An Efficient and Effective Approach for Performing Cost Benefit Analysis

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1. INTRODUCTION

Risk management involves the application of one or more of a variety of inter-related techniques (hazard and operability [HAZOP], hazard identification [HAZID], facility risk review [FRR], etc.). Most of these applications result in recommendations or suggestions for risk reduction. In fact, the number of recommendations is often significant (well over 100 in many cases and thousands in a case study discussed in this paper). A large number of recommendations is beneficial because each recommendation provides an opportunity for risk reduction and/or other actions for asset improvement. However, a large number of recommendations can overwhelm the managers responsible for their implementation, making it difficult to decide ***what to do*** and/or ***when to do it***. Additionally, there may be overlap or similarities of recommendations from the application of different techniques, sometimes confusing their review and resolution.

Cost benefit analysis is a powerful tool to help managers sort through the numerous recommendations and effectively/efficiently prioritize them. It consists of evaluating the risk reduction and the estimated cost associated with each recommendation, including Capital Expenditures (CAPEX) and Operational Expenditures (OPEX). This paper provides a simple, efficient, and effective approach for performing cost benefit analysis. This method is not intended to replace more detailed methodologies. Rather, it is a complementary tool particularly useful for applications with a large number of recommendations.

2. SUMMARY OF THE METHODOLOGY

This paper summarizes a cost benefit analysis approach based on ABS Group's methodologies: (a) described in training course manuals on process hazard analysis (PHA) and quantitative risk assessment (QRA) [1], (b) developed for the U.S. Coast Guard [2], and (c) developed for oil production and refining companies [3].

The basis of the approach is that the priority of a recommendation is (a) directly proportional to the risk reduction expected from the implementation of the recommendation and (b) inversely proportional to the cost of implementation:

$$\text{Priority} = \frac{\Delta\,\text{Risk}}{\text{Cost}}$$

That is, the Priority, or ***Benefit to Cost Index*** (***BCI***), is the ratio of the ***risk reduction*** to the cost of implementation of the recommendation.

2.1 Evaluation of Risk Reduction (Δ Risk)

The expected ***risk reduction*** (Δ Risk) is:

- The expected risk associated with continuing to operate under the current situation (i.e., if the recommendation is not implemented)
- Minus the expected risk associated with continuing to operate after the changes are implemented (i.e., if the recommendation is implemented)

If we assume that the risk associated with a scenario is the product of (a) the frequency of occurrence and (b) the consequence(s), then,

$$\Delta Risk = \sum_{n=1}^{D} F_{n,\text{ before}} \times C_{\text{n, before}} - \sum_{n=1}^{D} F_{\text{n, after}} \times C_{\text{n, after}}$$

Where:

D = number of accident scenarios affected by the recommendation

F_n = frequency of accident scenario n

C_n = consequences of accident scenario n

The consequences of interest may include any combination of a variety of concerns, including worker safety, public safety, environmental, business interruption, reliability, and so forth.

The frequency and consequences <u>before</u> the implementation of a recommendation (current situation) are evaluated during the hazard analysis [4]. The frequency and consequences <u>after</u> the implementation of each recommendation are evaluated as follows, for each recommendation individually:

- **Identify all risk scenarios that would be affected by the recommendation.** That is, the risk review team identifies the scenarios associated with the risks that the recommendation is trying to reduce. A recommendation may impact a scenario by reducing the frequency of the scenario, by mitigating one or more consequence(s) associated with the scenario, or by doing both.
- **Assess the expected impact that each recommendation has on (a) the frequency and (b) the consequences associated with each affected scenario.** This involves several individual evaluations for each recommendation and is accomplished by selecting <u>Impact Categories</u> from Table 1. Specifically, the team selects the impact category that best applies to the frequency of the scenario and additionally an impact category for each consequence of interest.
- **Evaluate the risk after the implementation of a recommendation.** This is accomplished by multiplying the original assignments of the frequency / consequences for each scenario by the corresponding <u>Risk Reduction Factor</u> from Table 1.

Table 1 — Example Categories for Assessing the Benefits of Implementing Recommendations [2]		
Impact Category	**Benefits of Implementing Recommendations**	**Risk Reduction Factor**
1	**No Impact** The recommendation does not help reduce the frequency or a specific consequence of a scenario	1.00
2	**Small Impact** The recommendation helps reduce the frequency or a specific consequence of a scenario, but this reduction is relatively small (no more than about 10%)	0.90
3	**Small to Medium Impact** The recommendation definitely helps reduce the frequency or a specific consequence of a scenario (as much as 50%)	0.50
4	**Medium to Major Impact** The recommendation significantly reduces the frequency or a specific consequence of a scenario (as much as 90%)	0.10
5	**Major Impact** The recommendation essentially eliminates the frequency or a specific consequence of a scenario (more than about 99%)	0.01

2.2 Limitations of the Evaluation of Risk Reduction (Δ Risk)

The methodology presented in the previous section to evaluate ΔRisk does not address some potential contributors to risk:

- The expected risk associated with making the modifications suggested by the recommendation (or simply the ***modification risk***)
- The possibility that the recommendation will increase risk by creating, for example, new hazards

Regarding the ***modification risk***, suppose the implementation of a recommendation requires construction at the facility. Also, suppose that at least a portion of the process at this facility continues to operate during construction. It is possible that an accident could occur during construction (e.g., a crane accident that damages process equipment and causes a release of hydrocarbons). Accidents may also result from other deficiencies and/or errors during the implementation of the recommendation, including during the phases of design, engineering, procurement, manufacturing, training of operations/maintenance staffs, and several others.

Our methodology does not consider the ***modification risk*** because of the difficulty in evaluating this risk at the time that we perform the cost benefit analysis. To properly evaluate the modification risk, the analysts would need detailed information about the modification (design documentation, construction plans, updated P&IDs, revised operating procedures, etc.), and this information is unlikely to be available when performing the cost benefit analysis.

However, operating companies have management systems in place to ensure adequate controls of modifications (e.g., a Management of Change [MOC] system), including procedures for all activities associated with the implementation of the recommendations. In the case of adequate controls, the risk of implementing the recommendations should be small compared to the other risks addressed here.

Regarding the possibility that a recommendation may increase the risk of some scenarios or create new hazards, consider, for example, a recommendation to add a fire sprinkler to reduce the risk of burning a building down. While the proposed sprinkler system should reduce the risk of fire, it may also increase in the risk of water damage (e.g., from inadvertent operation of the sprinkler). In general, experienced safety/risk analysis teams try to account for potential detrimental effects of the recommendations. In addition, an MOC system should review these hazards and ensure adequate controls. At any rate, we have not accounted for this issue in our previous applications of the approach presented in this paper.

2.3 Evaluation of the Cost of Implementation of Recommendations

The expected cost is evaluated using Cost Categories and Cost Ranges, as illustrated in Table 2. In selecting a cost category for each of the recommendations, the review team considers the total cost associated with the recommendation, including all capital expenditures (CAPEX) and operational expenditures (OPEX) related to design, engineering, procurement, construction, installation, training (e.g., operational and maintenance staffs), etc.

Obviously, this method for cost evaluation is only an approximation based on the experience of the review team. A precise cost can only be estimated after managers review each recommendation and decide the specific action that should be taken to address it. That is, the cost estimate depends on the details of implementation of each recommendation, and this information is generally not available when performing the consequence analysis. However, ranges similar to those in Table 2 are broad enough that it is possible to select a reasonable cost category even without these details.

3. CASE STUDY

Over a period of a little over one year, a major oil company conducted a series of safety, hazard and risk studies for nine production facilities in the Middle East. Most of these facilities were Gas Oil Separation Plants (GOSPs) with typical equipment such as manifold, separator, coalescer, desalter, gas compressing, oil pumping, control room, electrical station, chemical injection system, water treatment facility, oil storage, pipeline and so forth. The motivation for these studies came from internal company guidelines, insurance requirements and recommendations from incident investigation reports for these are other company operating facilities. There were five consequences of interest in this case study – people (worker and public), assets, environmental, production (i.e., business interruption), and company's reputation.

Table 2 — Example Cost Categories	
Cost Category	**Cost Range[1]**
5	Up to US $ 10,000
4	From US $10,000 to US $100,000
3	From US $100,000 to US $ 1,000,000
2	From US $1,000,000 to US $ 10,000,000
1	More than US $10,000,000

3.1 Safety and Risk Studies

To help satisfy the company's purpose and specific objectives, the company retained safety and risk consultants to conduct a total of nine studies for each of the nine sites (i.e., a total of 81 studies):

1. Hazard and operability analysis (HAZOP) and Facility risk review (FRR)
2. Hazard identification (HAZID)
3. Quantitative risk assessment (QRA), including event/fault tree, vulnerability and consequence analyses
4. Safety integrity level (SIL) assessment
5. Hazardous area classification review (HACR) and assessment of electrical/instrumentation equipment
6. Control of substances hazardous to health (COSHH) assessment
7. Permit to work (PTW) review
8. Design review
9. Asset integrity review (AIR)

The FRR [4] is of particular interest in the cost benefit analysis. As part of the FRR, the analysis team developed a list of risk scenarios for each facility, which included incidents that can lead to the release of hazardous materials with potential for fires, explosions etc. These, in turn, can generate the consequences of interest (impacts on people, assets, environment, production, and company's reputation).

[1] In using these cost categories in oil & gas applications, the analysts typically include all applicable CAPEX/OPEX costs (engineering, procurement, manufacturing, installation, operation, maintenance, training, etc.) for a period of time (e.g., five years).

The analysis team also made an assessment of the frequency and consequences of each scenario. Figure 1 illustrates the results of the FRR for one of the nine facilities. The matrix in Figure 1 considers “production”, and there were similar matrixes for the other consequences of interest.

PRODUCTION		Frequency				
		1 (A)	2 (B)	3 (C)	4 (D)	5 (E)
Consequence	5	6, 11, 12, 18, 21	27, 30, 37, 40, 43	15		
	4	5, 20, 46, 49	3, 17, 26, 29, 36, 39	2, 14, 32, 53, 55, 57, 59		10, 31
	3	24, 48, 52, 60, 61	42, 56	13, 25, 28, 34, 35, 38, 45	58	1, 33
	2	8, 9, 51, 62, 63		16, 19, 41	23, 44, 47	
	1			22, 50	4, 7, 54	

Figure 1 – Risk Matrix for Impact on Production

3.2 Consolidation of Recommendations

The nine safety and risk studies generated an average of 260 recommendations for each of the nine plants for a total of over 2,300 recommendations. But it was clear that there were overlaps and similarities among several of the recommendations from each of the nine distinct studies (HAZOP, HAZID, QRA, etc.). Thus, it was convenient to group or consolidate recommendations that addressed similar or related issues. The consolidation provided two benefits: (a) reduced the number of recommendations for the cost benefit analysis and (b) facilitated the work of managers by grouping similar issues for review and resolution.

For example, recommendations 1.43, 1.97, 1.113, 2.18, 2.19, 2.21, 3.3 and 4.9 addressed issues related to the fire protection system. Note that the recommendation number starts with the number of the study and finishes with the unique identifier from that study. For example, Recommendation 1.43 means the 43rd recommendation from the first study, which was a HAZOP study. Recommendation 2.18 is the 18th recommendation from the HAZID. Because 1.43, 1.97, 1.113, 2.18, 2.19, 2.21, 3.3 and 4.9 all addressed the same issues, it was convenient to group them for the purpose of the cost benefit analysis. For illustration purposes, the combined description of this group of recommendations is as follows:

The HAZID, HAZOP/FRR, QRA and SIL studies identified potential deficiencies in the firefighting capabilities at the facility. The specific recommendations for the fire water system, pumps, distribution, etc., include:

- ✓ Performing an engineering review of the entire fire water supply and distribution system to assess the adequacy of: (1) fire water pumps regarding their efficiency (i.e., head pressure); (2) pump start-up (i.e., manual vs. automatic); (3) the capacity of fire water tank; (4) fire pump drive-redundancy (i.e., diesel/electric), (5) the deluge systems on the tanks, (6) the design criteria (especially materials of construction) of the rupture disks of the foam pourer systems on the tanks. In this review, consider whether the fire water pumps should be replaced

- ✓ Adding emergency cooling systems (e.g., fire curtain, sprinklers) for selected equipment and providing long-range fixed monitors at critical locations
- ✓ Developing / improving a testing program for the entire system and components, including written procedures for testing and test acceptance criteria
- ✓ Developing / improving a maintenance program for the entire system and components, including written procedures and schedules for performing the different maintenance tasks
- ✓ Generating a complete set of comprehensive P&IDs for the entire system and components

The consolidation reduced the number of recommendations to a little more than 900, which is about 40% of the original 2,300 or so recommendations.

4. RESULTS

Tables 3 and 4 illustrate the results from the cost benefit analysis. The first column in these tables shows the recommendation numbers. The second column shows the impact category (using the definitions from Table 1) applicable to the frequency of each scenario. The next columns show the impact category (again from Table 1) for each of the 5 consequences of interest: people (worker and public), assets, environmental, production, and company's reputation.

The appropriate cost category (using the definitions from Table 2) appears next in Tables 3 and 4. Thus, for each recommendation, it was necessary to make one assessment of impact category on the frequency of the event, five assessments of impact category for the consequences of interest, and one assessment of cost category, resulting in over 7 x 900 = 6,300 assessments. It is clear that the consolidation of about 2,300 recommendations to about 900 provided significant efficiency during these assessments.

The last two columns in Tables 3 and 4 show the ***risk reduction*** (Δ Risk) and the ***BCI***, as defined in Section 2. In these tables, the ***risk reduction*** and ***BCI*** for a group of recommendations represent the combined impact of all recommendations in the group, not the impact of each one of them individually.

5. CONCLUSIONS

Two key results of interest are the rankings of the recommendations by the expected ***risk reduction*** (Table 3) and by the ***benefit to cost index*** (***BCI***) (Table 4). Note that the higher the ***risk reduction***, the higher the motivation to implement the recommendation because it provides greater potential to reduce the overall risk to a lower level. That is, ***risk reduction*** helps identify the most <u>effective</u> recommendations. In general, significant reduction in the risk at the facility can only be achieved by implementing at least a few of the recommendations ranked high by **risk reduction**.

The ***BCI*** is the ratio of the ***risk reduction*** to the cost of implementation of the recommendation. Note that the larger the ***BCI*** for a recommendation, the greater the risk reduction per unit of capital investment. That is, BCI helps identify the most efficient recommendations (i.e., most risk reduction per monetary unit). Therefore, high ***BCI*** often implies "quick wins." However, high ***BCI*** does not necessarily guarantee a significant reduction in the overall risk.

It is crucial that managers understand the definitions and meanings of the two measures provided in Tables 3 and 4 because, as illustrated in this example, the rankings provided by ***risk reduction*** and ***BCI*** may be different. That is, a recommendation may receive different priority depending on whether managers want to focus on efficiency or effectiveness. Furthermore, it is an iterative process, because given the risk reduction achieved by implementing the highest priority recommendations, the ***risk reduction*** and ***BCI*** will likely be different (smaller) for subsequent recommendations.

In summary, the cost benefit methodology presented here offers an approach to sort through the recommendations from safety, hazard, and risk evaluations and prioritize them effectively and efficiently. Its simplicity makes it particularly useful for applications with a large number of recommendations.

6. REFERENCES

[1] ABS Group training services: http://www.absconsulting.com/training/index.cfm.

[2] PAULA, H. et. al., *Investigation of Fuel Oil/Lube Oil Spray Fires on Board Vessels, Volume 1 (Main Report and Appendixes H through L) and Volume 2 (Incident Databases [Appendixes A through G])*, U.S. Department of Transportation, U.S. Coast Guard Headquarters, Washington, DC, October 1998.

[3] PAULA, H., "Cost Benefit Analysis", *Internal Publication*, ABS Group, originally published in October 2006 and updated in October 2010.

[4] CASADA, M., KIRKMAN, J. AND PAULA, H., "Facility Risk Review as an Approach to Prioritizing Loss Prevention Efforts", *Plant/Operations Progress*, Vol.9, No.4, October 1990.

Table 3 — Recommendations Ranked by *Risk Reduction*[2]										
	Impact Category									
		Consequence								
Recommendation Number(s)	Frequency	People	Assets	Environmental	Production	Reputation	Cost Category	*Risk Reduction*	*BCI*
1.43, 1.97, 1.113, 2.18, 2.19, 2.21, 3.3, 4.9	1	2	3	2	3	3	3	35 %	3.5E-01
1.73	3	1	1	3	1	1	3	27 %	2.7E-01
1.1a, 1.7	2	2	2	2	2	2	3	19 %	1.9E-01
1.1b, 1.7, 1.54, 1.109, 1.116, 9.16	2	2	2	2	2	2	3	19 %	1.9E-01
1.3, 1.22, 1.29, 1.55, 1.99, 2.8, 2.9, 9.4, 9.13	2	2	2	2	2	2	3	19 %	1.9E-01
1.24, 5.3	2	2	2	2	2	2	3	19 %	1.9E-01
1.13, 1.39, 1.47, 2.7, 2.23, 7.C, 9.19	2	2	2	2	2	2	3	18 %	1.8E-01
1.74	1	3	3	3	3	2	3	18 %	1.8E-01
1.45	4	1	1	1	1	1	4	16 %	1.6E+00
1.6	2	1	1	1	1	1	4	9%	9.3E-01
1.41	3	1	1	1	1	1	4	9%	9.2E-01
1.42	3	1	1	1	1	1	4	9%	9.2E-01
1.49	3	1	1	1	1	1	4	9%	9.2E-01
1.100	2	2	2	2	2	2	3	9%	8.8E-02
1.111, 2.22, 9.7	2	2	2	2	2	2	3	9%	8.8E-02
1.115	2	2	2	2	2	2	3	9%	8.8E-02
1.46, 9.8	2	2	2	2	2	2	3	9%	8.8E-02
9.3	2	2	2	2	2	2	3	9%	8.8E-02
1.38	5	1	1	1	1	1	4	6%	6.0E-01
2.10, 5.1	1	2	2	2	2	2	3	5%	4.6E-02

[2] This table presents all recommendations with ***Risk Reduction*** equal to or greater than 5%.

Table 4 — Recommendations Ranked by BCI[3]									
	Impact Category								
		Consequence							
Recommendation Number(s)	Frequency	People	Assets	Environmental	Production	Reputation	Cost Category	*Risk Reduction*	*BCI*
1.45	4	1	1	1	1	1	4	16 %	1.6E+0 0
1.6	2	1	1	1	1	1	4	9%	9.3E-01
1.41	3	1	1	1	1	1	4	9%	9.2E-01
1.42	3	1	1	1	1	1	4	9%	9.2E-01
1.49	3	1	1	1	1	1	4	9%	9.2E-01
1.38	5	1	1	1	1	1	4	6%	6.0E-01
2.1, 3.1	1	2	2	2	2	2	4	0%	4.6E-01
1.43, 1.97, 1.113, 2.18, 2.19, 2.21, 3.3, 4.9	1	2	3	2	3	3	3	35 %	3.5E-01
1.37	2	1	1	1	1	1	4	3%	3.0E-01
1.48, 1.112, 2.4, 3.5	1	2	2	2	2	2	4	3%	3.0E-01
1.73	3	1	1	3	1	1	3	27 %	2.7E-01
1.69	2	1	1	1	1	1	5	0%	2.3E-01
1.75	2	1	1	1	1	1	4	2%	2.0E-01
1.1a, 1.7	2	2	2	2	2	2	3	19 %	1.9E-01
1.1b, 1.7, 1.54, 1.109, 1.116, 9.16	2	2	2	2	2	2	3	19 %	1.9E-01
1.3, 1.22, 1.29, 1.55, 1.99, 2.8, 2.9, 9.4, 9.13	2	2	2	2	2	2	3	19 %	1.9E-01
1.24, 5.3	2	2	2	2	2	2	3	19 %	1.9E-01
1.40	2	1	1	1	1	1	4	2%	1.8E-01
1.13, 1.39, 1.47, 2.7, 2.23, 7.C, 9.19	2	2	2	2	2	2	3	18 %	1.8E-01
1.26, 4.3	2	1	1	1	1	1	4	2%	1.8E-01
1.27	2	1	1	1	1	1	4	2%	1.8E-01
1.28	2	1	1	1	1	1	4	2%	1.8E-01
1.74	1	3	3	3	3	2	3	18 %	1.8E-01
1.71	3	1	1	1	1	1	4	2%	1.7E-01

[3] This table presents all recommendations with ***BCI*** equal to or greater than 10% of the largest BCI in the table.