider the ROI and would likely make that investment if the ROI is >1 or is 100%. One can also use ROI to compare projects or investments. One would make one investment over another if it has a higher ROI (again if one were evaluating the investments from a business perspective) (Veltri and Ramsay, 2012).

It is also common in industrial investment decision-making to use a concept called payout period, which is generally accepted to be the time it takes for an investment to be returned in revenue generated by the investment. For example, if a \$100 000 investment is made in a production process and once that process is started up it takes 1 year for it to generate \$100 000 in revenue, that investment is said to have a 1 year payout period. The decision-making comparisons are then made between investments in terms of the length of the pay-out period. If one investment has a 1 year payout, it is generally selected over an investment with a 2 year payout period.

Loss prevention engineering or injury prevention investments present a unique difference and this difference makes the comparison more difficult than a pure business comparison. The first part of the difference is that usually, with an investment in an injury-preventing or loss-preventing investment, there is no return (or no addition of revenue). The expected or desired gain is in cost reduction or cost savings. If one prevents one injury with this investment, one will have saved, from the previous example, \$40 000 or \$200 000 depending on whether one considers direct costs only or both direct and indirect costs. The comparison of one intervention investment to another is still valid, but it just is not an ''ROI'' – it is a cost savings benefit or, in some cases; it could possibly be considered a productivity improvement saving if, due to an investment in an automated injury-preventing intervention, people could be redirected to other more productive tasks or activities. It is important to recognize that loss prevention expenditure savings are not direct revenue returns and, as such, it is not entirely accurate to use the ROI calculations for making these loss prevention engineering intervention decisions or comparisons (Investopedia, 2012).

This is not necessarily true in all cases, however. In some cases, such as investing in a loss-preventing intervention (e.g., automating a step in a process that takes the human operator out of harm's way), that also increases productivity. If the intervention also increases the number of revenue-generating units produced per unit time, revenue (income or return) can be considered and ROI becomes appropriate again. For example, investing in an automated loading and unloading system that takes human operators off fork lift trucks and away from the edge of the loading dock can prevent a truck fall from the edge of the loading dock, but it can also increase the number of trailers unloaded per day. In this case, one must be careful not to confuse the types of benefits from this investment. If they apply, loss-preventing benefits and revenue-generating benefits should be considered when making investment decisions; however, one should not extrapolate ROI benefits and include them in our arguments for a loss prevention intervention investment that only produces a cost savings.

3.4 Engineering Economics

Engineering economics is a discipline or field of study and practice that is often used by engineers in making project acceptance decisions. Using the concepts and practices of engineering economics, engineers are able to determine which or if any project option is feasible or would yield a result that would allow an

Table 3.1 Frequently used practices and elements of engineering economics.

Engineering economic decisions	Bond investments
Equivalence and interest formulas	Interest rates
Loan transactions	Present and future worth analysis
Net present value analysis	Rate of return analysis
Internal rate of return	Return on investment (ROI)
Depreciation	Taxes
Minimum acceptable rates of return	Developing project cash flows
Lease versus buy decisions	Replacement decisions
Inflation analysis	Project risk and uncertainty
Capital budgeting	Economic equivalence

Adapted from Haight (2012).

organization to say its investment was a "good investment." With engineering economics one can also monitor project performance or project progression in a positive or negative direction. This chapter includes discussion of some of the concepts listed in Table 3.1.

These concepts and methodologies allow engineers to make informed decisions about a project or its risk potential from a financial and uncertainty point of view. To do this, the time value of money should at least be discussed in review and in the form of the equations that are used to determine it (Park, 1997). The following equations are presented:

Single flow:

$$F = P(1+i)^N \text{ – Convert present value to future value } (F/P, i, n) \tag{3.2}$$

$$P = F(1+i)^{-N} \text{ – Convert future value to present value } (P/F, i, N) \tag{3.3}$$

Equal payments:

$$F = A\left[\frac{(1+i)^N - 1}{i}\right] \text{ – Convert periodic annuities (monthly or annual payments) for a given period to a future value } (F/A, i, N) \tag{3.4}$$

$$A = F\left[\frac{i}{(1+i)^N - 1}\right] \text{ – Convert a future value to annuities (monthly or annual values) for a given period } (A/F, i, N) \tag{3.5}$$

$$P = A\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] \text{ – Convert periodic annuities (monthly or annual payments) for a given period to a present value } (P/A, i, N) \tag{3.6}$$

$$A = P\left[\frac{i(1+i)^N}{(1+i)^N - 1}\right] \text{ – Convert a present value to annuities (monthly or annual values) for a given period } (A/P, i, N) \quad (3.7)$$

where P = present value, F = future value, A = annuity, i = interest rate, and N = number of compounding periods (Haight, 2012).

3.5 Engineering Economic Decision-Making

Engineers make most of their decisions to implement problem solving interventions (in this case, injury or loss prevention) based on many different strategic and tactical needs. The loss prevention or safety decisions made to implement one solution or another is often based in part on economic comparisons between intervention options; however, other variables should also be considered, variables such as risk reduction achieved, quality of product, length of useful life, market share captured, environmental impact achieved, and so on. In this chapter, the risk reduction variable along with the economic variable will be considered in the analysis in addition to the economic variable.

The types of comparisons that can be made are in equipment or process selection (e.g., deciding to replace an unsafe process with one considered to be safe), equipment replacements (older equipment may be more likely to experience spills, loss of containment, fires, etc., but new equipment may be too costly to be feasible), introduction of a new, safer product, overall operating cost reduction, and service improvements. Each of these types of decisions can all be considered for their risk reduction capacity in addition to the economic comparison (Park, 1997). For example, one may evaluate two options comparing their cost while concurrently satisfying risk reduction conditions established by one's organization. Examples are presented here using some of the comparison techniques available to engineers, such as net present value (NPV), internal rate of return (IRR), MARR comparisons, ROI and pay-back period (discussed above), and so on.

3.6 Net Present Value Comparison (Equipment Replacement)

This example involves the determination of the cash flow for each of two project options in which a decision will be made to develop a new facility or to invest in the upgrading or improvement of an existing facility. A comparison is made by converting the projected cash flows generated for each project over its useful life to an NPV. Presumably, one would select the defender (existing facility) or the challenger (the new system or facility) based on which has the highest NPV.

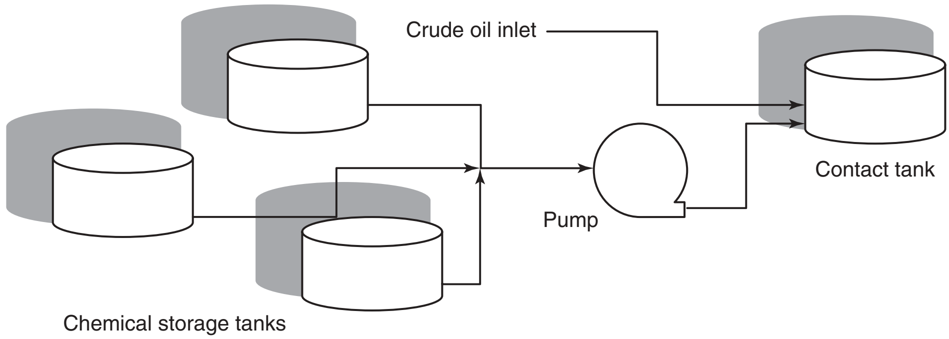

Figure 3.1 Simplified process flow representation of a mercaptan scavenger chemical storage and distribution facility.

The decision to upgrade an existing storage and distribution facility for a mercaptan scavenger chemical (defender) or to design and install a new mercaptan scavenger chemical facility (challenger) is an economic decision but, depending on what is driving the replacement consideration, it could also be a loss prevention engineering decision. If it is assumed that one of the facility options is safer or more environmentally sound than the other, a decision to reduce the risk of a fire or spill becomes a loss prevention engineering decision. The example below illustrates one method for making this decision.

Some crude oils are high in sulfur and even after passing the crude through a processing facility, to strip the gas and purify the oil, there can still be odor-causing mercaptans in the crude oil. These mercaptans have a very low odor threshold and so a concentration above allowable product specifications would generate negative reactions from customers and the public, due to the objectionable odor and potential for increased exposure to the mercaptans. Therefore, a chemical is added to the crude oil to strip the remaining mercaptans from the crude oil before the product is shipped. This mercaptan scavenging or stripping product must be stored and pumped to injection stations for contact with the crude oil in the pipeline. It is intended that this mercaptan scavenging material be stored in several atmospheric tanks where it can then be pumped through a pipeline to its operational location at injection stations. With this type of facility, there is a risk of leak or release and exposure of operators and the local population to the harmful sulfur-bearing chemicals involved. Figure 3.1 shows a representation of the existing facility.

The storage tanks in the existing storage facility are deteriorating, the chemical movement is manually controlled, and there are no provisions for fire protection or suppression. Leaks occur frequently. The scope of necessary repairs and upgrades that this system would need to remain operationally viable is extensive. The storage tanks are rusting and leaking at the riveted joints. The operators with a manual level-control and pumping system allow frequent overfills. There is no firewater available at this site and the chemical is flammable. The present system has been in service for 5 years. Due to permit requirements, upgrades are required to achieve minimum acceptable environmental and safety standards. Upgrades costing $147 000 will extend the system's life for a further 5 years. However, upgrades will not completely stop the leaks. The expected leak losses will amount to $6000 per year and the clean-up costs will be another $4000 per year. The annual operating costs for this upgraded facility are expected to be $42 000 and maintenance costs are expected to be $21 000 per year. Revenues generated would be realized from operational savings. Savings are due to reduced risk and reduced compliance costs. The amounts would be as follows:

Year 1 = $160 000
Year 2 = $167 000
Year 3 = $132 000
Year 4 = $135 000
Year 5 = $122 000.

A project design team has proposed a new design with input from a loss prevention engineering analysis team. The design meets all acceptable environmental and industry standards and practices, including appropriate fire protection and level control systems. The new facility, which requires an investment of $300 000, would last 5 years before a major upgrade would be required. However, it is believed that crude oil processing technology will be developed to the point that this chemical becomes obsolete (new stripping technology is expected to remove mercaptans more efficiently, not requiring the use of a chemical stripper). This new technology will be easily retrofitted to this new design after it has been in operation for 5 years. Management does not expect any spill clean-up costs; however, they would like a $4000 per year contingency set aside for education of the community (on mercaptan scavenger safety), possible clean-up, possible evacuation, and so on, just in case. The annual operating and maintenance costs would be $11 000 and $8000, respectively. For this new system, revenues generated would be realized from operational savings. The savings are due to reduced risk and reduced compliance costs. This income (savings) each year would be year 1 = $140 000, year 2 = $130 000, year 3 = $132 000, year 4 = $142 000, and year 5 = $150 000. Even though a mercaptan scavenger system will be obsolete in 5 years, much of the facility can be salvaged at the end of 5 years and used for the new technology installation that will become a more efficient mercaptan removal system. The remaining part of the plant would have a salvage value of $87 000. If this company's MARR is 15%, its tax rate is 35%, and the depreciation class for each system is 5 year class modified accelerated cost recovery system (MACRS), should this company upgrade the old facility or build a new one?

An effort will be made to compare the two options, the challenger (new mercaptan scavenger process design) versus the defender (the existing mercaptan scavenging system) on the basis of their NPVs. This means the two 5 year cash flows for each will be presented in a cash flow statement (Tables 3.2 and 3.3) and an accounting of the time value of money will be made. In this way, each project can be compared on equal terms.

Table 3.2 Net present-worth analysis – cash flow statement – defender (existing system).

	Year					
	0	**1**	**2**	**3**	**4**	**5**
5 year MACRS depreciation (%)		20	32	19.2	11.52	11.52
Income statement ($)						
Revenue						
Savings, reduced risk		160 000	167 000	132 000	135 000	122 000
Expenses						
Operating costs		42 000	42 000	42 000	42 000	42 000
Maintenance costs		21 000	21 000	21 000	21 000	21 000
Materials (losses)		6 000	6 000	6 000	6 000	6 000
Spill clean up		4 000	4 000	4 000	4 000	4 000
Depreciation (MACRS % at top of each column		29 400	47 040	28 224	16 919	16 919
Taxable income (revenue – expenses)		57 600	46 960	30 776	45 081	32 081
Income tax (35%)		20 160	16 436	10 772	20 625	11 228
Net income		37 440	30 524	20 004	24 456	20 853
Cash flow statement ($)						
Operating activities						
Net income		37 440	30 524	20 004	24 456	20 853
Depreciation		29 400	47 040	28 224	16 919	16 919
Investment activity						
Investment (I)	(147 000)					
Salvage						0
Net cash flow, F ($)		*66 840*	*77 564*	*48 228*	*41 375*	*37 772*

Adapted from Haight (2012).

$\text{NPW} = I + F_1(1+i)^{-N} + F_2(1+i)^{-N} + F_3(1+i)^{-N} + F_4(1+i)^{-N} + F_5(1+i)^{-N}$

$\text{NPW} = -\$147\,000 + \$66\,840(1+0.15)^1 + \$77\,564(1+0.15)^2 + \$48\,228(1+0.15)^3 + \$41\,375$ $(1+0.15)^4 + \$37772(1+0.15)^5$

$\text{NPW} = -\$147\,000 + \$66\,840(0.8696) + \$77\,564(0.7514) + \$48\,228(0.6575) + \$41\,375(0.5717) +$ $\$37\,772(0.4971)$

$\text{NPW} = -\$147\,000 + \$58\,124 + \$58\,281 + \$31\,714 + \$23\,654 + \$18\,776$

$NPW = \$43\,549.$

Table 3.3 Net present worth analysis – cash flow statement – challenger (new system).

	Year					
	0	**1**	**2**	**3**	**4**	**5**
5 year MACRS depreciation (%)		20	32	19.2	11.52	11.52
Income statement ($)						
Revenue						
Savings, reduced risk		140 000	130 000	132 000	142 000	150 000
Expenses						
Operating costs		11 000	11 000	11 000	11 000	11 000
Maintenance costs		8 000	8 000	8 000	8 000	8 000
Materials (losses)		0	0	0	0	0
Spill clean-up (contingency)		4 000	4 000	4 000	4 000	4 000
Depreciation		60 000	96 000	57 600	34 560	34 560
Taxable income		57 000	11 000	51 400	84 440	92 440
Income tax (35%)		19 950	3 850	17 990	29 554	32 354
Net income		37 050	7 150	33 410	54 886	60 086
Cash flow statement ($)						
Operating activities						
Net income		37 050	7 150	33 410	54 886	60 086
Depreciation		60 000	96 000	57 600	34 560	34 560
Investment activity						
Investment	($300 000)					
Salvage						87 000
Net cash flow, F ($)		*97 050*	*1 03 150*	*91 010*	*89 446*	*94 646*

Adapted from Haight (2012).

$\text{NPV} = I + F_1(1+i)^{-N} + F_2(1+i)^{-N} + F_3(1+i)^{-N} + F_4(1+i)^{-N} + F_5(1+i)^{-N}$

$\text{NPV} = -\$300\,000 + \$97\,050(1+0.15)^1 + \$103\,150(1+0.15)^2 + \$91\,010(1+0.15)^3 + \$89\,446$
$(1+0.15)^4 + \$94\,646(1+0.15)^5$

$\text{NPV} = -\$300\,000 + \$97\,050(0.8696) + \$103\,150(0.7514) + \$91\,010(0.6575) + \$89\,446(0.5717) +$
$\$94\,646(0.4971)$

$\text{NPV} = -\$300\,000 + \$84\,395 + \$77\,506 + \$59\,839 + \$51\,136 + \$47\,048$

NPV = *$19 924.*

3.6.1
Final Result and Decision

With these results, from a purely business perspective, this decision appears to be an easy one. With a higher NPV, one should choose the defender ($43 549 versus $19 924), that is, upgrade the existing facility, because its NPV is higher. However, from a loss prevention engineering perspective, one that may incorporate the humanitarian aspects of this decision, it might be claimed that the new facility is better because the risk of incident is lower. What would happen if the existing facility had a higher risk of experiencing a catastrophic loss or even just a serious release or fire? If one factored the cost of such an event into the table, the decision might be different. If that added cost meant that the NPV was lower than the challenger or the new facility, would the decision be to choose the new facility? Well, then one might ask, what is the likelihood of occurrence of that serious loss incident? In theory, a risk ranking would be based on both seriousness of the consequences and the likelihood of occurrence, but there is no universal method for this type of analysis and every organization has a different tolerance for that risk. It is not a straightforward decision when risk and the very subjective humanitarian sentiments are factored in. In fact, interestingly enough, in a university course in engineering management taught by the author, when a similar analysis to the one above was presented to a class of engineering students (some in the class were safety degree students and the rest were engineering students from various non-safety engineering disciplines), in all cases, even though the ‘‘replacement’’ defender had a higher NPV than the better built new facility, the non-safety engineering students all chose the defender because it had a higher NPV (the right business decision), but the safety students chose the challenger with the lower NPV because they perceived the new facility to be safer. What can be derived from that interesting mix of responses? This is left to the reader to consider.

3.6.2
Accept or Reject Decision for a Simple Investment Based on Rate of Return

Let us consider the same project as above and determine the accept or reject decision for an investment in building the new mercaptan scavenging storage and delivery system based on the rate of return that the organization can expect. Most organizations have a MARR for all investments, so if an investment yields an IRR of something greater than the MARR, one is inclined to accept the project or investment. If the IRR is nearly equal to the MARR, one is likely to be indifferent about the project and may consider other aspects, such as the public relations aspect of a new facility, or possibly may give greater weight to risk. If the IRR for the project is less than the MARR, one is inclined to reject the project. So, again:

$IRR > MARR$ Accept the investment proposal
$IRR = MARR$ Indifferent – possibly consider other non-financial attributes.
$IRR < MARR$ Reject the investment proposal

So, let us assume that the company's MARR is 20% and the required initial investment is \$1 000 000. Over the 5 year life of the project, after cash flows are calculated, the annual income is \$286 446 and there is a salvage value of \$80 000, so what is the return rate of the project? Since there is only one sign change in the project (the negative sign on the initial investment to the positive sign on the annual income and salvage value), there should be one unique interest rate internal to this project. If we calculate the NPV at a couple of possible interest rates using a trial and error approach to bracket the actual IRR of the project, we can make a determination as to whether the project is acceptable or not [adjustment factors, i.e., P/A, 30%, 5 years come from standard engineering economic tables – in this case found in Park (1997)]:

- Interest rate at 30%:
  NPV (30%) $= -\$1\,000\,000 + \$286\,446\ (P/A,\ 30\%,\ 5\text{ years}) + \$80\,000\ (P/F,\ 30\%,\ 5\text{ years})$
  NPV (30%) $= -\$1\,000\,000 + \$286\,446\ (2.2200) + \$80\,000\ (0.2230)$
  NPV (30%) $= -\$346\,249$
- Interest rate at 12%:
  NPV (12%) $= -\$1\,000\,000 + \$286\,446\ (P/A,\ 12\%,\ 5\text{ years}) + \$80\,000\ (P/F,\ 12\%,\ 5\text{ years})$
  NPV (12%) $= -\$1\,000\,000 + \$286\,446\ (3.6048) + \$80\,000\ (0.5674)$
  NPV (12%) $= \$77\,972.$

Since we see that the NPV is positive at 12%, the project's rate of return is somewhere between 12 and 30%. The project's rate of return is said to be that point where the NPV goes from negative to positive or at an NPV of zero. To calculate the NPV at 15%, we see:

$$\text{NPV} = -\$1\,000\,000 + \$286\,446\ (P/A,\ 15\%,\ 5\text{ years}) + \$80\,000\ (P/F,\ 15\%,\ 5\text{ years})$$
$$\text{NPV} = -\$1\,000\,000 + \$286\,446\ (3.3522) + \$80\,000\ (0.4972)$$
$$\text{NPV} = -\$1\,000\,000 + \$960\,224 + \$39\,776$$
$$NPV = 0$$

With an IRR at 15%, we see that it is less than the company's MARR and, therefore, this project should be rejected, if one were considering only the business perspective.

3.7 Payback Period Comparison

Let us explore the ''payback period'' methodology a little more deeply than the overly simplified example presented earlier in the chapter. If a comparison is made between the two mercaptan scavenger projects in the above example and the company's policy is to consider only projects with a payback period of 3 years or less, one can calculate each based on equal terms. If it is assumed that the defender (existing facility upgrade) with its initial investment of \$147 000 and assume and equivalent present value of its benefits to be \$50 000 per year and the challenger, with its initial investment of \$300 000 and equivalent present value benefits to be \$101 000 per year, what are the payback periods for each? Is either acceptable? Which is more acceptable?

- Defender:
  $\text{Payback period}_{\text{defender}} = \text{initial investment/annual benefit}$
  $\text{Payback period}_{\text{defender}} = \$147\,000/\$50\,000$
  $\textit{Payback period}_{\textit{defender}} = 2.94 \textit{ years}$
- Challenger:
  $\text{Payback period}_{\text{challenger}} = \$300\,000/\$101\,000$
  $\textit{Payback period}_{\textit{challenger}} = 2.97 \textit{ years}$

According to the company's criteria of less than 3 year paybacks, both projects would be considered acceptable. However, one is only slightly better than the other in terms of payback period and since risk is not being considered, it may be difficult to say that one project is actually better than the other. To choose definitively the defender over the challenger by virtue of its 0.03 year better payout period, one would have to be confident in the analysis that went into determining the annual benefit used in the denominator. This method is a simple project screening method and that is what prompts its frequent use; however, one should use caution in applying this method. This method does not allow one to consider the earning capability of an individual project and it neglects the time value of money, so one may not be getting a complete picture when using this method. It is certainly a valid method and certainly allows valid relative comparisons provided the natural flaws in this method are applied equally to both projects considered in the analysis (Park, 1997).

These are a few of the simple comparisons that can be made to determine whether to pursue certain loss prevention engineering intervention projects. There are many others and it is beyond the scope of this chapter to cover all possible methodologies; therefore, one should consult an engineering economics textbook to make additional comparisons. From a loss prevention engineering point of view, it should be emphasized that there are more than just pure business drivers. There are other economic aspects of loss prevention engineering that one can address, however, and some of these will be covered next.

3.8 Financial Considerations of a Loss Prevention Engineering Project

3.8.1 Project Budget

Once a decision to implement a loss prevention engineering intervention has been made, a project concept has been made identified and the plan and the necessary work are being developed, the engineer is likely to begin to establish a budget

Table 3.4 Task responsibility matrix.

Task	Welders		Carpenters		Steel erectors		Mechanical systems	Engineers	Total person-weeks
	No. of people in crew	Person-weeks	No. of people in crew	Person-weeks	No. of people in crew	Person-weeks	No. of people in crew	Person-weeks	
1	5	2	6	6	9	6			14
2	5	4			9	4	2	2	10
3			6	4			4	5	9
5	3	4	5	7.5	11	9	4	3	23.5
6			5	12	12	12	3	2	26
7	4	6							6
8							3	3	3
9	4	4	4	7	7	4	3	2	17
Totals		*20*		*36.5*		*35*		*17*	*108.5*

Adapted from Eisner (2002) and Haight (2012).

around that necessary work and plan. The project plan and its associated budget will require that the engineer seek also to determine the financial performance and its budgetary status throughout the project. There is no difference between a loss prevention engineering implementation project and any other project. This involves developing a direct labor and materials budget and then determining a cost budget per week so that the project's performance and progress can be tracked on a weekly basis (this can be done on a monthly, daily, or any other temporal basis).

An example of a direct labor budget is presented here to illustrate the process. Part of a construction project involving nine tasks and the input of welders, steel erectors, carpenters, and mechanical systems engineers is used to show some of the budget development steps. Using a table such as Table 3.4, one can determine how much time each craft and each task will require in completing this project. For example, one can determine that a project that requires 108.5 person-weeks to complete can be broken down to determine that Task 1 requires 14 person-weeks to complete and throughout the project 20 person-weeks of welders' time will be needed.

This can be helpful in scheduling and allocating resources depending upon how quickly the engineer wants the work to be completed and what allocation scheme the budget will support (Eisner, 2002; Haight, 2012). If an engineer has a crew of four welders assigned and it will take 4 person-weeks to complete a task, they would need to determine whether it is better to complete the work in 2 absolute weeks (four welders for 8 person-weeks would take 2 absolute weeks to complete the work) or add a second crew of four welders to complete the work in 1 absolute week.

Table 3.5 Project budget – total installation costs.

Direct labor	Rate per week ($)	Person-weeks required	Cost ($)
Welders	2200	20	44 000
Carpenters	2000	36.5	73 000
Steel erectors	2400	35	84 000
Mechanical systems engineers	3500	17	59 500
Subtotal 1			*260 500*
Fringe rate @ 20%			52 100
Subtotal 2			*312 600*
Overhead rate @ 24%			62 520
Direct costs (materials, supplies, delivery, etc.)	Steel, fasteners, drywall, fire water pumps, A/C units, equipment rental, and supplies		931 500
Subtotal 3			*1 306 620*
General and administrative @ 12%			156 794
Total cost			*1 463 414*

Adapted from Eisner (2002) and Haight (2012).

Charting the work in this fashion allows the engineer in charge of the work to make these determinations, while determining the overall project impact. There are other additional considerations and variables that can be used to make reallocation decisions, such as weekly costing rates (see Table 3.5). The project budget allows one to determine how to adjust and reallocate resources based on weekly costing rates. It may be more financially advantageous from an overall project perspective to add person-weeks of one craft or another in order to finish a project sooner (possible overall lower costs to the project). One can easily determine from Table 3.5 how the project budget would be affected by a change in resource allocation (addition or shifting of crews).

Of course, project performance is also measured in part by how well one adheres to the budget, but there are many other variables that are also tracked when determining project performance. These are beyond the scope of this chapter, but one could make a simplistic comparison between the size of the budgets of two options and the projected amount of risk reduction that each project option or each intervention would yield. In this case, one could put the decision comparison in terms of risk point reduction per monetary unit spent, that is, a risk reduction of 0.1 per dollar or per euro. If one was needing to make a comparison between the project above in Table 3.5 and another project with a cost of $1.1 million and both projects yielded a risk reduction (in terms of probability of occurrence) of 0.2, one would decide to implement the second option, the $1.1 million, rather than the $1.4

million for the project above. This is a simple but valid comparison. Unfortunately, most projects are not that simple or straightforward in terms of determining the risk reduction. This is often done on a qualitative basis using the traditional risk assessment matrix or similar process.

3.9 Conclusion

Loss prevention engineering is really just the application of multiple engineering disciplines to the process of preventing injuries and other accidental losses. Work in this area should be treated as any other construction, expansion, problem-solving project that bears cost, involves resource allocation, the movement of people, the reduction of risk, and the decision-making that are necessary in each case. This includes cost and cost comparisons and the use of engineering economics. However, there is a complication in the case of loss prevention engineering, namely that it deals with the very difficult concept of human cost (injury or death) and our humanitarian nature prevents us from making a purely business decision when injury or fatality prevention is being considered. That is where the concepts of risk assessment, risk comparison, and risk tolerance enter the decision-making process. If two project options are close in cost and one has been determined to have a lower risk, the decision seems easy: consider the cost or value differences as negligible and accept the project that includes a greater reduction in one's risk of loss. But what if the cost or value differences are great? Would these differences be considered to be negligible so that a lower risk project could be accepted? Probably not, and additional discussion would be necessary to determine how much risk the organization is willing to tolerate given the greater costs. It is not an easy process to determine which loss prevention engineering projects to accept, especially in times of constrained resources, but it is always appropriate to consider both business costs and risks and to make decisions based on appropriate levels of business drivers and humanitarian drivers.

References

Cecich, T.F. (2005) Where's my return? Many safety investments won't show financial gain. *Ind. Saf. Hyg. News*, **39** (9), 38–40.

Clemens, P.L. and Simmons, R.J. (1998) *System Safety and Risk Management – a Guide for Engineering Educators*, National Institute for Occupational Safety and Health.

Eisner, H. (2002) *Essentials of Project and Systems Engineering Management*, 2nd edn, John Wiley & Sons, Inc., New York.

Haight, J.M. (2012) Managing a safety engineering project, in *The Safety Professional's Handbook* (ed. J.M. Haight), American Society of Safety Engineers, Des Plaines, IL, pp. 113–148

Investopedia (2012) Return on Investment – ROI, *http://www.investopedia.com/terms/r/returnoninvestment.asp#ixzz1rHdlG7tW* (last accessed March 2012).

National Safety Council (2005) The ROI of Safety and the Business Leaders Who Get It! Reprint from *Business Week*, September 2005, special advertising section, *http://www.asse.org/practicespecialties/bosc/docs/ROI-bus-week.pdf* (last accessed 5 July 2012).

National Safety Council (2012) National Safety Council, *www.nsc.org* (last accessed February 2012).

OSHA (Occupational Safety and Health Administration) (2012) 29 CFR 1910.119, *Process Safety Management of Highly Hazardous Chemicals*, *http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760* (last accessed 15 January 2012).

Park, C.S. (1997) *Contemporary Engineering Economics*, 2nd edn, Addison Wesley, Menlo Park, CA.

US Department of Defense (1993) Military Standard 882 C. *System Safety Program Requirements*, US Department of Defense, Washington, DC.

Veltri, A. and Ramsay, J.D. (2012) Basic economic analysis and engineering economics, in *The Safety Professional's Handbook* (ed. J.M. Haight), American Society of Safety Engineers, Des Plaines, IL, pp. 1–16.