FINANCIAL EVALUATION AND DECISION MAKING PROCESSES FOR ENVIRONMENTAL TECHNOLOGY PROJECTS

by
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B.S., Information Systems Engineering
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Submitted to the MIT Sloan School of Management and
the Engineering Systems Division
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ABSTRACT

The convergence of the information age with an improved understanding of the effects humans have on the environment provides exciting new opportunities to improve our impact on the world. Though modern companies collect and store an increasing amount of environmental data, it often remains locked away after use in its intended, specific purpose. In many companies, this data remains unavailable despite its value in influencing critical decisions being made elsewhere in the organization. For example, though The Boeing Company has taken strides in incorporating environmental cost-benefit data when evaluating new environmental technology projects, a data gap between available data and data actually used for analysis still exists. This presents the opportunity for further data integration and the creation of a more standardized process for evaluating projects.

The decision model outlined in this paper is designed specifically to fill in the data gaps identified in Boeing's current evaluation methodology and provide consistent data for objective decision making. The prototype software created to address this opportunity is designed to access existing data sets of cost benefit information for each possible environmental factor and use this data to provide thorough and consistent information for any project that effects environmental costs or benefits. The software also incorporates this data into standard financial evaluation metrics currently used to compare different project proposals.

Initial tests of the prototype software developed in conjunction with this study yield improved financial attractiveness in three out of the three projects evaluated. The environmental data presented with the project proposals also provided key decision makers with more information for objective environmental decision making. Though no solution will integrate every detail or provide fully-automated decision making, this solution makes best use of the available data and presents it to key decision makers as a consistent part of all future project proposals.

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I would specifically like to thank Quang Nguyen and Brian Burnikel for serving as excellent mentors during my internship and providing me with numerous opportunities to present my ideas throughout the company. I would also like to thank Christer Hellstrand for his input and mentorship and Martin Chan and Linda Duschl from M&PT.

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Bibliographical Note

Jonathan Dreher graduated from the United States Military Academy at West Point, NY in 2003 with a Bachelor of Science degree in Information Systems Engineering and a commission in the United States Army as a Second Lieutenant. Upon graduation, he completed U.S. Army Ranger School and was assigned to the 2nd Battalion, 37th Armor Regiment in Friedberg, Germany. After serving as an Operations Officer and a Tank Platoon Leader, Jonathan was deployed to Iraq in 2006 as the Scout Reconnaissance Platoon Leader for a combat task force. Upon returning from Iraq after a 14 month tour of duty, he served as an All-Source Intelligence officer in Heidelberg, Germany and left the Army as a Captain in 2008. After leaving the Army, Jonathan was appointed a fellow in the Leaders for Global Operations (LGO) program at MIT and completed his research internship at The Boeing Company in Renton, WA. After graduation, he plans to work for The Boeing Company as part of its LGO leadership rotation program.

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1. Introduction

Several factors have increased the importance and transparency of corporate environmental performance over the past decade. Growing concern over the anthropogenic contributions to climate change, cheap and easy ways to measure environmental impacts and increasing data availability across global networks, for example, are three of the major reasons environmental effects are leading areas of concern for companies worldwide. Though these concerns have sparked a new wave of environmental initiatives and transparency, internal corporate structures and processes have not changed quickly enough to properly recognize and account for new environmental metrics. This paper how one company in particular, The Boeing Company, can address new environmental concerns by slightly modifying existing processes and leveraging data already in its possession.

1.1 Problem Statement

The Boeing Company is currently leading the aerospace industry in environmental performance with both its products and operations. Additionally, Boeing collects and digitizes a wealth of data related to its operations and is capable of drawing upon most of this data for making critical decisions within its different organizations. As a large company composed of many divisions with different functions, however, some data does not always flow freely across the divisions. Occasionally, this results in key decisions based on local organizational knowledge while key data from elsewhere in the enterprise remains unavailable. This data gap provides an opportunity to improve environmental decision making, in particular, by improving the collaborative use of important data that effect environmental projects. My research aims to bridge this data gap and provide a methodology for a more complete financial analysis of environmental projects using a combination of data already available within the Boeing Company and data readily available from outside sources.

This opportunity is significant for Boeing because it provides an opportunity for cost savings that will help give it a competitive advantage and because it will help the company meet ambitious environmental goals. This opportunity is also particularly important because even small gains in environmental performance at Boeing have an enormous impact on the aviation industry. As one of the two main players in the commercial aviation industry, Boeing works with thousands of suppliers and provides products and services to a significant percentage of the commercial aviation market worldwide. For example, this industry accounts for two to three percent of the entire world's output of CO_2 and reductions in emissions pioneered by Boeing can literally have global impacts.[1] Additionally, the industry depends on other potential pollutants, such as hexavalent chrome, to produce certain products and efforts to eliminate hazardous substances used in manufacturing can reduce exposure risk for workers throughout the industry.

1.2 Purpose of Study

The purpose of this study is to create a standardized process for environmental project evaluation so that more consistent and accurate estimates of each project's environmental and financial impact can be used for objective decision making.

New environmental technologies at Boeing are currently evaluated with different sets of data and assumptions that address each project's unique costs and benefits. Though it is often appropriate to calculate unique aspects of differing projects, the lack of standardization in other aspects results in inconsistent calculations for similar environmental effects. An opportunity exists to change this process, however, and have each project evaluator draw upon a common set of data and assumptions to better capture the value of common environmental gains.

Though common evaluation tools exist for different types of projects at Boeing, the unique challenges of determining the financial impacts of intangible or difficult to predict environmental risks and opportunities necessitate a fresh approach. Additionally, as Boeing strives to achieve ambitious five year targets for recycling, energy efficiency, greenhouse gas emissions, and

[1] J.T. Wilkerson et al. "Analysis of emission data from global commercial aviation: 2004 and 2006," Atmospheric CHemistry and Physics Discussions 10 (2010): 2955.

hazardous waste reduction, an environmental evaluation tool will help ensure the necessary projects and technologies are implemented to meet these goals.

1.3 Approach

The plan to address this opportunity was shaped by two key divisions at Boeing and by the author, who lead the project as an LGO fellow on-site with Boeing in Renton, WA. The Boeing divisions involved were Materials and Process Technology (M&PT), which is responsible for the development and integration of new technology and Environment, Health and Safety (EHS), which is responsible for managing the environmental performance of the entire enterprise (among other responsibilities).

To address the opportunity for data integration, development work was started on a software system to aid the assessment of environmental technology project options and the selection of alternatives. This approach allows quick development, distribution, testing and refinement and fits logically into existing computing infrastructure. It is designed to replace current software solutions that only exist as makeshift spreadsheet templates and consistently present environmental data in a manner that is easily adaptable and recognizable by future users. Easy integration will allow environmental data to play a more prominent and consistent role in future project decision making.

Figure one depicts the development timeframe broken down into key areas and actions along the six-month timeline of the author's time at Boeing.

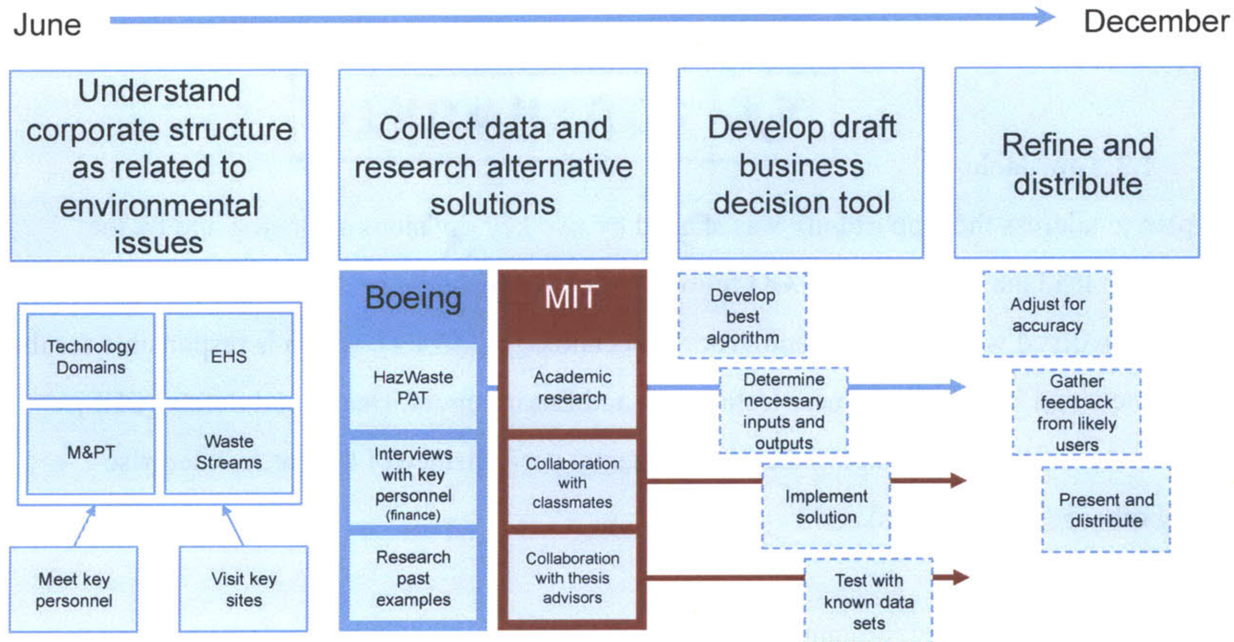

Figure 1: A timeline June through December 2009 that outlines the approach used in this study.

1.4 Thesis Roadmap

This paper addresses steps taken during my approach and explains my proposed solution by walking through several key components of my research. The following chapter provides general background information and context for the research and the subsequent chapter provides a discussion of how the problem is approached in different industries. Next, a discussion of key factors relating to environmental evaluation lead into the approach taken in looking at a solution for Boeing. Tests of the resulting evaluation model are explained using a hexavalent chrome replacement technology as an example and recommendations for future development and distribution at Boeing are made. Finally, a discussion of the resulting method's applicability in other industries is followed by concluding thoughts and appendices.

2. Background and Context

This chapter provides information on the aerospace industry and historical environmental efforts within the industry. It also provides more background information on Boeing, specifically, and describes key divisions at Boeing that were involved in this project.

2.1 The Aerospace Industry

The aerospace industry is dominated by several large firms that compete for business in the military, space, and commercial and private airplane markets. The industry for producing large civil aircraft (approximately 100 seats or more or an equivalent cargo capacity), however, is controlled by only two large companies - The Boeing Company and Airbus SAS (a subsidiary of the larger European aerospace conglomerate The European Aeronautic Defence and Space Company, EADS)[2]. The competition between these two companies is neck-and-neck and in 2009 alone, each company delivered nearly 500 commercial aircraft.[3] Additionally, the economic impact of this industry is huge and the International Air Transport Association claims that the industry supports up to 8% of global GDP.[4] Likewise, the previously mentioned impact of CO_2 reflects the ability of just two companies to effect both the world's economy and environment.

2.2 The Industry and the Environment

The commercial aviation industry has been working hard to reduce the impact of greenhouse gas, hazardous waste and noise pollution concerns for decades. In fact, many of the initiatives that produce environmentally positive results align with incentives that drive competitive advantage in the industry. Specifically, fuel economy, the use of biofuels, engine noise reduction, and hazardous waste reduction, have all played major roles in meeting both industrial and

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[2] Office of Transportation and Machinery, International Trade Administration, U.S. Department of Commerce, *Flight Plan 2009: Analysis of the U.S. Aerospace Industry* (Washington, 2009), 5-6.

[3] The Boeing Company, *Annual Report 2008* (Chicago: Boeing, 2009), 3.

[4] Geoffrey Thomas et al., *Plane Simple Truth,* (Perth: Aerospace Technical Publications International Pty Ltd., 2008), 170.

environmental goals. This section will take a closer look at fuel economy, biofuels and hazardous waste reduction.

As part of a low-margin industry, commercial airlines often rely upon small gains in operational efficiency to provide a significant competitive advantage. Especially in a challenging economic environment, competition is tight and the global aviation industry has reported losses in seven of the last ten years with over 30 airlines going into bankruptcy during the short span from 2008 to the end of 2009.[5] With fuel costs contributing significantly to flight costs, airlines have long looked for ways to save fuel and efficiently deliver passengers and cargo. The leading initiatives to increase efficiency include the development of more efficient engines, reducing the weight of aircraft by using new materials, structures, and systems, optimizing flight routes, and optimizing fuel burn during key phases of flight, particularly taxiing, approach, and landing. The amount of CO_2 released into the atmosphere is directly proportional to the amount fuel burned on any given flight and, therefore, any gains made in fuel economy that helps an airline's economic efficiency also limits the amount of CO_2 released into the atmosphere.

On the other hand, airline customers generally prefer quicker flights and it requires more fuel to fly an airplane at a higher rate of speed. The Concorde, a supersonic airplane developed by the British and French in the 1960's, could travel transatlantic routes in half the time of conventional airplanes while it was in service. This tremendous advantage in speed required a tremendous amount of extra fuel, though, and ticket prices eventually reached levels 20 times more expensive than conventional flights.[6] The resulting economic and environmental challenges limited the market the Concorde and it was eventually taken out of service in 2003. The famous American aviator Charles Lindbergh noted that the Concorde was both "economically and environmentally" unreasonable while it was still in development and Boeing cancelled a competing supersonic design in 1971 after citing similar concerns over cost and environmental

[5] The Boeing Company, *Annual Report 2008*, 33.

[6] Geoffrey Thomas et al., 20.

impact.[7] The Concorde proves that the industry is economically and environmentally sensitive and that excellence in one customer desire, such as speed, cannot trump these two important factors.

Biofuels are another important area where the aviation industry is making significant progress. Though the use of biofuels does not directly translate into lower operating costs for airlines, the alternative fuels reduce oil's monopoly as the sole source of aviation fuel. As instability in key oil-producing regions and rising demand create uncertainty in oil prices, the need for developing an alternative makes economic sense for the aviation industry. Though they also release CO_2 when burned, biofuels have the environmental benefit of absorbing CO_2 as they are cultivated. The UK Parliamentary Office of Science and Technology estimates that biofuels will contribute between 20% and 80% less CO_2 to the atmosphere over their life cycle than traditional fossil fuel sources.[8] Commercial aviation has embraced these benefits and industry estimates state that up to 30% of aviation fuel will come from biofuels by 2030.[9] Even in the military, the largest consumer of oil in the U.S., the Air Force is planning to certify all of its aircraft for a 50-50 biofuel blend by 2012 and procure enough biofuel to meet half of its jet fuel requirements by 2016.[10]

While biofuels compatibility and fuel efficiency have more of an effect during the use phase of an airplane, hazardous waste is produced in significant quantities both during the manufacturing and use phases of an airplane. During either phase, each unit of hazardous waste produced requires additional costs for special disposal and represents additional liability should it be mishandled. Hexavalent chrome, which will be discussed in more detail later in this paper, is one example of a hazardous chemical in use in the aviation industry today. It is used in the processing of metals when an airplane is being manufactured and it is also present in the most

[7] Geoffrey Thomas et al., 24.

[8] Ibid., 154.

[9] Ibid., 152.

[10] Green Technology Daily Editor, "US Air Force biofuel flight test a success," Green Technology Daily, http://www.greentechnologydaily.com/bio-fuels/668-us-air-force-biofuel-flight-test-a-success.

widely used primers (which are used both in initial painting and during routine maintenance and re-painting after the airplane is delivered and in use). When a chrome-free primer is used, it "eliminates the need for designated off-site disposal areas and special handling of paint waste and clean up." [11] Between 2002 and 2007, Boeing has achieved an over 35% reduction in hazardous waste production (normalized to revenue).[12] Additionally, airlines such as Gol and KLM are creating demand for chrome-free products and even volunteering to lead in-flight evaluations of new substitutes.[13]

Even as it works to lower its environmental impact, though, the aviation industry must continue to innovate in this realm and achieve even higher efficiencies. The industry's contribution of some pollutants, such as CO_2, for example, is still projected to rise as a proportion of global output, even with the adoption of new fuel efficient technologies and operations (see figure 2). With only two companies producing the majority of planes in operation, each has the power and responsibility to continue to reduce the industry's contribution of environmentally hazardous substances whenever possible.

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[11] Ostrower, Jon, "Boeing paints Gol 737-800 with chrome-free primer," Flightglobal, http://www.flightglobal.com/articles/2010/03/19/339537/boeing-paints-gol-737-800-with-chrome-free-primer.html.

[12] The Boeing Company, *Environment Report 2008,* (Chicago: Boeing, 2009), 44.

[13] Ostrower.

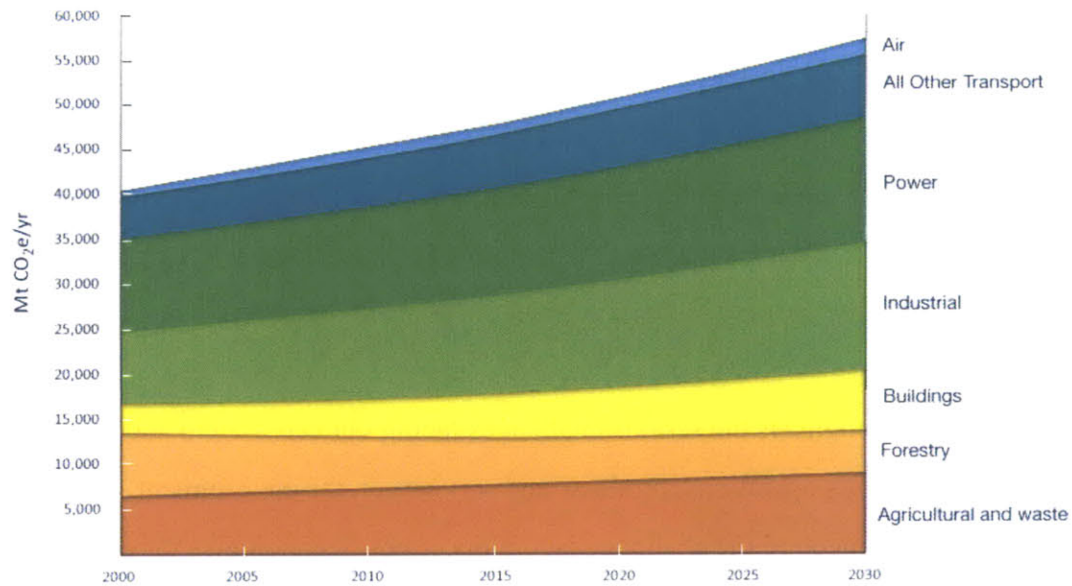

Figure 2: Air transport's projected CO_2 emissions/year compared to other industries.[14]

2.3 The Boeing Company

Boeing is the world's leading aerospace company and the largest manufacturer of commercial jetliners and military aircraft combined. Additionally, Boeing designs and manufactures rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles and advanced information and communication systems. As a major service provider to NASA, Boeing operates the Space Shuttle and International Space Station. The company also provides numerous military and commercial airline support services. Boeing has customers in more than 90 countries around the world and is one of the largest U.S. exporters in terms of sales.[15]

Founded in Seattle by William E. Boeing in 1916, headquartered in Chicago, Boeing employs more than 160,000 people across the United States and in 70 countries. The enterprise also leverages the talents of hundreds of thousands more skilled people working for Boeing suppliers worldwide.[16]

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[14] The Boeing Company, "Boeing and the Environment:Our Commitment to a Better Future" (Company presentation version 2.7, August 2009), Slide 6.

[15] The Boeing Company, *Annual Report 2008*, 33.

[16] The Boeing Copmany, "About Us," http://www.boeing.com/companyoffices/aboutus/, accessed July 9, 2009.

Boeing is organized into two business units: Boeing Commercial Airplanes and Boeing Defense, Space and Security. Supporting these units is Boeing Capital Corporation, a global provider of financing solutions; the Shared Services Group, which provides a broad range of services to Boeing worldwide; and Boeing Engineering, Operations & Technology (EO&T), which helps develop, acquire, apply and protect innovative technologies and processes.[17]

Additionally, Boeing recognizes the serious challenges facing our eco-system and is committed to reducing the effect of its operations, products and services on the environment. Boeing's greatest contribution to meeting the challenge is to pioneer new technologies for environmentally progressive products and services -- and to design, develop and build them in an environmentally responsible manner. The company has also implemented aggressive targets for reducing its impact on the environment both for its operations and the lifecycle of its products. Additionally, Boeing has a record of commitment to regulatory compliance and a legacy of environmental performance improvements in its products and services.

As part of the U.S. Environmental Protection Agency's "Climate Leaders" program, Boeing has committed to help reduce total U.S. greenhouse gas (GHG) emissions by one percent from 2007 to 2012.[18] Additionally, Boeing has set five year targets (culminating in 2012) for their facilities of increasing energy efficiency and solid waste recycling by 25 percent and reducing GHG intensity and hazardous waste output by 25 percent. Each of these targets, except solid waste recycling, is normalized to revenue. According to Boeing's Vice President of Environment, Health and Safety, Mary Armstrong, "we look at those targets just like we look at our financial performance."[19]

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[17] The Boeing Copmany, "About Us: In Brief," http://www.boeing.com/companyoffices/aboutus/brief.html, accessed July 10, 2009.

[18] U.S. EPA, "Climate Leaders: Partners," http://www.epa.gov/stateply/partners/index.html.

[19] Mary Armstrong, "Accelerating the Adoption of Green," (panel discussion in Renton, WA given the week of September 21-25, 2009).

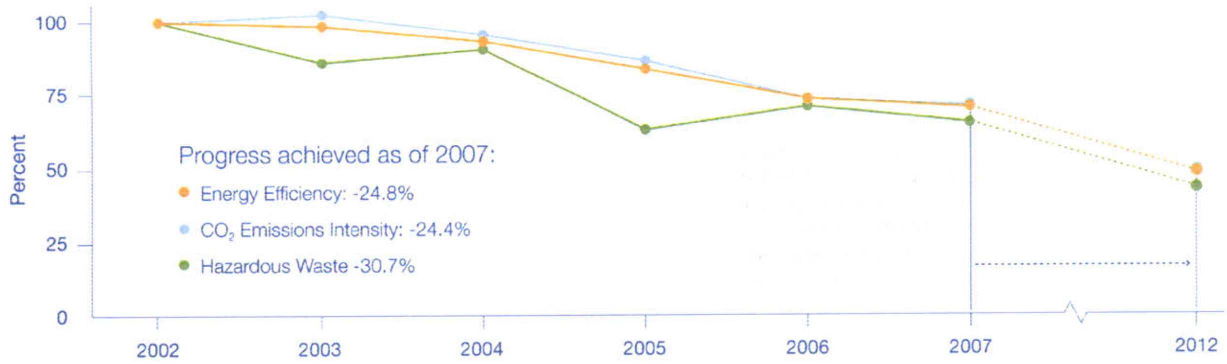

Figure 3: Boeing's progress in key environmental targets[20]

2.4 Boeing Environment, Health and Safety (EHS)

The Boeing EHS division is part of the EO&T group at Boeing and is responsible for the company's environmental strategy. It collects and reports data related to different aspects of the company's environmental performance in addition to its other responsibilities. This data is used to support both regulatory and internal goals and can identify key environmental strengths or opportunities. With previously mentioned environmental goals clearly listed as enterprise priorities that are answerable to shareholders, EHS reporting is highly visible across the enterprise and can command significant resources when needed.

2.5 Boeing Materials and Process Technology (M&PT)

M&PT is also part of the EO&T group and its role is to facilitate the development and transition of emerging technologies into Boeing products in order to provide a competitive advantage.[21] With part of Boeing's environmental vision focused on pioneering new environmental technology, M&PT's mission is key to making these technologies a reality. M&PT's evaluation of new environmental technologies play a major role in whether a technology is developed or adopted and the focus of this project is to standardize this evaluation method and provide objective outcomes for technology decision making.

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[20] The Boeing Company, *Environment Report 2008,* 44.

[21] The Boeing Company, *Integrated Vehicle Health Management and Wireless Applications,* (Boeing Research & Technology presentation abstract, February 23, 2009).

2.6 Chapter Summary

Though the aerospace industry is responsible for a significant contribution of certain environmental hazards on a global scale, it is also a major economic force that supports up to 8% of the world economy. Additionally, though, with competitive advantage in commercial aviation tied to environmental progress, the industry has a long history of improving its environmental record. Fuel efficiency, bio fuels, and hazardous waste reduction are three modern examples of environmental improvement areas as the industry continues to make strides for improvement.

The Boeing company is the world's largest aerospace companies, and, as one of two major manufacturers of large commercial airplanes, it is positioned to effect significant aspects of commercial aviation across the globe. Boeing also has made an effort to pioneer environmental technologies and is committed to key environmental performance goals for 2012. To meet these goals, it is employing data from its EHS division and counting on its M&PT division to deliver new environmental technology. To make the best decisions as to which technologies are worth pursuing, however, M&PT's evaluation process must be standardized and incorporate common data and assumptions provided by EHS.

3. Examples of Environmental Project Business Case Assessment

This chapter provides an examination of the current methods of environmental assessment and methods being used at other companies. An understanding of differing methods proves useful before developing a framework for future environmental assessment at Boeing.

3.1 At Boeing

As described earlier, the evaluation of technology projects is conducted in the Materials and Process Technology (M&PT) group of Boeing's Engineering, Operations, and Technology division. Projects are prioritized based on their projected impact on key variables such as financial performance or impact and contribution to key enterprise commitments, such as the environmental goals mentioned in chapter two.

The financial analysis of these projects attempts to consider as many factors as possible and monetize the effects of product performance improvements and environmental effects. Additionally, the input of different business units can increase or decrease the priority of a project based on the perceived needs of the business unit that may not be quantified in the financial analysis.

Though Boeing EHS currently has a wealth of environmental data, including cost data, that is uses to both ensure regulatory compliance and track the progress of internal goals, much of this data does not get incorporated into M&PT's financial analyses. This data gap exists in many large industries, however, and it is often rare for one division's applicable data point, which is often "lost" is a sea of other data and/or access restrictions, to make its way into another division's analyses in a consistent manner.

This data gap is the target of my research and a proposed solution that was developed for the Boeing company is outlined in subsequent chapters.

3.2 At Other Companies

Before exploring a framework for closing the data gap that often stands in the way of accurate and consistent evaluation of environmental project, we will take a brief look at how a few other companies handle similar challenges.

3.2.1 SCHOTT AG

SCHOTT is a German technology company that produces glass for a variety of domestic and industrial uses. The company employs over 17,000 employees in 40 countries and has sales of US $3 billion.[22]

Prior to implementing a new data management system in the late 1990's, environmental data was spread over several different information systems. Different environmental data, including waste disposal, recycling, water and energy consumption, emissions, and occupational health and safety, were collected and stored in different divisions of the company on isolated systems. Collecting and processing data for any reports that required different sets of data was very difficult and time consuming.[23]

To address this problem, SCHOTT made a decision to store all their environmental data centrally in SAP R/3.[24] Prior to moving the data, however, the company analyzed and restructured existing data into a set hierarchy. The one-time development of a uniform data structure was essential to the automated processing of reports. With this system in place, specific reports can

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[22] Schott AG, "Facts & Figures," http://www.us.schott.com/english/company/facts.html.

[23] Claus Lang et al., "Using Software Systems to Support Environmental Accounting Instruments," in *Implementing Environmental Management Accounting: Status and Challenges*, ed. Pall M. Rikhardsson et al., (Netherlands: Springer, 2005), 161

[24] Ibid.

be generated that "contribute to a better diffusion of environmental information into the decision making at SCHOTT."[25]

3.2.2 Wal-Mart

The U.S. reatailer Wal-Mart is the world's biggest public corporation by revenue and employs 2.1 million employees in several different countries.[26] The focus of Wal-Mart's sustainability strategy is on logistics and supply-chain - the key components needed to deliver and sell low-cost goods at thousands of retail locations around the world.

When Lee Scott took over as CEO in 2000, he reviewed logistical processes at the company and soon realized that changes in the supply chain that could save the company millions of dollars also had positive environmental effects. For example, a one mile-per-gallon increase in the company's trucking fleet would save over $50 million per year.[27] In Wal-Mart's case, the company did not need to maintain and regularly interface with a large environmental reporting dataset. Suppliers did most of the manufacturing and Wal-Mart concerned itself with internal operations that required less environmental regulatory data and reporting. First, Wal-Mart needed to identify the proper metrics to look for (such as energy consumption, emissions, waste, etc.) and then link appropriate cost data from its operations to possible improvements in the new metrics. A data-gap existed between Wal-Mart and its suppliers and it would take a shift in strategy to close the gap and start linking environmental concerns across its entire value chain to its economic success.[28]

In 2005, Mr. Scott detailed the company's new sustainability strategy and set ambitious goals for the company. The three main goals were to be supplied by 100 percent renewable energy, create zero waste and sell sustainable products. These goals were viewed as a way to add to the

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[25] Ibid., 164

[26] Wal-Mart, "About Us," http://walmartstores.com/AboutUs/.

[27] Adam Heying and Whitney Sanzero, "A Case Study of Wal-Mart's 'Green' Supply Chain Management," Operations Management, Stanford University (2009), 3.

[28] Ibid., 4.

company's low-cost competitive advantage and forced the linkage between social and environmental costs to economic impact.

3.3 Chapter Summary

Whether it be an issue of strategy and/or data availability, companies in different industries and companies face many of the same challenges in linking environmental impacts with economic costs. Wal-Mart's change in strategy addresses the importance of goals and supplier coordination while Schott's initial internal problems with unorganized data demonstrate the power of well-designed software and automated solutions.

4. Key Factors Driving Project Decision Making

Though many business decisions are made primarily on economic merits, the decision making processes for environment, health and safety projects must pay special attention to human, environmental, and regulatory inputs, as well.[29] Environmental projects have their own unique costs and benefits in these areas and the potential for negative externalities with far reaching consequences require a more thorough analysis.

4.1 Human

The most sensitive and important of the factors to consider is the health and safety of both employees and members of the general public. The other key factors discussed in this chapter are the result of human interaction with the environment, economy or government and, ultimately, a company will not last long if it fails to adequately recognize the safety and welfare of its employees, customers, and the public as a whole.

Before the dawn of the information age and internet boom in the 1990's, many human impacts were not directly connected with specific sources or activities because the information was not available or easily communicated. These impacts are gaining increased visibility now, however, as new data uncovers the full effect of externalities (both positive and negative). As a result, corporate leaders are increasingly taking responsibility for externalities and paying more attention to the full spectrum of human and environmental factors.[30]

4.2 Environmental

The environmental impact of a project should be measured across the entire life cycle of a product, from raw material extraction, through manufacturing and use, and ultimately to end-of-life and disposal or recycling. Though many different firms are responsible for various steps in

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[29] Natalia Falinski, "A Methodology for Assessing Environmental Projects" (LGO Master's Thesis, Massachusetts Institute of Technology, 1997), 26.

[30] Christopher Meyer and Julia Kirby, "Leadership in the Age of Transparency," Harvard Business Review (April 2010), 41.

the life cycle, the manufacturer truly shapes the product and incorporates the technology that meets market needs. Leading environmental considerations that must be considered include greenhouse gas emissions, other air pollutants, production of hazardous waste, water consumption, recycling and energy efficiency.

4.3 Regulatory

Regulatory impacts are often the most predictable impacts to measure. Rules are published and the consequences of not following the rules are known. Additionally, new regulations take a long time to develop and the potential impact of future regulations can be estimated with a high degree of accuracy. Regulatory enforcement and reporting requirements, however, are not always straightforward and the vast amounts of data needed can often limit the abilities of both regulatory agencies and reporting companies. As a result, the "pattern of information, like the pattern of regulation it is designed to support, is a confusing, disjointed, and erratic patchwork."[31]

Regardless of a regulatory agency's ability to effectively use them, vast environmental datasets exist that are valuable to other applications, as well. Data sets that are collected to ensure local and federal regulatory compliance are often used as building blocks for measuring the impacts of other factors discussed in this chapter. For example, Superfund liabilities in the U.S. and take-back provisions in the European Union can lead to large environmental costs and command large data sets for tracking and cost management.[32] The regulatory-driven data sets in highly regulated industries, such as the aerospace industry, are particularly large and, as a result, increasingly cross-functional to serve other analyses. It is the ability to effectively parse the data and make sense of it that is the limiting factor.

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[31] Bradley C. Karkkainen, "Information as Environmental Regulation: TRI and Performance Benchmarking, Precursor to a New Paradigm?", Georgetown Law Journal 257 (January, 2001).

[32] Roger L. Burrit, "Challenges for Environmental Management Accounting," in *Implementing Environmental Management Accounting: Status and Challenges*., ed. Pall M. Rikhardsson et al. (Netherlands: Springer, 2005), 19.

4.4 Financial

Financial data often produces the key decision making variables used for determining a project's success and future. Costs associated with a particular project are weighed against benefits and the overall effect the project will have on a business is calculated. Some of the specific decision making variables that are calculated with a project's financial data include return on investment (ROI), net present value (NPV), and yearly cash flows. Many of the non-financial impacts discussed above can be factored into the cost-benefit analysis but only if the proper data is available to monetize the impact.

4.5 Chapter Summary

Though financial and regulatory variables tend to enjoy increased significance when making business decisions, two trends are boosting the importance of human and environmental factors. First, externalities associated with human and environmental impacts are more visible and increasingly important and second, the data needed to monetize these factors so they can influence financial variables is more readily available.

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5. Initial Approach and Framework

Typical financial calculations for environmental projects do not factor many of the second-order and intangible benefits that can increase the value and attractiveness of a project. For instance, a project that reduces or eliminates the use of a chrome compound may not consider the value of long term health benefits or the value of helping Boeing reach its publicly stated environmental goals. Financial evaluations may even miss some direct benefits, such as reduced need for protective equipment in the chrome example above, if the data needed is difficult to obtain or outside of traditional organizational boundaries. This chapter outlines the framework for a new financial evaluation tool that is specifically designed for environmental projects and will capture the benefits that are left out of traditional ROI models.

5.1 Framework for New Process

The financial outputs of the evaluation tool are calculated with standard financial equations that use cost and benefit data to provide meaningful financial metrics. With these outputs in mind, one must look at the entire cost-benefit accounting process before diving in to address the specific opportunities for environmental accounting. To obtain a complete picture of a project's financial impact, a thorough understanding of project variables can be defined with standard cost-benefit accounting methods: the definition of the project, identification of all project impacts, identification of impacts that are economically relevant, physical quantification of relevant impacts, and monetary valuation of relevant impacts.[33]

[33] Nick Hanley and Clive Spash, *Cost-Benefit Analysis and the Environment*, (Northampton: Edward Elgar, 1993), 8.

5.1.2 Understanding the Data Flow

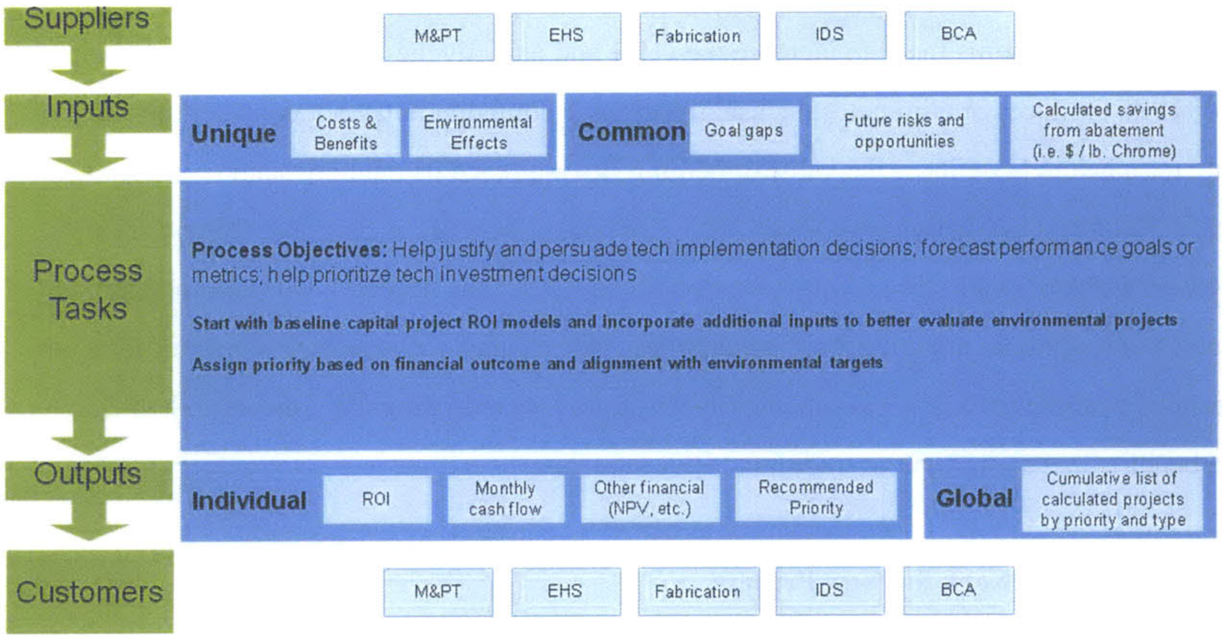

Figure 4: SIPOC Analysis

Another way to understand the project and its key variables is to use an approach that identifies suppliers, inputs, process tasks, outputs, and customers (SIPOC analysis). The suppliers identified are key stakeholders in any new environmental technology and provide data on any proposed technology that is relevant to their operations and concerns. Figure four provides an outline of this project's SIPOC analysis.

Figure five take a closer look a specific inputs that contribute to the financial analysis of environmental projects. It categorizes data as unique to a specific project or universal to the type of environmental effects, in general, and tracks the data interactions needed to quantify the environmental effects in terms of dollars.

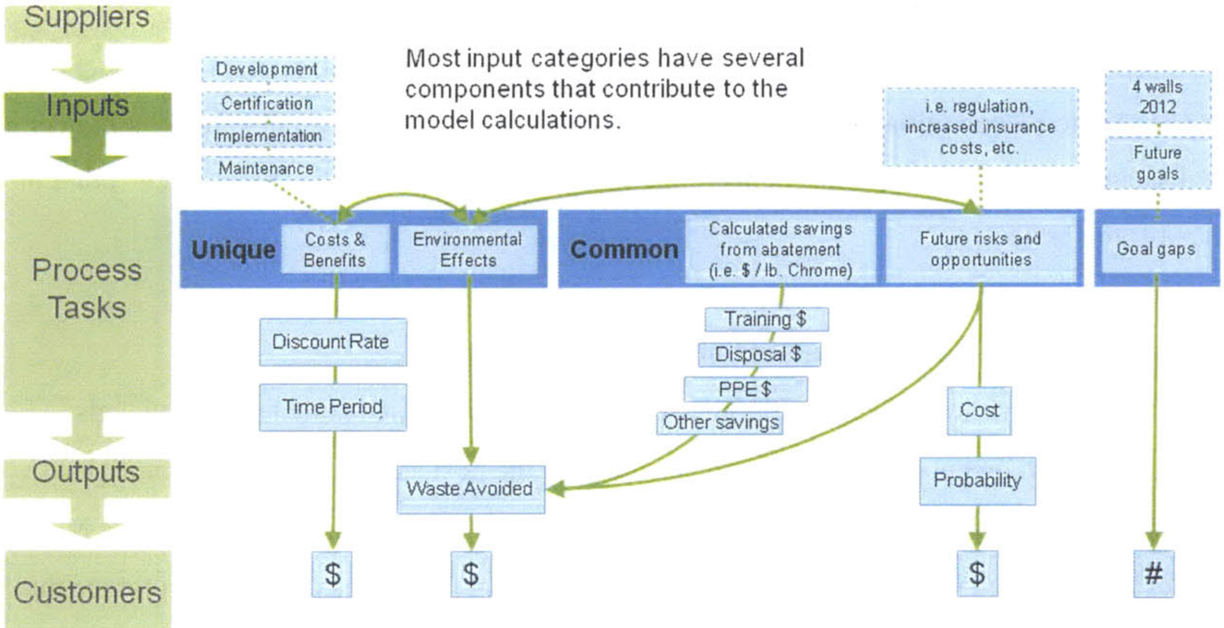

Figure 5: A selection of the key data groups that contribute to environmental financial analysis

5.1.2 Using Data to Calculate Meaningful Outputs

A number of financial outputs are used to compare projects and determine which are the most beneficial to pursue from a purely financial standpoint. Four key metrics used at Boeing and around the world are net present value (NPV), return on investment (ROI), discounted payback period, and internal rate of return (IRR).

Net present value is calculated with the value of cash inflows and outflows using a given discount rate. Cash flows are determined from the yearly cost-benefit analysis of the project and the discount rate, in this case, is provided by Boeing finance. The formula for NPV is depicted below.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Figure 6: formula for NPV

ROI provides the amount, in terms of a percentage, earned on a project's invested capital. It is useful in comparing the efficiency of capital spent for different projects.

The discounted payback period is used to determine a project's profitability and the amount of time needed to recoup initial investment. Whereas NPV provides the overall value of a project, the discounted payback period discounts future cash flows to indicate the "break even" point in years for the project.

5.2 Prototyping and Development of Software Framework

With the proper data identified and a framework in place to make it available to individuals conducting environmental technology project analysis, the next step is to create a prototype analysis tool. Though this tool would ideally exist as an online application to facilitate easy updates for data used in the financial calculations, Microsoft Excel was chosen to prototype the tool because of its ease of use and built-in spreadsheet functionality. The entire application can be simulated using VisualBasic macros embedded in excel worksheets that contain the appropriate data. Specifically, macros were used to create the proper formulas and layout, to setup the workbook for user-specified timelines and environmental effects, to reset the workbook to starting conditions, to produce a user-customizable sensitivity report, and to produce graphs of a project's financial performance over time.

5.4 Data Collection

To test the prototype, two sets of data are necessary: the projected impacts of the example project and environmental cost benefit data needed to assess those impacts. Much of the environmental cost data was available from different EHS databases that are in place to track regulatory compliance and additional data was found by directly querying Boeing manufacturing sites and conducting research on the specific impacts of certain environmental substances.

To gather data for a sample project, a Boeing M&PT analyst supplied data from previously conducted financial analyses. This data was aggregated and converted to units that were compatible with the prototype evaluation tool's expected input units.

5.3 Data Analysis

The evaluation tool's design trades off a certain degree of accuracy for ease of use. For instance, the tool could provide environmental effects for every detail specified in the project and provide a fine degree of accuracy. However, if an analyst is then required to research and provide a much greater number of inputs into the model, some efficiency gains are lost and specific numbers for each scenario may not be readily available. To make the tool easy to use and provide an acceptable level of accuracy, raw cost benefit data for key environmental factors is averaged and used by the model for similar scenarios. For example, if a project eliminates a ton a chrome from the hazardous stream every year, one of the benefits of the project will be savings from hazardous waste disposal. Rather than quantifying the precise disposal savings from the specific site and type of chrome waste eliminated, however, the tool will use an average "chrome waste disposal" figure for the region. Regions are defined by concentrations of Boeing manufacturing facilities and cost figures vary by region because of differences in local transportation costs, regulatory compliance and disposal methods.

5.4 Integration Into Decision Model

The prototype environmental evaluation tool stores data in a separate tab on the excel spreadsheet. Different data sections are formatted with standard fields so that the macros that drive the tool can retrieve updated data automatically. In future versions of the tool, data will be stored in a database that can both be accessed by the online application used by technology project evaluators and updated by EHS analysts with up-to-date cost benefit data. Additionally, project data will be saved in the database so financial results can be automatically updated as environmental data is updated and projects can always be compared with the same, most accurate data.

The first screens in the prototype provide areas for basic project information and identification and a subsequent screen allows a project analyst to input specific cost benefit data and identify environmental benefits to be calculated by the tool. The next four tabs provide the results of the automated financial analysis. One tab depicts more detailed information, including cash flows for each year of the analysis, another tab provides a quick summary of key metrics, the next tab provides graphs and visual representation of the financial results and the final tab provides an interactive sensitivity analysis.

5.6 Chapter Summary

By connecting existing datasets and standardizing a financial evaluation process with common assumptions and processes, the evaluation tool outlined above can open the door to increasingly objective decision making. Use of this tool and the increased accuracy and visibility it provides will allow Boeing to more efficiently spend technology development dollars and exceed its ambitious environmental goals.

6. Evaluation Method Example - Hexavalent Chrome

To more thoroughly test the completed evaluation model, a real environmental technology project was input into the spreadsheet. After considering a range of projects, a project proposing a hexavalent chrome replacement was used. The project was chosen because of a wealth of data available on hexavalent chrome compounds and because the compounds are high-visibility substances that are under considerable regulatory pressure.

6.1 Background

Hexavalent chromium compounds are used in different steps of the airplane manufacturing process and are also used during the "in use" phase of many aircraft when they are serviced and repainted. These compounds, however, are known carcinogens and have adverse effects on the environment if released improperly.[34]

The following paragraphs explain these uses and impacts in more detail and set the stage for the first real tests of the evaluation model.

6.1.1 How Hexavalent Chromium is Used

Hexavalent chromium compounds are primarily used during aluminum anodization processes and during the priming and painting of aircraft and smaller parts.

[34] U.S. Department of Health and Human Services, "Draft Toxicological Profile for Chromium," 4.

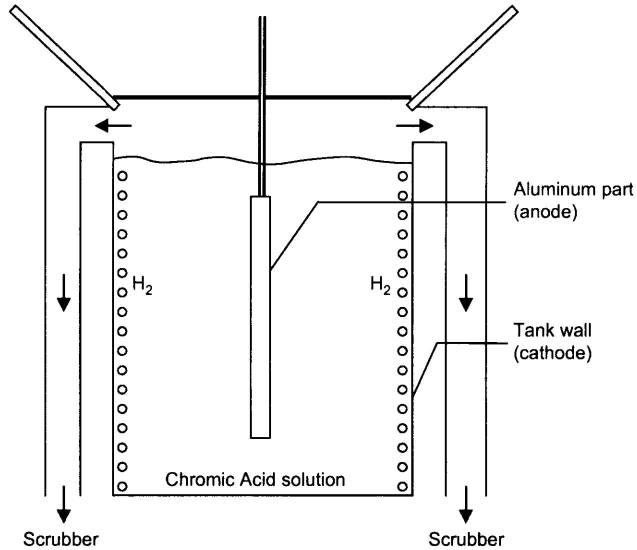

Figure 7: A diagram of part of the aluminum anodization process, including vapor recovery[35]

During the anodization process, the largest dangers involving chromium compounds involve splash when large pieces of work-in-process (WIP) are lowered into the chemical tanks and from the evaporation of chemicals from the tanks. Workers are present in the chemical tank areas and significant amounts of training and precautionary measures are needed to ensure safe operations around the tanks.

The largest source of chromium hazardous waste from the anodization processes occurs when the chemical tanks are dumped for cleaning, retrieval of lost WIP, or replacement of chemicals. Tank dumps are large events that do not occur frequently and a single tank dump contributes significantly to the annual total of hazardous waste for many individual manufacturing sites. Waste from tank dumps can be treated and reduced locally before disposal or immediately shipped off site for processing by a third party.

Hexavalent chromium compounds are used when painting aircraft parts and whole airplanes when being prepared for delivery. Additionally, an aircraft will be repainted several times while it is in use in the fleet, adding to the total amount of chromium used for any given aircraft over

[35] Erwan Harscoet and Daniel Froelich, "Use of LCA to evaluate the environmental benefits of substituting chromic acid anodizing (CAA)," *Journal of Cleaner Production* 16 (2008): 1298.

its lifetime. Chromium primers are preferred because they provide superior paint adhesion to the metal skin of the aircraft. This quality is particularly important because the aircraft is operated in extreme conditions and must be both protected from corrosion and remain aesthetically pleasing. Additionally, chromium primers posses a limited "self-healing" quality that minimizes the damage caused by small scratches.

Primers and paints containing chromium produce environmental hazards in several different ways. The compounds are applied most frequently as an aerosol in a standard compressed air painting system. Workers require significant training, protective gear, and ventilation to protect themselves from exposure to compounds in the air in the work area. Also, unlike chromium waste from anodizing, there is a constant stream of hazardous waste from painting operations. Contaminated paint cans, masking tape and paper, and paint rollers are produced everyday and provide a steady stream of hazardous chromium waste. Additionally, disposable personable protective equipment (PPE), such as face masks and gloves, add to the stream of waste.

6.1.2 Health and Environmental Effects of Using Chrome

The most common health issues found in workers exposed to chromium occur in the respiratory tract.[36] From minor irritation to breathing problems and even lung cancer, chromium can cause a wide range of costly respiratory ailments. Exposure to chromium in drinking water increases the observation of stomach tumors in a given population and exposure to hexavalent chromium can damage sperm and the male reproductive system.[37] Direct contact with the chemical can cause non-allergic skin irritation or even "chrome ulcers" when contact with broken skin occurs.[38]

When chromium is released into the environment it can easily go into solution and move through soil. As a result, concentrations can occur a long distance from the original site of

[36] Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, "Public Health Statement: Chromium," CAS# 7440-47-3 (2008), 4.

[37] Ibid.

[38] U.S. Department of Labor, Occupational Safety and Health Administration, "Health Effects of Hexavalent Chromium," (Washington: DSG, 2006), 1.

contamination.[39] Once in the water system, it is difficult and expensive to test for contamination. In one study in Missouri, for example, it would cost $2.3 million to test for hexavalent chromium in all supply wells and surface water sources of drinking water.[40] Treatment and clean-up of contamination is even more expensive, and in one example of an accident involving a single truck hauling chromium and cadmium waste in Missouri, remediation costs totalled nearly $50 million.[41] Many of the same health problems from chromium exposure occur in animals, as well, and chromium contamination in waterways can have adverse effects on certain fish populations.[42]

Land filling is the most common method for the disposal of chromium wastes generated by chemical industries. Before land disposal, though, it is important to convert chromium wastes into forms of chromium that have low mobilities in soils and low availabilities to plants and animals.[43] This conversion is most often conducted by waste disposal contractors prior to landfilling.

6.1.3 Current and Future Regulatory Pressure

Because of the negative health and environmental effects, chrome is a highly regulated substance that requires adherence to strict workplace standards and disposal guidelines. The Occupational Health and Safety Administration (OSHA) time-limits exposure to certain concentrations of chromium and requires monitoring of employees at least every six months if initial monitoring

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39 Cheryl Pellerin and Susan M. Booker, "Focus on Hexavalent Chromium: Health Hazards of an Industrial Heavyweight," *Environmental Health Perspectives* 108 (2000), A405.

40 Missouri Department of Natural Resources, "Frequently Asked Questions: Chromium in Municipal Drinking Water Supplies" (2010), 4.

41 U.S. EPA and Missouri DNR, *Proposed Chromium and Cadmium Remediation Plan* [Powerpoint Slides], retrieved from http://wwweng.uwyo.edu/civil/publications/presentations/CE5445present.ppt.

42 D.A. Benoit, "Toxic Effects of Hexavalent Chromium on Brook Trout (Salvelinus Fontinalis) and Rainbow Trout (Salmo Gairdneri)," *Water Research* 10 (1975), 497.

43 Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, "Draft Toxicological Profile for Chromium," (2008), 345.

indicates a certain exposure level.[44] Appropriate personal protective equipment to prevent skin and eye contact and inhalation are also required.

6.1.4 Key Considerations for Replacing Chromium-based Compounds

A replacement chemical for processes currently using chromium should preferably not have any adverse health or environmental effects. This will reduce the environmental impact and eliminate many of the costs associated with safe operation and regulatory compliance. Additionally, products processed using a chromium replacement must adhere to the same performance standards as those processed with chromium. For example, a non-chromium primer is used instead of the legacy chromium primer, paint must adhere to the primer in a manner that maintains appearance and corrosion protection. In some cases, products that have been certified using a chromium-containing process must be re-certified to use a replacement chemical. The recertification and required testing can be expensive and time-consuming.

6.2 Use of Previous Methodologies

This section outlines how financial evaluation methods previously used at Boeing evaluated a project proposing a replacement for chromium in one particular application. Each identifiable factor that could contribute to cost savings or additional expenses was listed in a worksheet that was used to calculate project cash flows. Example factors for a chrome replacement include comparing the cost of raw materials, the effects of weight differences between different raw materials (a very important and potentially costly factor in the aviation industry), and health/ medical savings. The evaluation worksheet also attempted to quantify several environmental factors and succeeded with many by providing specific cost benefit data over a specific time horizon that effects the project's overall cash flows. For certain other environmental factors, however, the financial effects were only indicated with a note that they would either have positive or negative effects on the cash flow. As a result, these factors were marginalized and not factored in the financial metrics that drive much of the decision making for the particular project. Additionally, those that were quantified were calculated with one-time research and data that

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[44] U.S. Department of Labor, Occupational Safety and Health Administration, 2.

may change between project analyses. If similar projects are evaluated with different data, it is difficult to objectively compare them.

6.3 Use of Decision Model

The decision model outlined in the previous chapter is designed specifically to fill in the data gaps identified in the previous methodology and provide consistent data for objective decision making. The tool is designed to access a complete data set of cost benefit information for each possible environmental factor and use this data to provide complete and consistent information for any project that effects environmental costs or benefits. Though no solution will integrate every detail or provide fully-automated decision making, this solution makes best use of the available data and presents it to key decision makers as a consistent part of all future project proposals. In the case of chrome, the relevant data needed for three specific projects was input into to the tool and used to test its functionality. The results from the evaluation tool were then compared to the results of the previously calculated analyses.

Figure eight outlines how data flows between different Boeing organizations and the evaluation tool. Also visible is an additional level of financial evaluation that occurs beyond the organizations studied.

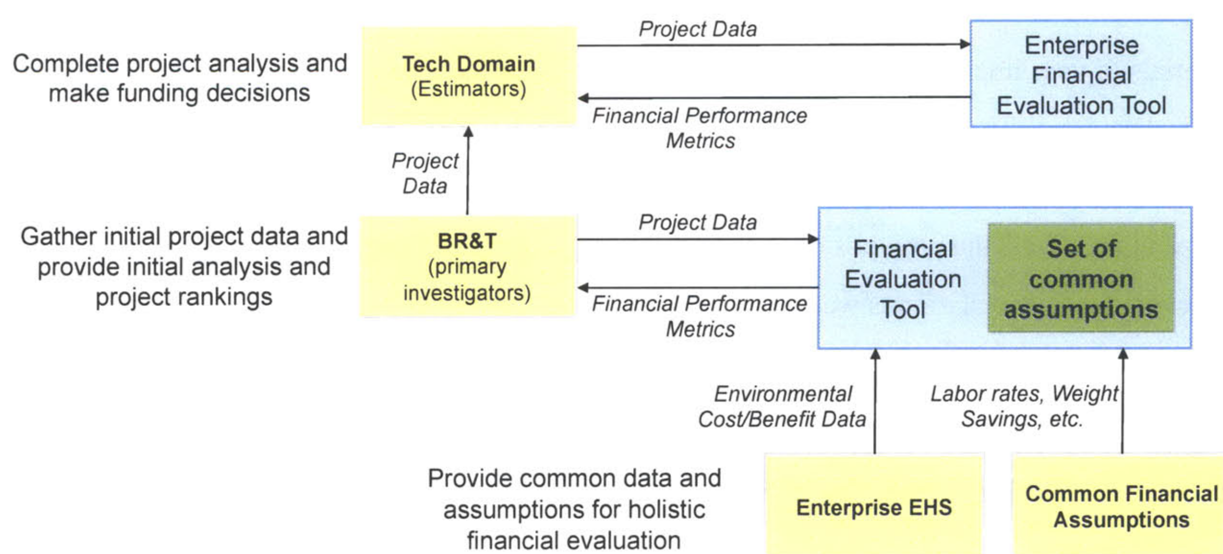

Figure 8: Data flow with the evaluation tool and how it related to key organizations.

6.4 Analysis and Results

The comparison between the financial evaluations of three different projects using the current evaluation process and the evaluation using the methodology developed in this paper yields financial differences that increase the attractiveness of each project when evaluated with the new method. Though the differences are all less than five percent, many of the technology projects under consideration for continued funding have similar financial results and a small change can make the difference between immediate funding or an uncertain future for a project.

Perhaps more important, however, is the fact that other related projects with similar environmental effects will be assessed with the same data. Even if financial metrics do not change significantly, the knowledge that all considerations were factored in a consistent way will aid decision making.

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7. Conclusions and Next Steps

A combination of common data and standardized processes is necessary to make the best decisions that result in the greatest environmental gain and financial efficiency. The integration of environmental accounting methods can lead to enterprise-wide advantages in information quality and transparency.[45] By consolidating important environmental data and incorporating it into a standard financial evaluation tool, different projects can be objectively compared and selected for implementation. The resulting project portfolio will make the best use of technology investments and enable Boeing to most efficiently reach its environmental and operational goals. Additionally, the initial analysis provided by the evaluation tool serves as a baseline that can be compared to actual results in the future. Performance data from projects will provide important feedback that will be used to update and improve the model.

7.1 Recommendations

Further testing with projects in different stages of development is recommended to validate the tool. For example, data from old projects that were selected for implementation and are currently in use can be used in the evaluation tool and compared against known results. This may provide insight into additional considerations that are not calculated by the tool.

7.2 Opportunities for Improvement

As discussed previously, the prototype software developed in conjunction with this research would best be implemented as an application on a central server. This would allow it to be regularly be updated without a need for redistribution and would provide easy access through any web browser on the Boeing network. Additionally, project analysis should be saved on a similar central server so that it can be revisited when environmental cost-benefit data changes (if oil prices change significantly, for instance, or if new regulations are codified).

[45] Claus Lang et al., 168.

Additionally, if the algorithms in the tool are updated and accepted by different levels of financial estimators, the resulting reports could replace the need for multiple levels of financial analysis that currently takes place. The prototype software currently provides reports that are satisfactory for use by primary project investigators. If higher level financial organizations at Boeing buy-in to this approach and augment the software with their processes and considerations, however, it could eliminate the need for redundant analyses. Figure nine addresses this area of possible improvement.

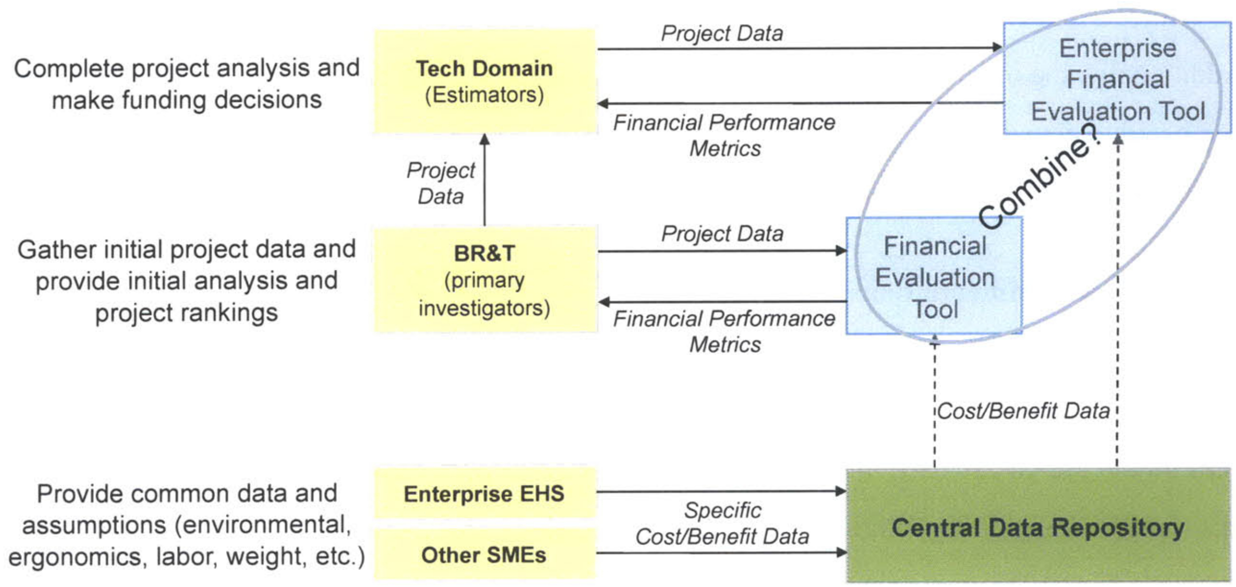

Figure 9: Reduction of redundant analyses

7.4 Areas for Further Research

As mentioned in the previous section, there are opportunities for improvement that would require additional research. In addition to these suggestions, it is worth researching other tools that may help bridge the gap between environmental data and project accounting. SCHOTT AG used advanced enterprise software made by SAP to reorganize its environmental cost data and this approach should be revisited and studied to see how it can be applied to other industries and with more modern IT systems. Additionally, the same data referenced throughout this paper may be useful in other applications other than project evaluation. If similar, relevant data is available to workers on the factory floor or staff in cubicles, it may lead to individual behavior change and further environmental and economic savings.

8. Recommendation for Evaluation Tool Distribution

This chapter provides an outline for future use, testing and maintenance of the evaluation tool at Boeing.

8.1 Organizational Support

Initially, M&PT analysts will be the primary users of the tool and maintenance of the code and functionality will lie within the M&PT organization. Other organizations will interface with the tool to provide data but support responsibilities will lie with M&PT.

8.2 Implementation Strategy

Though the new evaluation tool can be useful to many different divisions at Boeing, further testing is needed to validate the tool before it is put into widespread use. Additionally, it will take time to enter a complete dataset that is useful across the wide variety of applications. Therefore, it is recommended that the tool stay within M&PT (which is specific to Boeing Commercial Airplanes) until further testing is complete. After testing at M&PT, it can be expanded for use in other business units. Recommendations for further testing are outlined in chapter nine.

8.2.1 Model Ownership

It is recommended that enterprise EHS be responsible for completing and periodically updating the core dataset of common cost benefit assumptions in the evaluation tool. Analysts at M&PT will be the primary users of the tool and M&PT should continue to provide feedback to EHS on needed data and update options and functionality in the tool itself. Boeing's engineering, operations and technology (EO&T) group and finance group will provide other key evaluation data, such as burdened labor rates and discount rates.

8.2.4 Tailoring for Different Organizations

Future deployment of the evaluation tool may necessitate changes to address the specific needs of a new host organization. Flexibility for these types of changes are built into the coding of the tool and different environmental impacts can be added as considerations for different types of projects. Additionally, the tool provides an option for the individual manual input of data for use one time with a specific project.

8.2.5 Tracking Success

In the early stages of deployment, when access to old methodologies is still available, comparative results should be tracked and added to provide a total picture of the tool's impact. Additionally, individual success stories can be used to aid further deployment of the tool.

References

Benoit, D. A. 1975. Toxic Effects of Hexavalent Chromium on Brook Trout (Salvelinus Fontinalis) and Rainbow Trout (Salmo Gairdneri). Water Research 10 (1975). 497-500.

The Boeing Company. 2008. Environment Report 2008. Chicago: Boeing.

The Boeing Company. 2009. Annual Report 2008. Chicago: Boeing.

Burritt, Roger L. 2005. Challenges for Environmental Management Accounting. In *Implementing Environmental Management Accounting: Status and Challenges.*, ed. Pall M. Rikhardsson, Martin Bennett, Jan Jaap Bourma and Stefan Schaltegger, 19-44. Netherlands: Springer.

Congressional Budget Office. 2009. *Cost Estimate: H.R. 2454 American Clean Energy and Security Act of 2009.* Washington: CPO.

De Azevedo, José Sergio Gabrielli. 2009. The Greening of Petrobas. *Harvard Business Review* March 2009: 43-47.

Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. 2008. Public Health Statement: Chromium. CAS# 7440-47-3

Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. 2008. Draft Toxicological Profile for Chromium.

Falinski, Natalia K. 1997. A Methodology for Assessing Environmental Projects. Master's Thesis, Massachusetts Institute of Technology

Green Technology Daily Editor. "US Air Force biofuel flight test a success." Green Technology Daily. http://www.greentechnologydaily.com/bio-fuels/668-us-air-force-biofuel-flight-test-a-success.

Hanley, Nick, and Clive Spash. 1993. *Cost-Benefit Analysis and the Environment*. Northampton: Edward Elgar.

Harscoet, Erwan, and Daniel Froelich. 2008. Use of LCA to evaluate the environmental benefits of substituting chromic acid anodizing (CAA). *Journal of Cleaner Production* 16 (2008): 1298-1304.

Jameson, Blythe. 2010. Environment for Change. *Boeing Frontiers* March 2010: 46-48

Karkkainen, Bradley C. Information as Environmental Regulation: TRI and Performance Benchmarking, Precursor to a New Paradigm? Georgetown Law Journal 89 (2001): 257.

Lang, Claus, Daniel Heubach, and Thomas Loew. 2005. Using Software Systems to Support Environmental Accounting Instruments. In *Implementing Environmental Management Accounting: Status and Challenges.*, ed. Pall M. Rikhardsson, Martin Bennett, Jan Jaap Bourma and Stefan Schaltegger, 143-168. Netherlands: Springer.

McKinsey Global Energy and Materials. 2009. Unlocking Energy Efficiency in the U.S. Economy. Milton: Villanti&Sons.

Meyer, Christopher, and Julia Kirby. 2010. Leadership in the Age of Transparency. *Harvard Business Review* April 2010: 38-46.

Miel, Rhonda. 2008. Cascade's Green Goals Produce Solid ROI. Plastics News 31 (2008): 11-24.

Missouri Department of Natural Resources. 2010. Frequently Asked Questions: Chromium in Municipal Drinking Water Supplies.

Office of Transportation and Machinery, International Trade Administration, U.S. Department of Commerce. 2009. *Flight Plan 2009: Analysis of the U.S. Aerospace Industry*. Washington.

Ostrower, Jon. "Boeing paints Gol 737-800 with chrome-free primer." Flightglobal. http://www.flightglobal.com/articles/2010/03/19/339537/boeing-paints-gol-737-800-with-chrome-free-primer.html

Pellerin, Cheryl, and Susan M. Booker. 2000. Focus on Hexavalent Chromium: Health Hazards of an Industrial Heavyweight. *Environmental Health Perspectives* 108 (2000): A402-A407

Parks, Liz. 2008. By the Numbers: The ROI of Sustainability. *Supermarket News Summer 2008 Whole Health Supplement* Vol. 56: 51-53.

Raman, Anand. 2009. The New Frontiers: How the global showdown is reshaping competition from emerging markets. *Harvard Business Review* July-August 2009: 130-137.

Thomas, Geoffrey, Guy Norris, Steve Creedy, Christine Forbes Smith. 2008. *Plane Simple Truth*. Perth: Aerospace Technical Publications International Pty Ltd.

Unruh, Gregory. 2008. The Biosphere Rules. *Harvard Business Review* February 2008: 111-117.

U.S. Department of Labor, Occupational Safety and Health Administration. 2006. Health Effects of Hexavalent Chromium. Washington: DSG.

U.S. Environmental Protection Agency. *2008. Technical Support Document on Benefits of Reducing GHG Emissions*. Washington: GPO.

U.S. Environmental Protection Agency and Missouri Department of Natural Resource. *Proposed Chromium and Cadmium Remediation Plan* [Powerpoint Slides]. Retrieved from http:// wwweng.uwyo.edu/civil/publications/presentations/CE5445present.ppt.

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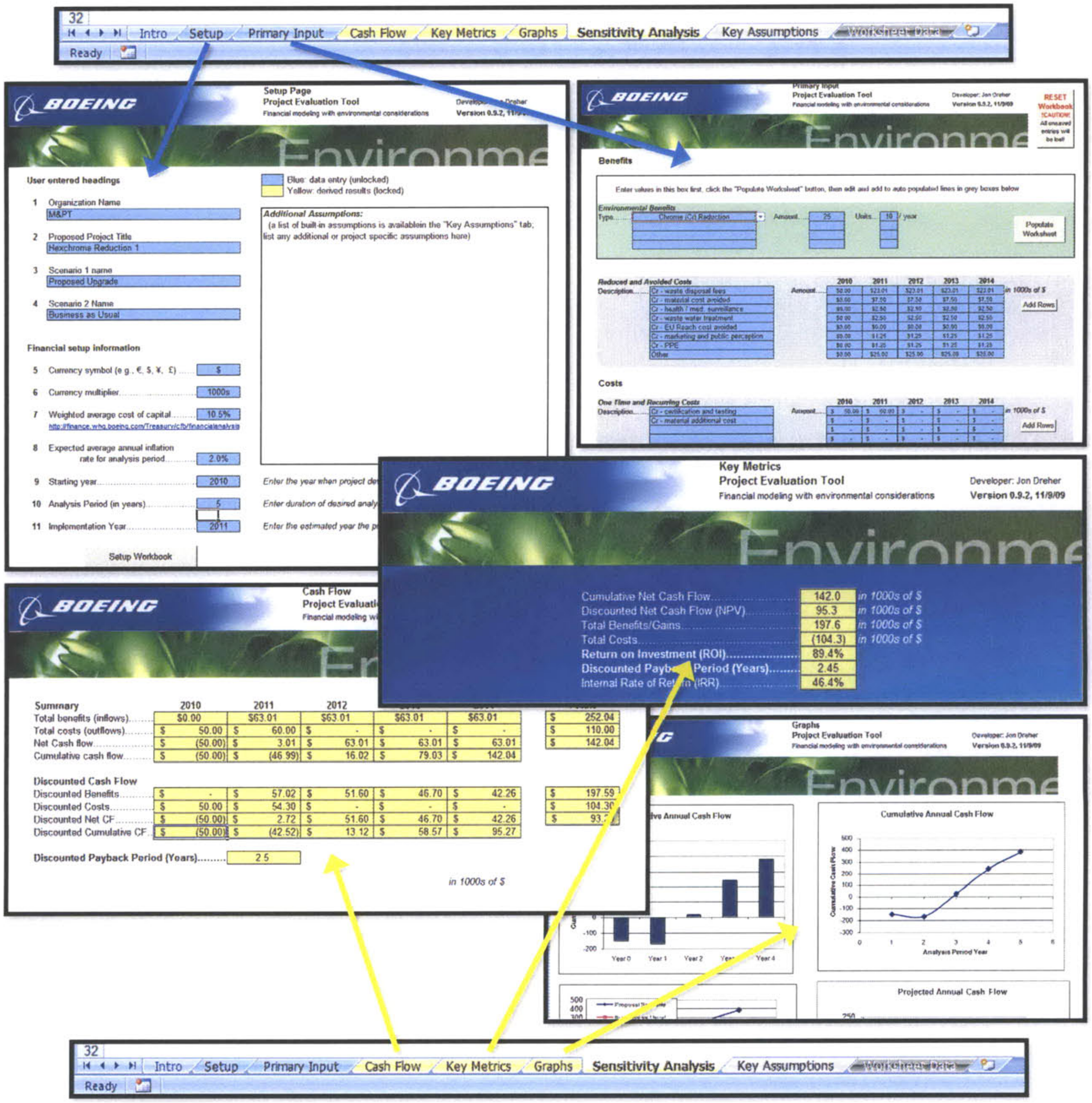
Appendix A - Evaluation Tool Screen Shots

Note: Any data depicted in the screen shots below are for reference only and do not reflect actual Boeing data.



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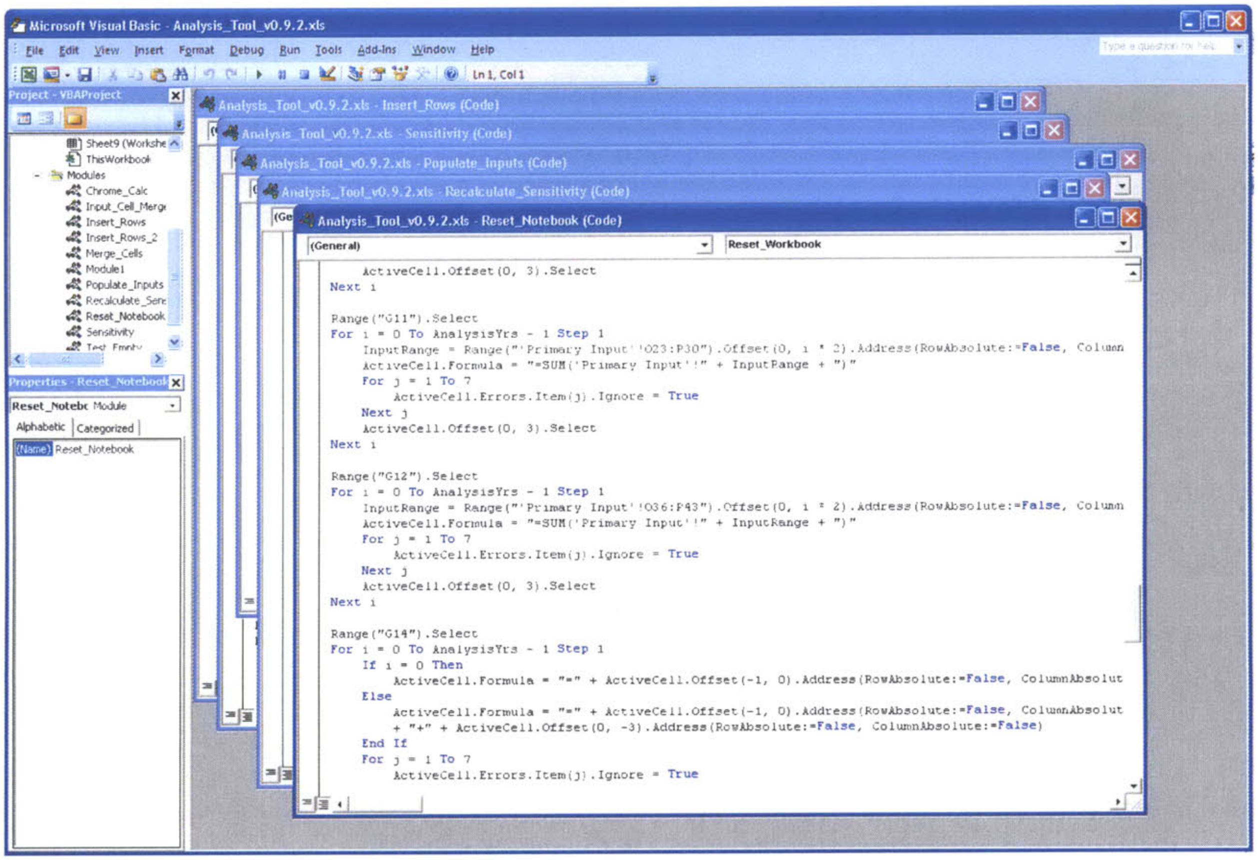
Appendix B - Example Visual Basic Code

An example of code used to manipulate spreadsheet and provide key functionality is shown below.



To handle user-customizable options for project timespan and multiple environmental effects, macros were used to dynamically create the equations and data structures needed to handle each situation.

Macros were also programmed to conduct sensitivity analysis of certain inputs to customizable levels, reset the workbook to starting conditions, and create graphs of a project's financial performance over time.

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Appendix C - Acronyms

BCA – Boeing Commercial Airplanes

BDS - Boeing Defense, Space, and Security (formerly IDS)

BR&T – Boeing Research and Technology

EADS - European Aeronautic Defence and Space Company

EHS – Environment, Health and Safety

EMP – Environmental Management Process

EO&T – Engineering Operations and Technology

EPA – Environmental Protection Agency

GHG – Greenhouse Gas

IDS – Integrated Defense Systems (former name of BDS)

LGO – Leaders for Global Operations

LRBP – Long Range Business Plan

M&PT – Materials and Process Technology

O&R – Opportunity and Risk

OSHA - Occupational Safety and Health Administration

PAT – Process Action Team

PPE - Personal Protective Equipment

ROI – Return on Investment

SIPOC – Suppliers, Inputs, Process Tasks, Outputs, Customers

TLA – Three Letter Acronym

WIP - Work in Process