POTENTIAL IMPACT OF CHANGES IN RISK ASSESSMENT TO ADDRESS WICKED PROBLEMS: A CASE STUDY OF BRITISH PETROLEUM'S ASSESSMENT STRATEGIES

A Thesis

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ABSTRACT

In the last decade, in lieu of many financial and environmental problems, the confidence in a traditional risk management strategy has fallen. Due to issues facing the sustainability of natural resources and globalization of the oil and gas industry, problems have become too complex to solve with traditional risk management strategies. The complexities of these problems have resulted in a characterization of the problem as "wicked problems." Wicked problems are those that arise that are unstructured, irregular, and adaptive. In order to deal with wicked problems, different risk analysis strategies have been developed. These strategies have tried to create a beneficial form of risk analysis and management that will be more productive when dealing with wicked problems. Therefore, it should be of benefit to analyze whether broadened risk assessment and management principles for wicked problems are more environmentally sound and economically effective.

Using BP as a case study, this thesis hypothesizes that the execution of broadened risk assessment and management strategies will be more effective and efficient environmentally and economically.

This study examines the environmental and economic efficiency of British Petroleum (BP) in order to determine if the introduction of a broadened risk assessment strategy was beneficial. Emissions data were compiled from reported emissions records on the Environmental Protection Agency's (EPA) greenhouse gas (GHG) data website from the years 2010-2012. Economic data were gathered through BP's annual reports from the years 2008-2013. The data were compared through a series of environmental and economic analyses in order to determine the impact of a broadened risk assessment: The environmental data were assessed by analyzing the emissions levels and scaling the emissions by output of the company. The economic data were evaluated through two average product analyses and a risk savings analysis. The results showed an overall improvement in economic efficiency, and no environmental efficiency improvement after the introduction of a broadened risk assessment strategy.

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NOMENCLATURE

BOP	Blowout Preventer
BP	British Petroleum
CH4	Methane
CO2	Carbon Dioxide
DWOP	Drilling and Wells Operations Practice
EHS	Environmental, Health, and Safety
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
HAZOP	Hazard and Operability
MOBED	Thousand Barrels of Oil Equivalent Per Day
NGO	Non-governmental Organization
N2O	Nitrous Oxide
OMS	Operating Management System
OSHA	Occupational Safety and Health Administration
PM-2	Project Management of the Second Order
S&OR	Safety and Operational Risk
SSM	Soft Systems Methodology

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1. INTRODUCTION

Although Horst Rittle and Melvin Webber first introduced the concept of wicked problems in 1973, it has been relatively absent in research until the last decade (Rittel & Webber, 1973). Some of this more recent research includes Kampf's paper about risk management in the Arctic (Kampf & Haley, 2011) and Pollack's paper about paradigms changing in project management (Pollack, 2007).

The focus of this research is to bridge the gap of information on wicked problems and their assessment. For example, although there is a growing number of research and publications on what wicked problems are and how to determine if a situation is a wicked problem, the information about the effectiveness of using broadened risk assessment and management strategies is sparse. In particular, this research will be focusing on risk assessment and management practices in the oil and gas industry. Therefore, the study will focus on what wicked problems are, how the oil and gas industry's operation may be seen as a wicked problem, and if the use of broadened risk assessment and management strategies may be of benefit.

Due to accessibility of data and prior events within British Petroleum (BP), such as the *Deepwater Horizon* oil spill, this research will use BP as a case study. Although this study will focus on BP's *Deepwater Horizon* oil spill as a trigger for the changes in the company's risk assessment, the emissions data and economic data of the company are more consistent indicator of environmental and economic efficiency associated with risk. Therefore, BP's emissions data and economic data will be analyzed in order to determine if the implementation of broadened risk assessment and management strategies are economically and environmentally more efficient then traditional risk assessment and management strategies.

Using BP as a case study, this thesis hypothesizes that the execution of broadened risk assessment and management strategies will be more effective and efficient environmentally and economically.

1.1 Limitations

The limitations of this study are mainly due to the fact that it is a present day study, with limited data available. When looking at environmental data, the most unbiased source for emissions data are the government records such as the EPA site that was used in this study. However, the records for specific petroleum/natural gas and refinery sites only went as far back as 2010. After contacting the EPA directly, past records (before 2010) were not able to be obtained because they were not available through the GHG database, and other methods of retrieval such as contacting state agencies were not time permitting for the study. Therefore, the study was limited in the amount of data that could be compared.

Another limitation to the study is that it becomes hard to show cause-and-effect relationships between the calculations of environmental and economic data and the change in risk assessment strategies. The study is able to show the timing of the risk assessment change (2010) and determine if the company has improved in its environmental and economic efficiency, which shows important patterns within the company. It can become hard to measure non-static complexities with static procedures. Therefore, as this is a correlational relationship, it becomes challenging to prove that one change is actually causing the other. Although the study tries to account for other factor contributions, the complexities make it hard to prove causation. Other factors such as differing state regulations, shifts in business activity and assets, or unexpected market fluctuations may play a contributing part. With this in mind, it must be taken into consideration that the results of the study could be due to other factors than risk assessment changes.

1.2 Traditional Risk Assessment

Risk analysis is the closest thing science has given us to a method for analyzing our existential condition of uncertainty and doubt in the face of decisions.

-Crawford-Brown (1999)

Risk measures the probability and severity of adverse effects (Haimes, 2009). The basis for risk assessment is to determine where uncertainty in a project occurs in order for organizations to determine preventative measures (D. Hancock & Holt, 2003). It focuses on risk as objective and identifiable rather than subjective (Kampf & Haley, 2011). Therefore, the traditional risk assessment uses mathematical and statistical, or linear processes (Kampf & Haley, 2011). The typical way to determine the risk of a project is through the use of mathematical models that are used to estimate risk as a function of one or more inputs (Thompson & Graham, 1996). This method reviews risks in linear chains of cause and effect over short periods of time (Gray & Wiedermann, 1999). Traditional risk assessment places the uncertainties in sequence, which allows a weight to be given to the risk according to the likelihood of its occurrence and possible impact (D. Hancock & Holt, 2003). Traditional risk assessment is also very rigid in its classifications of risk (D. Hancock & Holt, 2003). The use of a traditional method disregards, and ignores, any uncertainties arising from systems' complexities and unpredictable behaviors.

Traditional risk assessment focuses on the technical and quantifiable risks of an organization. It takes an approach that uses managerial techniques to develop a process that revolves around the use of qualitative and quantitative tools (Kampf & Haley, 2011). With these techniques, the risks are perceived as always being identifiable and manageable (Kampf & Haley, 2011).

Risks can include financial, physical, and technical areas of the organization (Table 1). In order to address these risks organizations use a variety of methods. Traditionally, engineering estimates are used for risks associated with maximum foreseeable loss, property expenditures, and expected loss levels (D. Hancock & Holt, 2003). Insurance systems have also been implemented for risk associated with product or service liability (Meulbroek, 2001). Financial risk is measured using two main calculations; probability distributions linked with policies of risk spreading and risk pooling. First, probability distributions linked with policies of risk spreading measures the bearing of risk amongst the spread of multiple investors (Klein, 2000). Second, risk pooling measures the involvement of the company in a series of uncorrelated projects (Klein, 2000). These traditional risk assessment measurement tools are all solution based. They drive for optimal solutions that are sought through careful analysis and are linked to changes in the business activity. By using these tools, the decision making process is pushed towards a linear framework and gives clear modes or response. Risks are therefore “priced” to have tolerable thresholds, and managed with sequential layers of decision-making (D. Hancock & Holt, 2003).

In an attempt to develop methods that can help in the assessment of uncertainties, traditional risk assessment has fallen short. William Ruckelshaus states, “risk assessment is the product of a shotgun wedding between science and the law” (Suter, 2007). The seemingly clear solutions that are presented with traditional risk assessment can actually make things more complicated through these shortcomings. For example, knowledge about some or all inputs may be lacking in risk models (Thompson & Graham, 1996). Therefore, traditional risk assessment does not reflect how the risks are perceived or interpreted by others (D. Hancock & Holt, 2003). It also fails to convey the judgmental and structural assumptions that influence the risk focus (D. Hancock & Holt, 2003). Finally, and most importantly, traditional risk assessment does not present all realities. It ignores the influence of cultural, social, environmental, and temporal aspects of uncertainty, which leaves some risks to not be addressed properly (Table 2).

1.2.1 Traditional Risk Assessment of Oil and Gas Problems

An important example about how traditional risk assessment is used in the oil and gas industry is seen through research highlighted in Kampf’s paper about risk management in the Arctic. Kampf and Haley evaluated and analyzed the results of a conference in which the risk assessment used was discussed by the oil and gas industry (Kampf & Haley, 2011). The majority of the topics from the conference used a traditional risk assessment for different projects in the offshore oil and gas industry. Traditional risk assessment was seen in many projects including disaster management, internal risk management, and oil and gas infrastructure (Kampf & Haley, 2011). A main characteristic of these presentations is that they assess the risks by multiplying the probability of the risk by the severity of the risk (Kampf & Haley, 2011). However, this is problematic because probability does not always accurately depict the reality of the risk (David Hancock, 2010).

Another issue is that risks are often determined with a linear method which can cause problems because human risk decisions are made in a nonlinear fashion (Samuelson, 2011). Human risk can be attributed to two different categories of risk. First, the person approach views risk acts as arising from irregular mental processes such as inattention, carelessness, negligence, or recklessness (Reason, 2000). Whereas the systems approach views humans as being imperfect and attributes error to be expected even in the best of circumstances (Reason, 2000). In both categories errors tend to fall into recurrent patterns, where similar circumstances provoke similar errors (Reason, 2000). This concept shows that both categories of risk occur because humans are predictably irrational and the errors happen in the same ways over and over again (Ariely, 2008). These behaviors are not random and they are consistently repeated which makes them important in improving decision making processes (Ariely, 2008). Furthermore, most companies that use a traditional risk assessment tend to view human error only from a systems approach category (Reason, 2000). Therefore, the use of a traditional risk assessment becomes inaccurate because it does not account for the person approach of human error.

More examples of the use of traditional risk management in the oil and gas industry are referenced through Schroeder and Jackson's paper about the failure of traditional risk management in the oil and gas sector. The first example is of an offshore oil and gas platform, operated by Shell, located in Russia's jurisdiction in the Pacific. The construction of the platform (Sakhalin II) faced multiple changes in the platforms construction costs due to unrealistic estimates of the cost and currency losses (Schroeder & Jackson, 2007). Another problem occurred when disputes arose between Russia's government and the project over environmental violations (Schroeder & Jackson, 2007). The inefficiency of the risk management used on the project eventually caused Shell to sell most of the operation. The second example includes the problems associated with a refinery-wide turnaround of the entire plant structure. This project would take the plant off-stream for a projected to be more than 500,000 man-hours in a time period of 40 days. However, because the risks were never fully understood or addressed, the project ended up doubling in time for completion and increased in costs by 30% (Schroeder & Jackson, 2007).

1.3 Wicked Problems

Wicked problems have multiple characteristics that make them unique. Generally, wicked problems are extremely difficult when it comes to addressing cause and effect (Batie, 2008). They are influenced by many differing social and political factors, and biophysical complexities (Batie, 2008). Wicked problems are so complex that they can never fully be solved; instead they can only become better or worse (Rittel & Webber, 1973).

Specifically, when defining a project or an industry as a wicked problem, key characteristics must be noted (Fig. 1). First, they are unique due to the social and technical complexity (Kampf & Haley, 2011). Wicked problems are complex because every wicked problem can be considered to be a sign or cause of a different problem (Rittel & Webber, 1973). For example, an oil spill may be the sign of not following procedure, regulatory problems, lack of safety, differing opinions in management, poor auditing tactics, all of the above, or none of the above.

Second, wicked problems have constantly changing requirements and constraints to any possible solutions (Kampf & Haley, 2011). Therefore, they cannot be easily categorized into specific disciplines (Batie, 2008). There are no specific categories into which wicked problems fit into because there are no solutions that can be developed to categorize all wicked problems. There is no way to define the similarities of each wicked problem for comparison because even if two problems seem to be similar, it is impossible to be completely certain the wicked problems are one hundred percent similar (Rittel & Webber, 1973).

Finally, wicked problems have multiple stakeholders that have differing views and values (Conklin, 2006). One of the main reasons this concept is important is because stakeholder participation is becoming a much larger part of different industries due to globalization. Globalization of industries allows for more wicked problems to occur because it increases the social complexities of the industry. Globalization also increases the number of changes and constraints that an industry may face due to the increased number of stakeholders (Seijts, Crossan, & Billou, 2010). Because industries are becoming more globalized, it becomes critical to look at policies that will be able to manage and assess risks that arise with projects that may have wicked problems.

As different industries become more connected with the rest of the world, more stakeholders will continue to get involved. Wicked problems always occur in a social context involving multiple stakeholders whose opinions of the problem can drastically differ (Pidd, 2004). However, a split can occur among the stakeholders when they view their contribution as independent of other stakeholders as apposed to viewing the multiple stakeholder contributions as being united (Conklin, 2006). It is important to understand that as stakeholders are included in the problem the opinions about what the problem is, what the cause of the problems is, and how to tackle the problem become larger and more complex. Multiple stakeholder participation means there will be trade-offs when dealing with the causes and effects of the problem, and when understanding the outcomes (Batie, 2008).

Many wicked problems raise the concern for systems' interdependency because there are often many different organizations within different situations (AustrialianGovernment, 2007). Organizations exhibit different benefits, and therefore mutually dependent relationships arise. It is important to include the human aspects such as judgments, perceptions, and anxieties in a risk assessment because they are highly influential in organizational decision-making. Another area of concern with wicked problems is the multiple and varying behavioral influences. These influences can be both internal and external, and can have large impacts on industries and projects. External influences include shareholder demands, changes in technology, and changes in environmental regulations while internal influences can include ethical decisions, finances, and production (Mckinney, 2014). Therefore it is important to take both human aspects and behavioral influences into consideration in risk management, but they are often left out because they can be difficult to identify (AustrialianGovernment, 2007; Mckinney, 2014).

Many risks that arise with wicked problems are due to poor communication channels, team skills integration, and stakeholder involvement (AustrialianGovernment, 2007; D. Hancock & Holt, 2003). This is because an increasing number of industry projects deal with communication, not only between and among the project teams, but also with project experts and stakeholders from many different organizational cultures (AustrialianGovernment, 2007). These problems are also more likely to occur than traditional problems, and they are actually easier to resolve when the proper policies are implemented. For example, a traditional problem such as product failure may not occur very often in a well-maintained industry, but when it does, it may take a long time to resolve because it can be technically complex (AustrialianGovernment, 2007). However, a wicked problem, such as multiple-stakeholder project communication, is likely to occur on every project but can be easy to resolve if it is managed properly.

When dealing with problems that may arise during a project or in industry, one author has characterized categories associated with the problem. Different problems can fall under the categories of tame, messy, and wicked. Tame problems fall on the opposite side of the spectrum than wicked problems, with messy problems falling somewhere in between the two extremes (Batie, 2008) (Table 3).

Tame problems are not necessarily simple, as they can be technically complex, but tame problems have simple and linear relationships that have a clear beginning and end point; tame problems can be solved through data gathering and solving each constituent part (AustrialianGovernment, 2007). Messy problems are a bit harder to define because they deal with the complexities of interrelated problems that may arise within a project; as well, messy problems are puzzles, they are not solved, but the complexities can be resolved (David Hancock, 2010). Wicked problems are those that are complex, adaptive, and interactive (Kampf & Haley, 2011). Wicked problems are different from messy problems because they introduce a social aspect to the problem. They have multiple stakeholders that bring a human aspect to the problem. The uncertainties that arise due to the human behavior aspect allow for wicked problems to be more complex than messy problems (AustrialianGovernment, 2007). This means the wicked problems are constantly changing and have no definitive statement of the problem (AustrialianGovernment, 2007; David Hancock, 2010).

In order to separate what characterizes a tame, messy, and wicked problem King describes four different problem types (King, 1993):

Type I: Known outcomes + fixed sequences = deterministic

Type II: Known outcomes + known probabilities = statistical or stochastic

Type III: Known outcomes + unknown probabilities = uncertainty

Type IV: Unknown outcomes + debatable issues = emergence

Traditional risk assessment typically assumes that problems are tame, or Type I and Type II problems. Therefore, if the outcomes, sequences, and probabilities are known, then traditional risk assessment may be a productive way of determining risks. However, because projects and industries are becoming more interconnected with outside stakeholders, have social and technical complexity, and have constantly changing requirements, most problems fall under Types III and IV. The increasing complexities of projects are leading to a larger number of problems becoming Type III, or messy problems. However, messy problems are not as large of a concern because, if specific boundaries or conditions for the industry or project can be agreed upon, there can be a single solution (David Hancock, 2010). Therefore, the main concern for industries and projects is that of wicked problems (Type IV).

Because wicked problems do not have a definitive problem, or a problem that can be easily determined, there cannot be a definitive solution (AustrialianGovernment, 2007). Wicked problems arise as a result of what the project is trying to achieve (David Hancock, 2010). Unfortunately, traditional project management focuses on Type I and II problems, and underestimates the potential of Type III and Type IV problems (Kampf & Haley, 2011). According to Bentley and Wilsdon (2003), "in these complex circumstances, people and organizations have to become adaptive...the question is whether policy-makers can embrace this shift in perspective" (Bentley & Wilsdon, 2003). In order to fully address risks associated with wicked problems, a broadened risk assessment needs to be developed that can adapt to complex situations and focus on the variety of problems that can arise from wicked problems.

1.4 Wicked Problems of the Oil and Gas Industry

The projects associated with the oil and gas industry fall into the category of being a wicked problem because they share the characteristics of wicked problems. The oil and gas industry is very unique due, in part, to their social and technical complexities. First, there are the social issues that are centered around oil and gas. These issues include human rights; revenue management; environmental; health and safety (EHS); governance; and corruption (Wagner & Armstrong, 2010). The vastness of the social issues that face oil and gas only add to the complexities of the industry. As well, drilling in general is technically complex. Because drilling has expanded to include offshore sites, the complexities of the engineering and response and rescue have become even more difficult to control (Kampf & Haley, 2011).

The oil and gas industry also faces the characteristic of dealing with constantly changing requirements and constraints to solutions. These constraints include challenging weather predictions, industry demand, and lack of data. Global climate change is one constraint that the oil and gas industry must face. Because the weather can be hard to predict, engineers must constantly look for ways to improve the rigs in order for them to be suitable for weather inconsistencies. With the change in climate happening at an accelerated pace, it can be a challenge to keep the industry moving in the right direction (Kampf & Haley, 2011). It is also important to note that the weather conditions will have different effects depending on where the drilling takes place.

For example, drilling will have more risk if it is located in a cold offshore environment than it would have in a warm landlocked environment (Goodyear, Clusen,

& Beach, 2012). In a colder environment, such as the Arctic, there are many factors that can increase the risk associated with drilling. First, the Arctic's extreme weather and freezing temperatures make the oil behave differently. In lower temperatures oil takes longer to disperse, it is near impossible to clean up if underneath ice, and it would linger for longer periods of time if spilt (GreenPeace). The movement of sea ice in the Arctic also poses a complex problem, as it introduces the presence of icebergs that need constantly moved (GreenPeace). Finally, the remote location of the Arctic is a problem because if an accident were to occur, it would take longer to get the proper personnel to the scene.

The demand of the industry also keeps pushing drilling to go further offshore, and into deeper waters. In order to keep up with the demand of the industry, engineers are forced to modify rig structure so drilling can occur in deeper waters (Faucon, 2013). Another issue that arises is the lack of sufficient baseline and monitoring data (Kampf & Haley, 2011). Without proper understanding of certain drilling site system dynamics, it can be difficult to predict the consequences of drilling and the affects on the environment (Kampf & Haley, 2011). To begin with, onshore and offshore drilling may differ in how they affect the environment. For example, offshore drilling can create various forms of pollutions such as drilling muds, brine wastes, and deck run off, that may be different from onshore drilling pollution(Oceana, 2012). On the other hand, onshore drilling may affect humans due to the proximity certain sites may have to communities (WildernessSociety, 2010).

Finally, the oil and gas industry includes many different stakeholders that may have conflicting views and values. Stakeholders can include employees, customers, suppliers, the local community, and even future generations. It is important for an industry, company, or even a project to ensure that the interests of a wide range of stakeholders are taken into consideration (Fremond, 2000). In order to approach a diverse group of stakeholders important principles to consider include transparency or full disclosure of information, accountability that ensures that management is effectively overseen, fairness in terms of unbiased treatment, and responsibility that ensures that the corporation fulfills its societal roles (Fremond, 2000). Specifically, oil and gas stakeholders range from governments, business partners, shareholders, suppliers to communities, employees, and customers(Looney, 2012). Each of these groups may be interested in the oil and gas industry for different reasons because they are all seeing the industry from differing perspectives, and working towards different goals. Therefore, they may all have differing views and values. With such a large range in stakeholders, it can be difficult to use one system to address all of the differing views and opinions.

Wicked problems are unstructured, interactive, adaptive, and complex (AustrialianGovernment, 2007). These problems are socially and technically complex, they are constantly changing, and they have multiple stakeholders with different views and values. After discussing the oil and gas industry, it is understandable why it can be defined as a wicked problem. Therefore, the implementation of risk assessment systems that will address the wicked problems associated with oil and gas projects and industries is a key step in improving oil and gas risk management.

1.5 Implementation of a Broadened Risk Assessment to Address Wicked Problems

In order to fully address the risks that are associated with the wicked problems in a globalized industry, it is important to understand that a broadened risk assessment needs to replace the traditional risk assessment approach. As previously mentioned, traditional risk assessment follows a technical approach. It develops management that is chronologically driven, and solves problems in a linear way. Broadened risk assessment attempts to develop a management system that looks for continuous improvements instead of solutions to problems. Wicked problems are never fully solved, and there is no best approach to dealing with a wicked problem. Unlike traditional risk assessment that focuses on the technical and quantifiable risks such as financial, physical, and technical, a broadened risk assessment is more adaptive to allow it to address wicked problems. A broadened risk assessment uses multiple management and assessment theories, and it can also focus on the cultural, social, temporal, and environmental risks (Table 2). Although there may be other approaches to address wicked problems, systems thinking is being focused on here because it is the method that is addressed most in the literature.

Wicked problems call on a system that is continually adapting to risks that never stop changing. The importance of a broadened risk assessment approach is that it focuses less on solving problems and finding a definitive answer and seeks to continually come up with new problem-solving techniques. The process does not end until the industry runs out of time, money, energy, or some other resource (D. Hancock & Holt, 2003). This is a particularly important concept. A wicked problem is always changing due to its complexities and multitude of components. Therefore, a risk assessment that seeks to address a wicked problem must also never stop changing. There must be multiple techniques that always continually search for solutions (Harvey, 2012).

Systems thinking was introduced in 1950 by Ludwig vonBertalanffy. He explained that the emergence of 'systems' has changed in scientific research because people have begun to study systems as an entity instead of a assortment of parts (vonBertalanffy, 1950). It allows for the various risk assessment systems to be integrated in order to tackle the variety of risks from a wicked problem, and it allows for a better understanding of the wicked problems that are associated with a globalized industry. The systems view allows for risk assessment to combine multiple tools and processes in order to deal with complexities that traditional linear techniques do not provide (Kampf & Haley, 2011).

By using systems thinking, the risk assessment can be broadened because it calls upon many different approaches to be combined in order to account for the large number of risks that wicked problems trigger. In order to better understand systems thinking, a few of the methods used to tackle some wicked aspects of a project are addressed. The industry can include systems such as Actor Network Theory, Soft Systems Methodology (SSM), Concept Mapping, Complexity Theory, and Critical Systems Thinking in order to better assess possible risks (Fig. 2).

As an introduction to one of the theories, SSM is an interpretive approach that encourages viewing organizations from a cultural perspective. SSM tries to evaluate as many different options as possible by learning from different sensitivities that exist in each of the people involved (Maqsood, Finegan, & Walker, 2003). The human aspects of an industry are essential in determining the characteristics of the organization (Finegan, 2010). Therefore, SSM is tries to tie in the factors that may be caused due to human interactions. As another example, concept mapping is a way of representing different ideas and topics while linking them all in a web (Liles, 2011). Concept mapping can be useful because it can help to show possible relations between the complexities of a wicked problem (Fig. 3).

A useful example of how some of these different theories can be used in different management techniques is the Project Management of the Second Order (PM-2). This management system is a newer project management paradigm that calls for the use of systems thinking. It uses multiple management systems such as SSM or Concept Mapping, simultaneously in order to manage wicked problems that arise from complex projects (Kampf & Haley, 2011). Therefore, PM-2 is able to utilize systems thinking approaches because it addresses complexities in industry by using multiple management and risk assessment systems in order to tackle wicked problems.

The use of a broadened risk assessment can also be used to build decisional matrices that help to identify continually improving efficiencies within the project (vonBertalanffy, 1950). These matrices are dependent on the skill and commitment of the industry's employees at many different levels. Systems thinking based management relies on the subsystems of an industry or project, and employees at different levels are an important and valuable subsystem (Ingram, 2014). Therefore, it is important to include employees of all different levels such as work groups, departments, and individual employees. This method requires a self-critical awareness and evaluation at an organizational level, and it requires a constant revision of expectations at a personnel level (Ingram, 2014). Employees need to be encouraged to contribute more than simply doing what they are told to do. Employee innovation and awareness need to become a key factor in everyday project and organizational analysis (D. Hancock & Holt, 2003).

Wicked problems are complex, ever changing, and call upon a strategy that can adapt. Broadened risk assessment uses techniques such as systems thinking and continual improvement to address wicked problems. Overall, by applying various techniques in order to broaden a risk assessment, an industry can work to manage the complexities of wicked problems.

1.6 Case Study: British Petroleum (BP)

As a multinational company, BP is the sixth largest energy company by production, and the fifth largest company in the world by revenues (Oil&GasIQ, 2014). The company has operations in all areas of the oil and gas industry including exploration, distribution and marketing, production, and refining. Although BP is headquartered in London, its largest division is BP America based in the United States.

1.6.1 Risk Assessment Issues

Since 2005, BP has been under consistent scrutiny due to different risk management issues and the resulting problems that have occurred. Although the company may have faced smaller risk issues before 2005, comparatively little attention was brought to the company prior to this time. However, in March of 2005 the Texas

City refinery experienced a large explosion that caused 15 deaths and 23 injuries (Mauer & Tinsley, 2010). After that incident, BP's Thunder Horse oil rig in the Gulf of Mexico nearly sank during Hurricane Dennis in July of 2005 due to human error and design weakness in the ballast system (Roberto, 2011). In 2006, BP's Prudhoe Bay oil pipeline experienced a major leak which resulted in over 200,000 gallons of oil to be spilled (Roach, 2006). The leak was due to a failure, by the employees, to maintain the pipeline over the year (Roberto, 2011). Also, in 2006, BP's Toledo, Ohio refinery was fined $2.4 million by the Occupational Safety and Health Administration (OSHA) for safety violations (Roberto, 2011).

On April 20, 2010, BP experienced its most critical risk management issues with the *Deepwater Horizon* oil spill in the Gulf of Mexico. This accident occurred on the Macondo rig which was rented by Transocean from BP (Kaufman & Winig, 2012). Due to the extent of the litigation that followed this accident, this study has focused on a group of case studies and trial evidence in order to develop accurate information pertaining to the spill (Kaufman & Winig, 2012; Roberto, 2011; Rogers, 2010; Rotemberg, 2012; SPAIntegrityManagement, 2007).

Leading up to the accident, there were signs that there may be future problems. In mid-March of 2010, Lloyd's Register Group was hired as a risk management organization in order to assess the rig's safety. The risk assessment report found that workers were concerned with equipment maintenance, safety practices on the rig, and pressure from managers off the rig (Kaufman & Winig, 2012). The report found that many of the systems to be in poor or bad condition which lead to the shut down of the rig for five days to address 383 issues (Kaufman & Winig, 2012). At the end of the shut down, seven issues remained but BP had decided they were “not serious enough” to keep the rig shut down (Kaufman & Winig, 2012).

After the accident, a BP report names eight key elements that could have prevented the oil spill (Fig. 4). First, the cement job of the well did not adequately stop the oil and gas from reaching the well pipe casing (Rogers, 2010). There was also failure in the cement and valve at the bottom of the drill (Rogers, 2010). Halliburton, the cement company, tested the cement’s stability before use, but the results suggested uncertainty (Roberto, 2011). Investigators concluded that BP may not have reviewed the cement laboratory results carefully before deciding to use the cement (Roberto, 2011). Another error was found with the readings of the pressure test. The pressure test was used in order to examine the integrity of the casing and the cement job (Roberto, 2011). During the test, the line was blocked which kept any fluids from escaping (Rogers, 2010). The workers misread these results to show everything to be working correctly (Rogers, 2010).

Since the pressure test was misread, when oil and gas started flowing up the well, it went unnoticed for forty minutes (Rogers, 2010). Gas in the Macondo Prospect well where the *Deepwater Horizon* was drilling gushed upward, causing the drilling mud to eject into the air (Roberto, 2011). From this point, oil and gas was swept onto the rig when it should have been directed overboard (Rogers, 2010). As the oil and gas flooded the rig surface, a cloud of gas spread around the rig underneath the deck (Rogers, 2010).

Also, the rig's fire prevention system failed, allowing the ventilation systems to transfer the gas in to the engine rooms (Rogers, 2010).

Finally, the failsafe blowout preventer (BOP), a piece of safety equipment used to seal the well shut in case of an emergency, had been damaged during drilling (Kaufman & Winig, 2012). The fire had prevented the remote shut down of the BOP from working, and the automated system also failed The fire had prevented the remote shut down of the BOP from working (Rogers, 2010). As flames shot 250 feet in the air, workers were not able to do anything to save the rig or prevent the oil from spilling (Roberto, 2011). The rig burned throughout the following day and the Macondo well continued to spill oil into the Gulf of Mexico for almost three months (Roberto, 2011).

BP immediately sent skimming vessels and aircraft to the rig after the explosions (Rotemberg, 2012). In first attempts to control the leak, BP placed a large funnel on top of the explosion area to try and capture spewing oil (Rotemberg, 2012). This method had proved successful in shallow waters, but low temperatures at the seafloor delayed any further progress to capture the oil (Rotemberg, 2012). The next effort focused on clogging the leaking pipe. BP attempted to shoot a mix of material into the pipe and also worked to drill a relief well parallel to the Macondo well (Rotemberg, 2012). However, before the relief well was ready BP successfully capped the Macondo well by placing a new BOP on top of the old one (Rotemberg, 2012). After the cement that flowed into the pipe through the new BOP solidified BP removed both BOPs (Rotemberg, 2012).

The pipe was capped almost 5 months after the explosion, on September 19, 2010 (Kaufman & Winig, 2012). Despite response efforts, the events of the *Deepwater*

Horizon oil spill caused 11 deaths, 16 injuries, and an estimated total of 4.9 million barrels of oil to be leaked (NationalResponseTeam, 2011). Currently, the *Deepwater Horizon* spill is the largest offshore oil spill in U.S. history. On September 4, 2014 New Orleans judge Carl Barbier ruled that BP should be held 67% responsible for the disaster, while Transocean should shoulder 30%, and the cement firm Halliburton should hold 3% (BBC, 2014).

Through the court evidence from the *Deepwater Horizon* spill trials, the risk assessment has been documented. Prior to the *Deepwater Horizon* spill, and even prior to the Texas City accident in 2005, BP used a technical approach for its risk assessments. Specifically, the Macondo project implemented the GoM Risk Management System (SPAIntegrityManagement, 2007). The GoM Risk Management System is a form of traditional risk assessment because it places the uncertainties in sequence, and it leads management to be chronologically driven which solves the problem in a linear way (Fig. 5).

1.6.2 Risk Assessment Changes

During the Offshore Technology Conference in April of 2012, the Executive Vice President of Developments for BP, Bernard Looney, explained the changes BP has made subsequent to the *Deepwater Horizion* spill, in order to enhance safety and risk management including:

1. Implementation of the Safety and Operational Risk Organization (S&OR) team;

2. Enhancement of education for the company employees and the company's contractors; and
3. Implementation of the 26 recommendations made in the Bly Report.

These three changes include ways to tackle the problems associated with wicked problems (Table 4). First, the implementation of the S&OR team promotes adaptability, which is key in addressing the constant changes of wicked problems. Next, the enhancement of the education structure works to address the differing opinions of multiple stakeholders. Finally, the implementation of the Bly Report recommendations addresses shareholder input, continual improvement and continuity, and adds experts who are apt to deal with complex situations.

Through the S&OR team, BP will be able to assign experts to continuously improve standards as problems arise and change. This is important because it addresses the need for continual adaptation that wicked problems introduce. The S&OR team was designed and given the authority to stop unsafe operations, and to provide technical expertise for all of the operations leaders (Looney, 2012). The team will also utilize it's knowledge base to design and update standards (Looney, 2012). Overall, the main goals of the S&OR team is to provide technical expertise in order to enable production to proceed in a safe, reliable, and compliant manner (Looney, 2012).

Enhancement in education structure is important because helps to lessen the problems associated with multiple stakeholders. If all of the stakeholders are being trained in one location, they will be less likely to exhibit risky behaviors due to differences in training. In order to enhance education, the company has implemented the new training program through the establishment of a Global Wells Institute (BP, 2013a). The Global Wells Institute allows for training of BP employees and BP contractors to be at the same time and in one location (BP, 2013a). During the training, the well site leaders are tested through a seven-part system that assesses their capabilities to control basic well incidents and also tests their ability to prevent an incident from happening in the first place (BP, 2013a).

Finally, BP has implemented all of the recommendations that were made in the Bly Report, an internal inquiry report of the *Deepwater Horizon* spill. Mark Bly, the Executive Vice President of S&OR for BP, compiled a report of the incident through rigorous investigation by an internal team (M. Bly, 2010). As a result of the investigations, the Bly Report came up with 26 recommendations for BP. These recommendations were based on eight key findings and were to apply to BP, its contractors, and its service providers (M. Bly, 2010). Overall, the recommendations focused on two main areas (M. Bly, 2010):

1. Drilling and Well Operations Practice (DWOP) and Operating Management System (OMS) implementation; and
2. Contractor and service provider oversight and assurance

With DWOP and OMS implementation, Bly recommended four areas of improvement. These sections included procedures and engineering technical practices, capability and competency, audit and verification, and process safety performance management (M. Bly, 2010). Each section includes multiple sub-sections that specify procedures that need to be taken and areas that need to be regulated. One of these subsections included training programs with both employees and outside stakeholders. Specifically, the training programs were focused on advanced deep water well control in order to develop better response capabilities and a better understanding of well control conditions (M. Bly, 2010). However, the main importance behind the new training programs was that they brought in current employees and outside stakeholders in order to expand the amount of people involved in the procedures. Another important subsection concentrated on continuous reviews for consistency, rigor, and effectiveness of risk management processes (M. Bly, 2010). In order to accomplish this step, action plans that address areas that need strengthened and definitions of minimum requirements were put into place (M. Bly, 2010). This subsection is particularly important because it includes continual improvement. Including steps towards improvement and continuity of procedures focuses a key factor in addressing with wicked problems. Finally, the report included subsections that focused on the development of formal subsea engineering certifications for personnel involved with maintenance and modification of the control systems, implementation of auditable integrity monitoring systems that include continuous assessments, and the creation of central expert teams in order to provide assurance of the integrity of the BOP control systems (M. Bly, 2010). These subsections conform to a broadened risk assessment by improving the qualifications of the personnel dealing with the complexities associated with wicked problems.

Bly also included four recommendation areas that focus on the contractor and service provider oversight and assurance. These included cementing services assurance, well control practices, rig process safety, and BOP design assurance (M. Bly, 2010).

One subsection of this focus area included conducting a review of the quality of the services provided. This subsections goal is to develop effective communication and mitigation improvements with associated providers' services (M. Bly, 2010). Another subsection concentrated on establishing redundancy and reliability by requiring drilling contractors to implement reinforced repeated audits of risk management processes (M. Bly, 2010). This is important because it makes the contractors implement a process that allows them to change their procedures with the constantly changing factors of a wicked problem. Finally, the subsections also included regular hazard and operability (HAZOP) reviews in order to improve rig safety standards, and strengthening of BP's minimum requirements for drilling contractors in order to prevent miscommunication between BP and the drilling contractors (M. Bly, 2010).

The implementation of the 26 recommendations and the other safety and risk management changes meant new practices, new training, new verification processes, and new expectations (Looney, 2012). The implementation would help to improve risk management for issues that arise in industry working practices, training and competency assessment, and limitations among operators, contractors, and service providers (M. Bly, 2010). Overall, the changes BP made in order to enhance safety and risk management developed "broader systematic responses and recommendations associated with possible broader industry issues" (M. Bly, 2010).

BP has also shown improvements in risk assessment through S&OR updates. In 2011, Mark Bly made a presentation on the S&OR updates showing the teams improvements (Mark Bly, 2011). The presentation included a new continual approach to risk management that covered numerous levels of focus areas (Fig. 6). BP's sustainability review from 2013 also showed extended focus on more stakeholder relationships (BP, 2013b). These relationships have been expanded to include employees, shareholders, governments, regulators, industries, contractors, partners, communities, non-governmental organizations (NGOs), and customers (Fig. 7).

1.7 Summary: Indications of Improvement

The analysis of the trial evidence and investigation reports of the *Deepwater Horizon* spill have provided evidence of BP's risk management procedures from before and after 2010. Trial case evidence from the *Deepwater Horizon* spill has indicated the use of traditional risk management procedures prior to 2010, and the incident reports such as the Bly report and the Offshore Technology Conference speech have shown that BP has implemented a broader risk management system after 2010. The broader system that has been implemented since 2010 follows a systems thinking approach. It works to bring in and understand the impact outside stakeholder opinion, it understands that possibility of human error, it works to improve communication channels, and it continuously tries to improve procedures in order to prepare for issues that arise with wicked projects.

BP has shown clear recognition of the need for implementing a broadened risk assessment through top-level management implications for its importance. This study recognizes that it is relying on BP's reports and publications. For purposes of the study, the push from top management for implementation of broadened risk assessment strategies is being recognized as enough approval, of said strategies, to show indications of a broadened risk assessment through the rest of the company. Therefore, analyses can be done to see if the attempts of implementing a broadened risk assessment have translated into data that show environmental and economic efficiency associated with risk.

2. METHODS

2.1 Emissions Analysis

Emissions data were analyzed because, although the introduction of a broadened risk assessment in BP may have been triggered by an oil spill, the emissions of the company are an underlying continual measurement for the improvement in a company's environmental risk. The *Deepwater Horizon* oil spill was a large disaster that allowed for a major change to take place in the company. However, due to the rarity of a large oil spill, it becomes less accurate to use the spill as an indicator for environmental risk. Therefore, the company's continual emissions are a more consistent measure of the environmental efficiency attributed to risk.

Due to the availability of information, the emissions analyses were conducted for the years 2010-2012. The database could not be expanded further into the past because emissions data was not recorded before 2010 in the current EPA software. The site used for the studies' database provided emissions data from the years 2010, 2011, and 2012; Emissions data were compiled from reported emissions records on the EPA greenhouse gas (GHG) data website (EPA, 2012). The EPA website allows emissions data to be searched by site location and type of facility. The data were narrowed down to twenty-four petroleum/natural gas and refineries that BP operates in the U.S. Twenty-four sites were selected in order to remain consistent with the number and type of sites data-based per year. The twenty-four individual sites were also alike in production in order for the emissions data to be kept to similar scales. The study focused on only U.S. BP sites in order to compare emissions differences in locations that were operating under the same environmental regulations. Once all of the sites' data were compiled, the data were further narrowed down to each specific site. Further research narrowed the emissions gases by type. The gases were recorded for their corresponding year by total Carbon Dioxide (CO_2), total Methane (CH_4), and total Nitrous Oxide (N_2O) emitted by each BP petroleum/natural gas and refinery plant in the U.S. (Table 5-7).

After all of the raw emissions data were compiled, the totals for each gas per year and the number of sites assessed in each year were recorded (Table 8). The data for the total BP production in the U.S. and the total emissions of BP in the U.S. were compiled in order to scale the greenhouse gas emissions by output (Table 9-10). All of the data compiled allowed for two separate environmental calculations to be run in order to determine the environmental efficiency of using a broadened risk assessment.

The first calculation showed the total emissions of CO_2, CH_4, and N20 from the years 2010-2012 (Fig. 11). The second calculation recorded environmental efficiency by scaling the emissions' data by output (Fig. 12). The analysis of the calculations looked at the changes in emissions from the time of the risk assessment changes (2010) to current practices (2012).

2.2 Economic Analysis

Economic data were analyzed as an indicator for economic risk in terms of the company's cost. Three calculations were conducted in order to provide multiple economic indicators in terms of risk. The first two indicators were calculated through average product analyses in order to determine economic efficiency. Economic efficiency was defined for the purpose of this study as a company's output in terms of their production and a company's input in terms of their capital or labor. The production and operating costs or labor of the company was then used in order to conduct two average product analyses for the years of 2008-2013 (Fig. 8). The third calculation determined BP's annual savings in terms of risk reduction (Fig. 9). The economic analyses assess data from both the U.S. entities of the company, and for the company as a whole in order to provide multiple comparisons of the company's cost associated with risk. Although the study is still focusing on a U.S. comparison, adding the total economic data allows for another dimension that may help to substantiate or compliment the U.S. findings.

The economic analyses were conducted from the years 2008-2013 in order to provide an accurate calculation of economic efficiency from before the risk assessment changes (2008-2010); through the risk assessment change (2010); to the most current practices (2010-2013). The database for the economic efficiency calculations could be expanded further than the environmental efficiency calculations due to availability of data. The data for the average product analyses and the savings analysis were extracted from BP's annual reports for the years 2008-2013 (Fig. 10). Specific numbers that were documented were BP's sales and operating revenues, profit (loss) for the year, operating costs, profit (loss) for the year attributed to BP shareholders, capital expenditures and acquisitions, total number of employees, production (barrels of oil), production ($ft.^3$ of natural gas), total production (MBOED), production ($ million), and EHS fines and penalties (Table 11).

Once all of the data were compiled for each year, each average product analysis (Fig. 8) was calculated in order to determine the trend of the economic efficiency for BP from 2008 to 2013. Average Product Analysis 1 used the company's production, which was the total amount of barrels of oil and natural gas per year, and divided it by the total operating costs for the same year. Average Product Analysis 2 also used the company's total production for the year but divided it by the total labor, or employees, for the same year. By using two different approaches to the average product analysis, the data are able to show a clearer picture of the economic efficiency because more than one calculation of economic efficiency can be analyzed and compared.

The savings analysis was also calculated in order to compare the dollar amount saved by the company when a new risk assessment strategy was put in place in 2010. By focusing the savings strictly on costs associated with risk, the data are able to show the money spent due to risks. In order to calculate the savings analysis, EHS fines and penalties were subtracted from the total production ($ million) (Fig. 9). By targeting specific costs (EHS fines and penalties), the saving analysis will only measure costs the company faced from risk assessment problems.

By compiling data that relates specifically to risk assessment, and comparing both of the economic analyses and the savings analysis, it is possible to see trends of the company that relate to the change in risk assessment strategies.

3. RESULTS

3.1 Environmental Analysis

The graph of emissions shows the total of each gas type from twenty-four petroleum/natural gas and refinery sites in the U.S. (Fig. 11). This graph records the metric tons CO_2, CH_4, and N_2O per year. The data indicate that CO_2 levels are the highest with emissions around nineteen million, and steadily increase over the three-year period. CH_4 levels follow a similar pattern as CO_2, increasing steadily over the three years, with levels peaking at about 150,000 metric tons. N_2O levels decreased slightly, with levels consistently around 2,400 metric tons.

As stated earlier, emissions levels were used as a consistent indicator of the company's environmental risk. Therefore, in order to record environmental efficiency, the data from the emissions levels were scaled by output. The environmental analysis was calculated by dividing total emissions by the production in the U.S. (Fig. 13). The CO_2 and CH_4 analyses showed a steady increase throughout the three-year period. The N_2O analysis was consistent in its levels, with a slight increase over the three years.

3.2 Economic Analysis

Average Product Analysis 1 showed the data from the calculation of production divided by operating costs for the years 2008-2013 in total and U.S. specifically (Table 12). The calculations showed two distinct sets of declines in economic efficiency around 2010 for BP, both in total and in the U.S. (Fig. 13). The economic efficiency increased from the years 2011-2012 for the U.S., and then showed another decrease from

2012-2013. However, in total, the economic efficiency stayed consistently low from 2010-2013.

The Average Product Analysis 2 graph showed another economic analysis that still uses the company's production, but looked at labor instead of capital (Fig 14). The calculation was conducted by dividing the production by the number of employees (Table 13). Both in total and U.S. trends followed the same pattern in this analysis. In 2009, the economic efficiency dropped dramatically, and sharply increased from 2010-2011 until it steadied in 2012, forming a V-shaped pattern.

In order to calculate the company's savings from the time before (2008-2010) and after (2010-2013) adapting a different risk assessment a calculation was made where risk costs were subtracted from production (Table 14). The savings analysis graph showed the trend in savings that are attributable to risk costs from the years 2008-2013 (Fig. 15). The data showed that the company's savings dropped heavily from 2008 to late 2010. The savings started to rise again from mid 2010, and have continued to rise through 2013.

4. SUMMARY AND CONCLUSIONS

4.1 Summary of Results

Overall, the data compiled and the calculations conducted in this study lead to five analyses. Two of the analyses add to the information pertaining to the environmental efficiency, and three of the analyses add to information about the economic efficiency of the company. These analyses give information that help to make conclusions about the economic and environmental efficiency of BP attributable to risk assessment and management changes. The environmental efficiency is measured from the time of the risk assessment changes in 2010 to current emissions in 2012, and the economic efficiency was measured from before the risk assessment changes occurred in 2008 through the changes in 2010 to current practices in 2013.

The emissions data (Fig. 11) give accurate data about the emissions levels for the twenty-four BP petroleum/natural gas and refineries in the U.S. The total emissions/production (Fig. 12) data allows for the emissions data to be scaled by the output of the company. The average product analyses (Fig. 13 & 14) help draw conclusions about the economic efficiency of BP, both in the U.S. and for the company as a whole. Finally, the savings analysis (Fig. 15) adds to the economic analysis by showing how much the company was able to save from before the *Deepwater Horizon* spill through 2013.

The first environmental analysis (Fig. 11) patterns of emissions levels show an overall consistent increase per site over the years 2010-2012. Emissions levels scaled by production have also consistently increased per site over the three-year period (Fig. 12).

When concentrating on the economic analyses, the data from the Average Product Analysis 1 (Fig. 13), which scales the data by operating costs, show a drop in economic efficiency around the time of the *Deepwater Horizon* oil spill. After the spill, the company is able to increase its economic efficiency quite quickly from 2011-2012 in the U.S., but it drops again from 2012-2013. The company as a whole has a drop in economic efficiency from the years 2009-2010 and was not able to increase its economic efficiency through 2013.

When Average Product Analysis 2 is scaled by labor (Fig. 14), the economic efficiency follows a similar pattern for both the U.S. and for the company as a whole. Average Product Analysis 2 shows a significant drop in economic efficiency during the *Deepwater Horizon* oil spill with a quick increase in the years following the spill. The economic efficiency stabilizes in 2011, and remains constant. Finally, the savings analysis (Fig. 15) shows a significant drop in savings associated with risk from the year 2008 until the time of the *Deepwater Horizon* spill. The company savings associated with risk increased in 2010 and has continued to increase through the current years.

4.2 Conclusions

In order to determine overall conclusions for the analyses conducted in this study, it is important to determine what the analyses are representing. From records compiled from trial evidence of the *Deepwater Horizon* oil spill, it can be concluded that BP adopted new risk management approaches that fit a broadened risk assessment model. The application of new risk management practices was put in place after the 2010 *Deepwater Horizon* spill in order to develop "broader systematic responses and recommendations associated with possible broader industry issues" (M. Bly, 2010). This is important because BP is part of a "wicked industry." Wicked industries deal with broader risks, and therefore, need to use broadened risk management assessment strategies.

Although the *Deepwater Horizon* spill was an important trigger for the change of risk assessment strategies within BP, the emissions data and company costs associated with risk are a more consistent indicator of environmental and economic efficiency. The emissions and economic data were compiled in order to determine if the environmental and economic efficiencies improved once BP adopted new broadened risk management and assessment strategies. Therefore, by looking at the environmental and economic data analyses for the years before and after the *Deepwater Horizon* oil spill, the study can draw conclusions that show how the company reacted, environmentally and economically, with the new broadened risk management and assessment strategies that focus more on the wicked problems.

When focusing on the environmental efficiency, BP's emissions levels increased overall. Therefore, when all of the analyses for environmental efficiency are compared, a conclusion is drawn that the BP has not been able to lower emissions levels even with a change in risk assessment. These results may be due to a number of different factors that could effect emissions. First, differences in state regulations may affect emissions levels per site. Also, sites may be monitored and measured differently which could have an effect on emissions levels. Another factor may be due to the inability for the risk assessment to have permeated to the local level, which is the level that emissions are recorded at within BP. Finally, fluctuations within BP's business activity and assets could also affect emissions levels.

The economic efficiency analyses were able to show a bit more information because data were available for a larger interval of time. BP showed a drastic decrease in economic efficiency around the time of the *Deepwater Horizon* oil spill. The company also showed improvement in economic efficiency in the years following the accident.

When scaling the analysis by operating costs, the company as a whole was not able to increase its efficiency (Fig. 13). Although the broadened risk management and assessment strategies were applied both to the company as a whole and in the U.S., the U.S. was able to improve after the introduction of the new broadened risk management and assessment strategies (Fig. 13). However, the economic efficiency in the U.S. decreased again in more current years. The fluctuations in the economic efficiency when scaled by operating costs could be due to the large changes in the operations associated with BP's structure. With the change of BP's risk assessment strategies, it may take more time to see these implementations through data.

When the analysis was scaled by labor, BP shows again the expected pattern of decrease during the years of the *Deepwater Horizon* spill. However, BP was able to quickly increase its economic efficiency after the years of the spill, both for the company as a whole and in the U.S. (Fig. 14). Both economic efficiency analyses, scaled by labor and by operating costs, show that BP decreased in economic efficiency in 2010 during the *Deepwater Horizon* spill, but the introduction of the new, broadened risk management and assessment strategies may have helped the company to increase its economic efficiency in the years following the accident, and may have continued to improve its economic efficiency in the current years.

Finally, the savings analysis helps to show an overall company pattern of savings associated with risk from years 2008-2010, before the *Deepwater Horizon* oil spill, until 2013. This analysis showed that BP had large savings declines from years 2008-2010. BP hit an all time low with savings attributed to risk in 2010 (Fig. 15), but after the implementation of the broadened risk management and assessment strategies, the company has experienced a consistent increase in savings from 2010 through 2013. By comparing all of the analyses for economic efficiency, the study shows that BP was able to increase overall in economic efficiency after the introduction of new broadened risk management and assessment strategies.

4.3 Future Research

There are many studies that could be done in the future in order to contribute to this type of research. The most obvious would be to continue the data collection for this company as more data become available. These patterns that have been developed only measure three years after the main accident in BP. With environmental cases, trials can proceed far in to the future. Even in 2014 there have been new rulings on the 2010 *Deepwater Horizon* spill that have found the company to be 'grossly negligent', which may increase the amount of money paid in civil penalties (BBC, 2014). Therefore, if the data were collected for the next few years, more patterns may emerge that would continue to add to the understanding of the effectiveness of a broadened risk assessment.

It may be of benefit to look into other oil and gas companies in order to determine where these broadened practices are being used, and see why they are not being adopted more frequently if, in fact, that is the case. This study has shown that broadened risk assessment strategies may be helping to improve BP, both environmentally and economically, but it is still in need of further research to determine if the adoption of these practices is beneficial.

Finally, it would also be interesting to assess a broadened risk assessment with different sectors of the energy industry. This study was conducted as a tool to understand the effectiveness of a broadened risk assessment on a specific energy sector. By looking at other sectors in the energy industry, the toolbox can continue to grow and add to the knowledge of the environmental and economic impacts of using broadened risk management and assessment strategies to address wicked problems.

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APPENDIX A

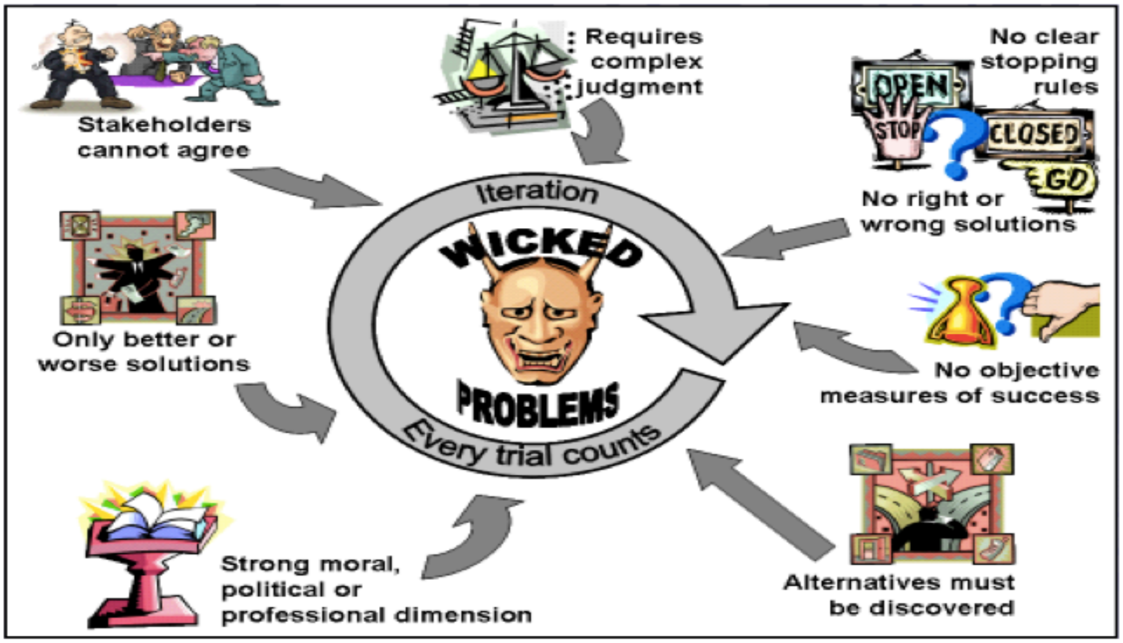

Figure 1. Key Characteristics of Wicked Problems (Finegan, 2010)

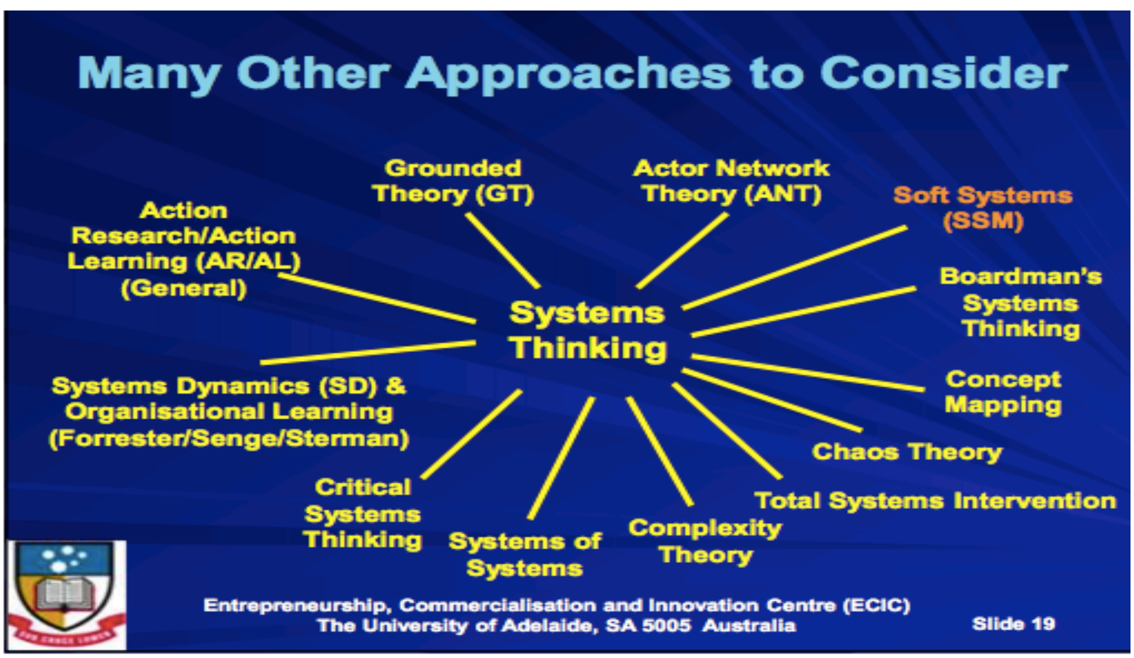

Figure 2. Systems Thinking Approach (Finegan, 2010)

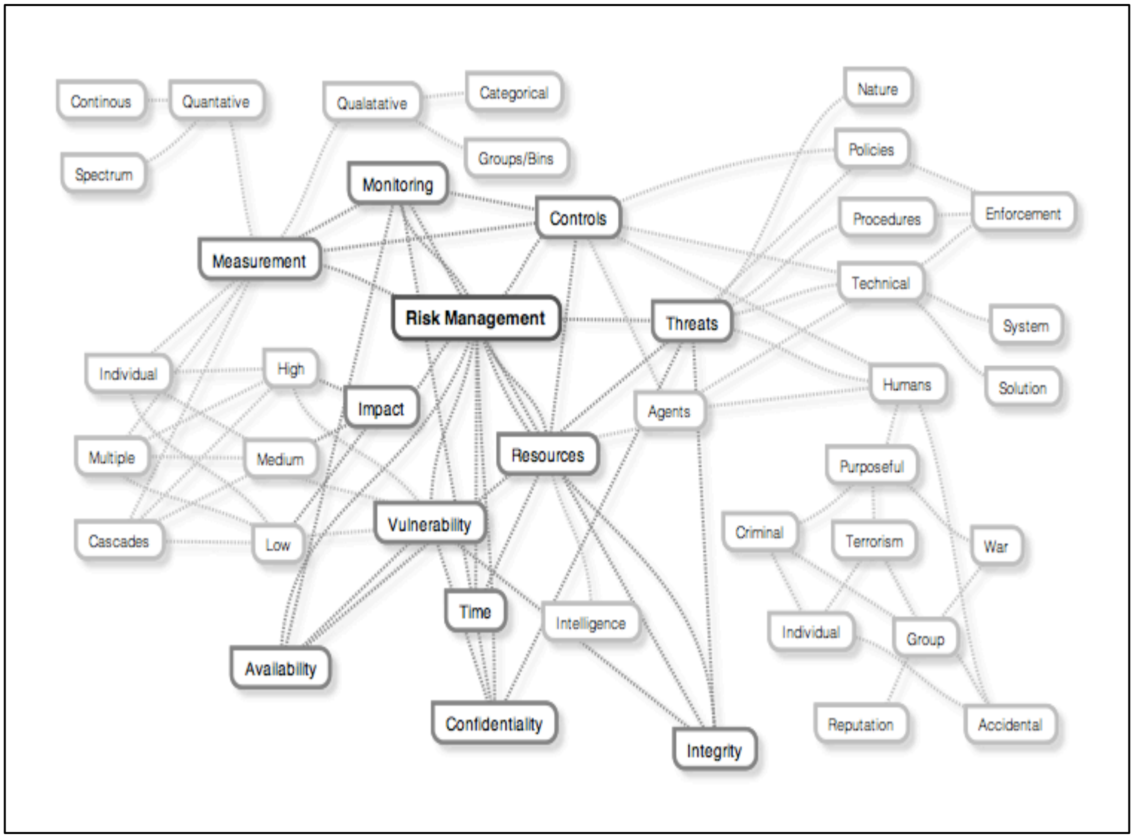

Figure 3. Concept Map (Liles, 2011)

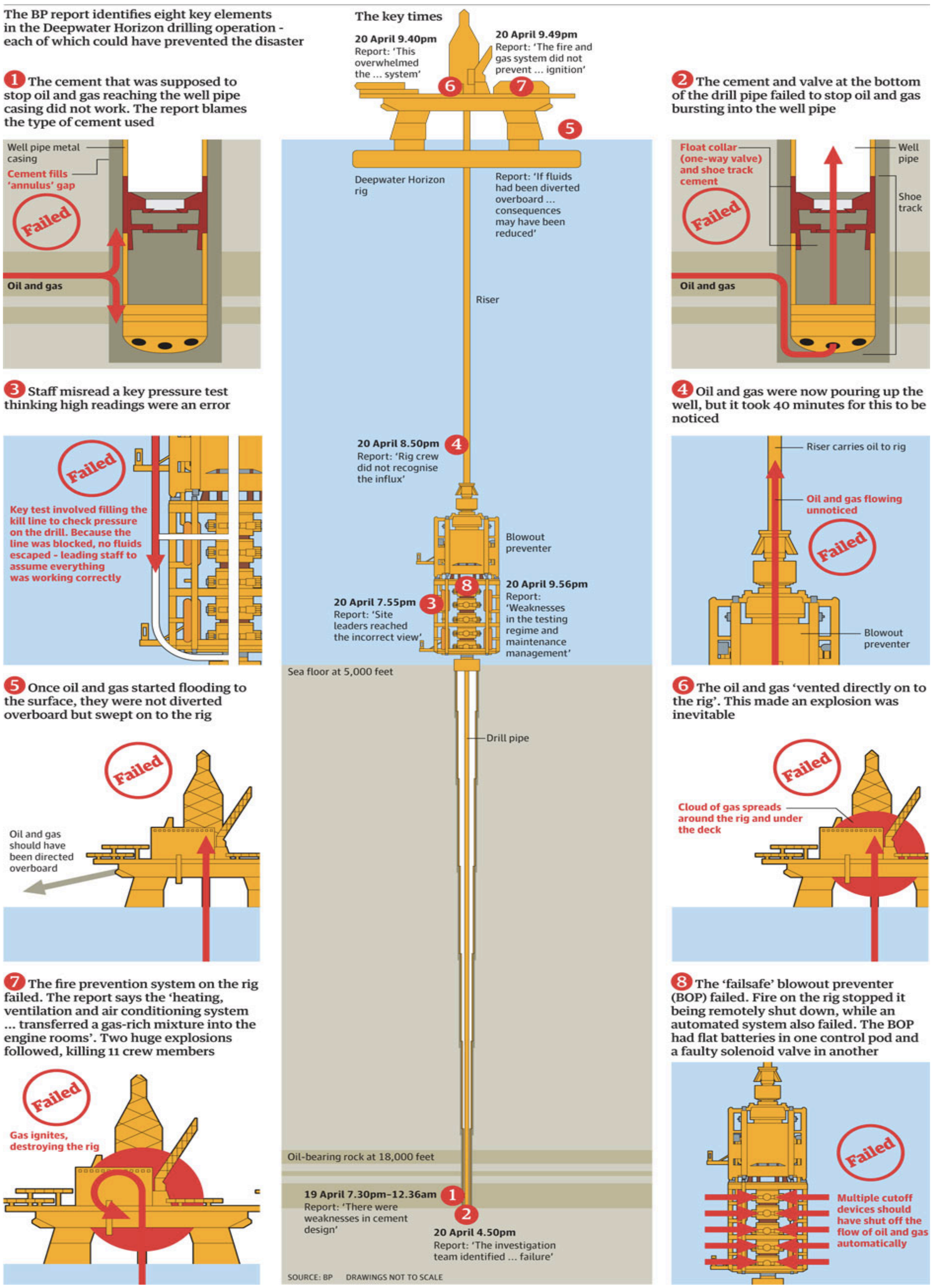

Figure 4. 8 Key Elements of the Deepwater Horizon Spill (Rogers, 2010)

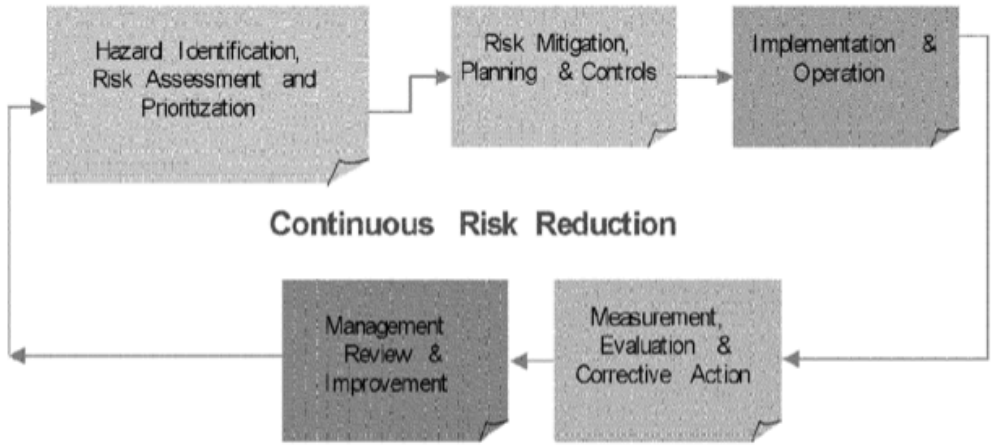

Figure 5. GOM Risk Management System (SPAIntegrityManagement, 2007)

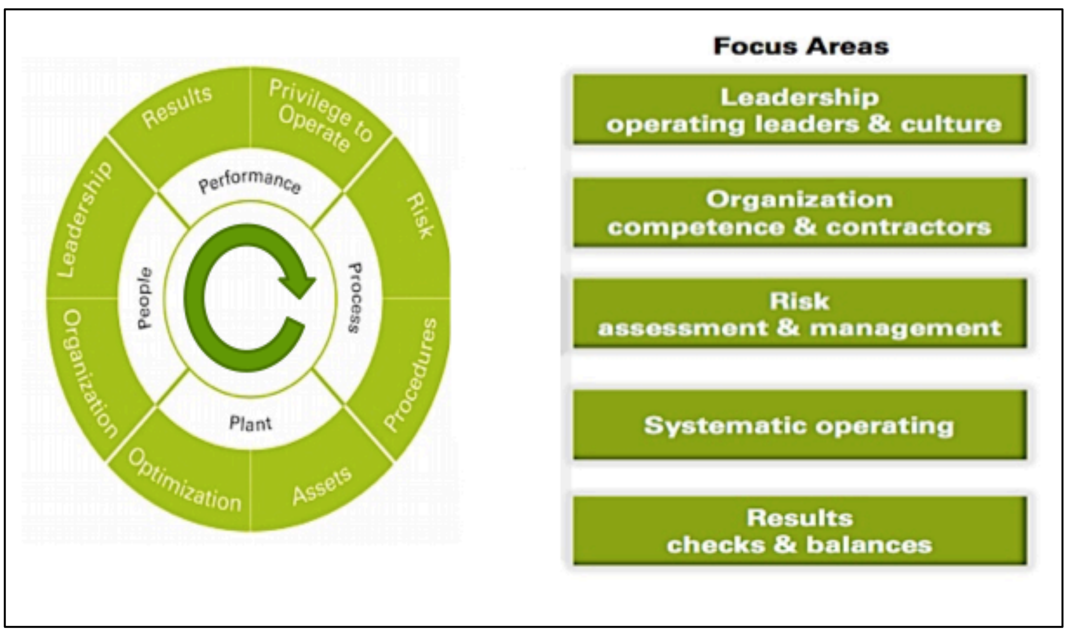

Figure 6. S&OR Update: Continual Risk Management (Mark Bly, 2011)

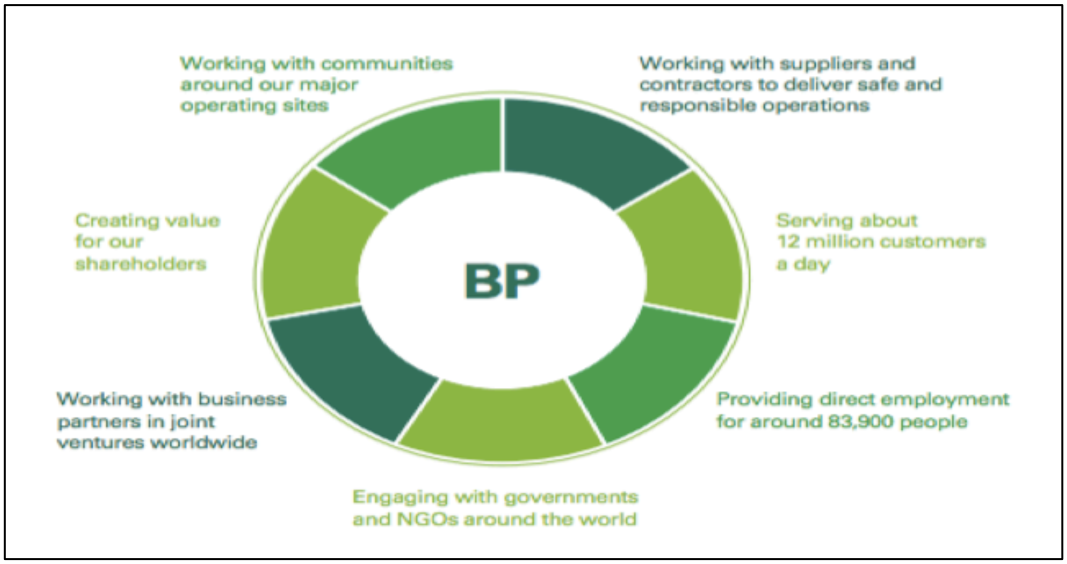

Figure 7. Expanded Stakeholder Focus (BP, 2013b)

$$\textbf{Average Product Analysis 1} = \frac{\text{Production (MBOED)}}{\text{Operating Costs (\$ million)}}$$

$$\textbf{Average Product Analysis 2} = \frac{\text{Production (MBOED)}}{\text{Labor (\# of employees)}}$$

Figure 8. Average Product Analyses 1 & 2

$$\textbf{Savings Analysis} = \text{Production (\$ million)} - \text{EHS fines and penalties}$$

Figure 9. Savings Analysis

Index of Data

All data recovered from BP's Annual Report from the years 2008-2013.
http://www.bp.com/en/global/corporate/investors/annual-reporting/archive.html

- **Sales and operating revenues**- found in BP income statement data
  - Page Numbers/Document:
    - US
      - Pg. 201 (2013)/ 2013 Annual Report
      - Pg. 203 (2012)/ 2013 Annual Report
      - Pg. 205 (2011)/ 2013 Annual Report
      - Pg. 263 (2010)/ 2012 Annual Report
      - Pg. 231 (2009)/ 2010 Annual Report
      - Pg. 233 (2008)/ 2010 Annual Report
    - Total
      - Pg. 236 (2010-2013)/ 2013 Annual Report
      - Pg. 146 (2009-2008)/ 2010 Annual Report
- **Profit (loss) for the year**- found in BP income statement data
  - Page Numbers/Document:
    - US
      - Pg. 201 (2013)/ 2013 Annual Report
      - Pg. 203 (2012)/ 2013 Annual Report
      - Pg. 205 (2011)/ 2013 Annual Report
      - Pg. 263 (2010)/ 2012 Annual Report
      - Pg. 231 (2009)/ 2010 Annual Report
      - Pg. 233 (2008)/ 2010 Annual Report
    - Total
      - Pg. 236 (2010-2013)/ 2013 Annual Report
      - Pg. 146 (2009-2008)/ 2010 Annual Report
- **Profit (loss) for the year attributable to BP shareholders**- found in BP income statement data
  - Page Numbers/Document:
    - US
      - Not found
    - Total
      - Pg. 236 (2010-2013)/ 2013 Annual Report
- **Capital expenditures and acquisitions** found in BP income statement data
  - Page Numbers/Document
    - US
      - Pg. 153 (2013)/ 2013 Annual Report
      - Pg. 153 (2012)/ 2013 Annual Report
      - Pg. 154 (2011)/ 2013 Annual Report
      - Pg. 207(2010)/ 2012 Annual Report

Figure 10. Index of Data

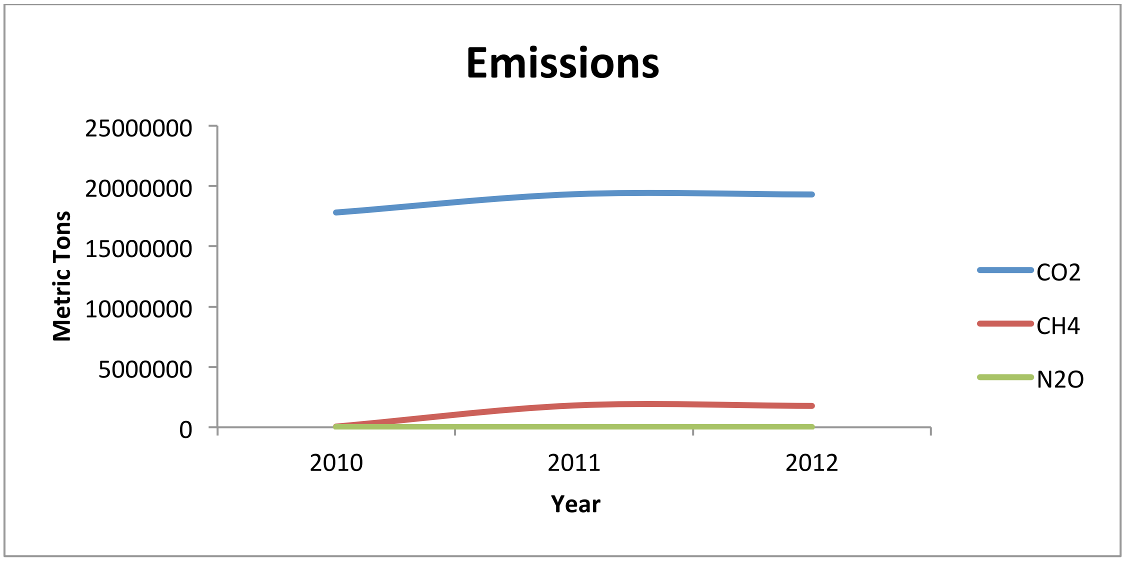

Figure 11. Total Emissions in US Graph

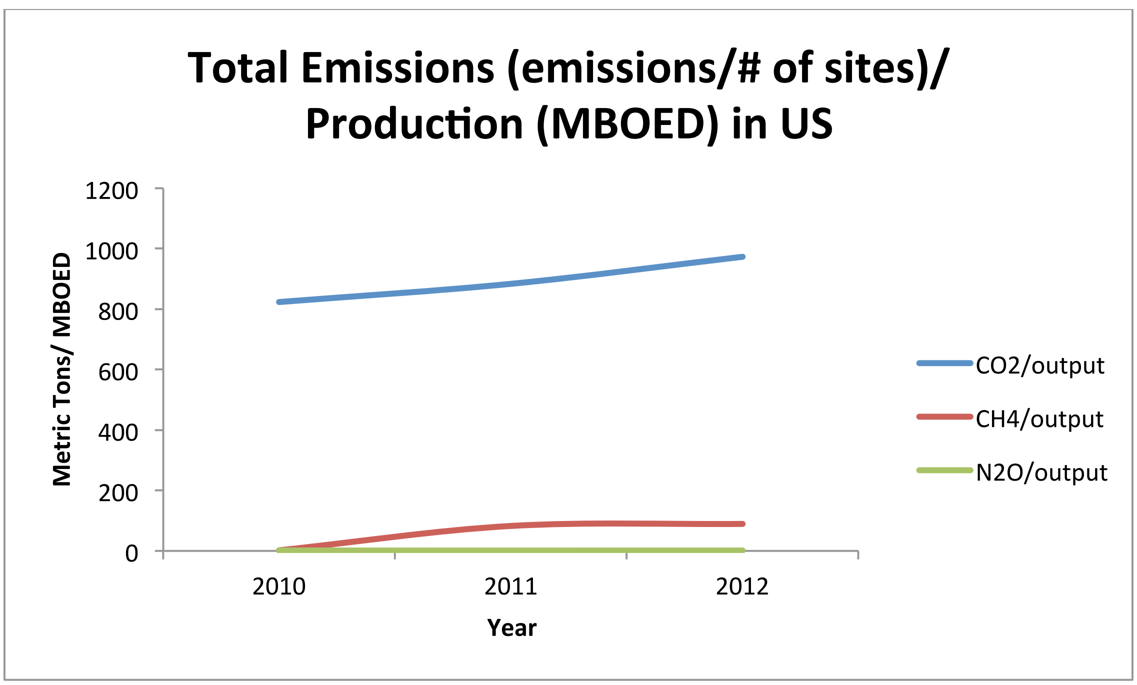

Figure 12. Total Emissions in US/Production

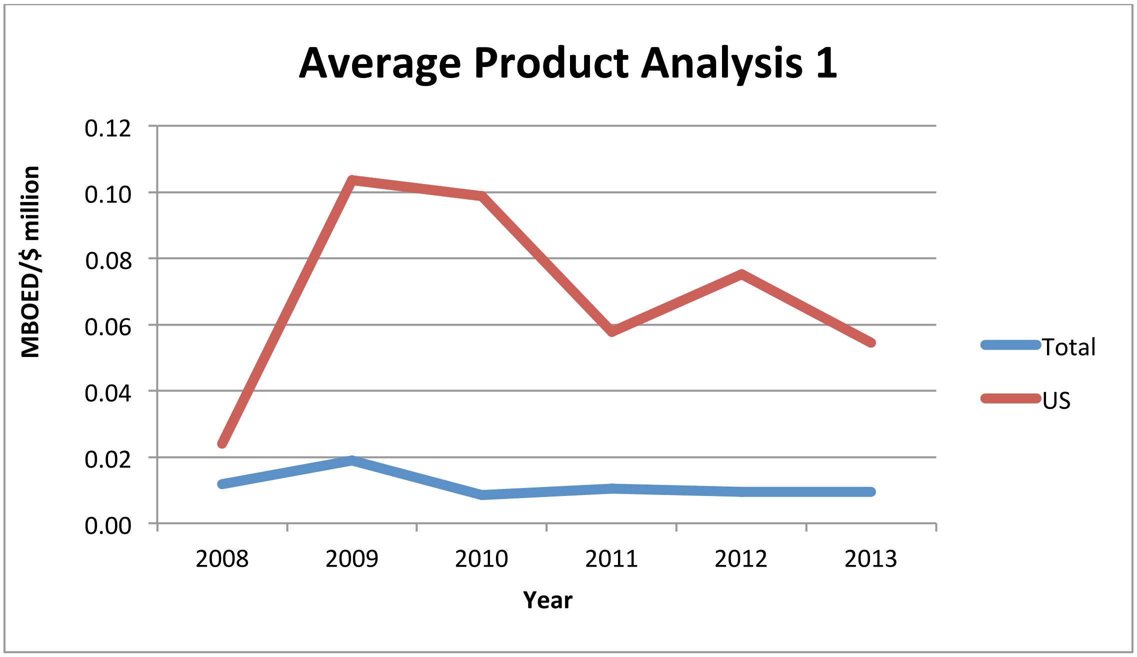

Figure 13. Average Product Analysis 1 Graph

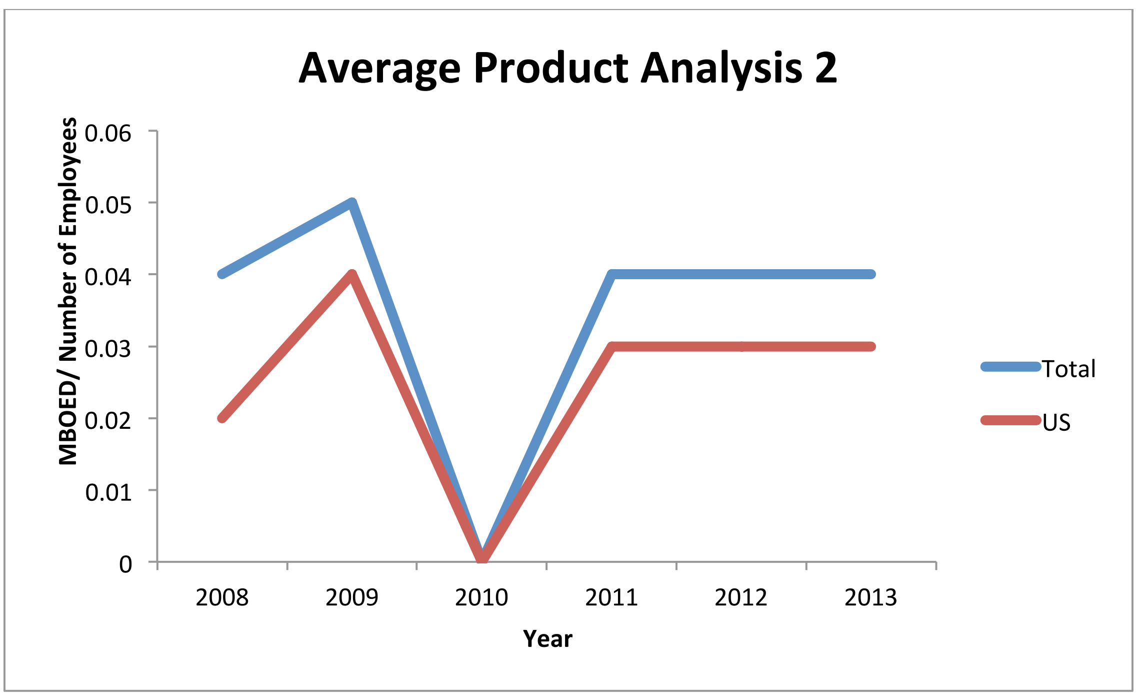

Figure 14. Average Product Analysis 2 Graph

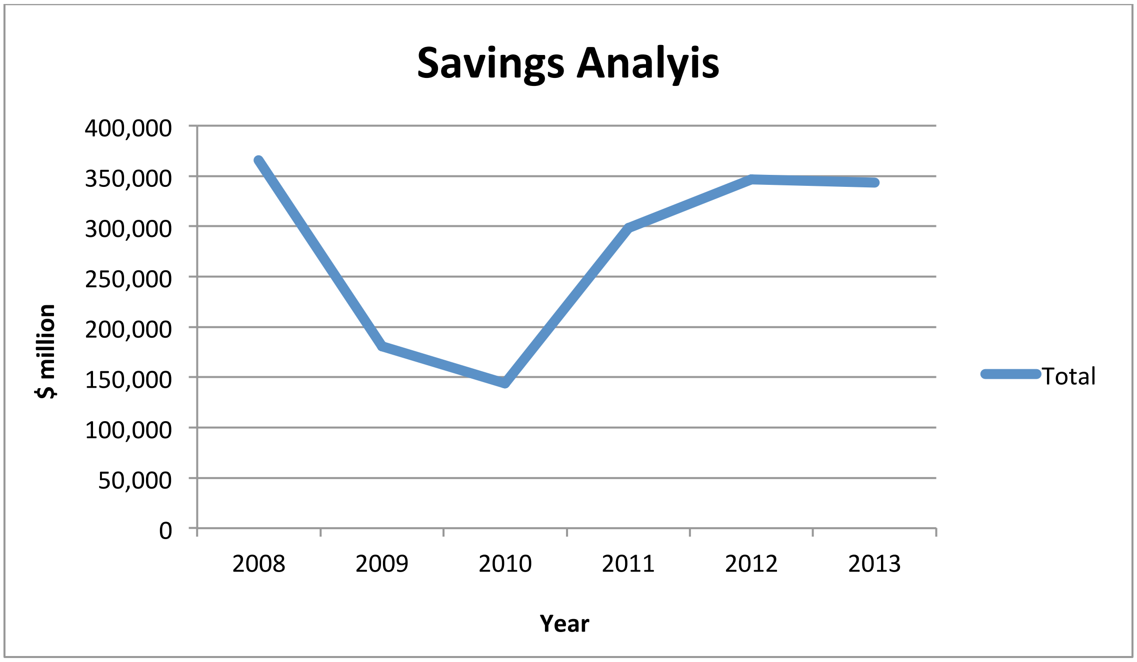

Figure 15. Savings Analysis Graph

APPENDIX B

Table 1. Traditional Risk Areas (D. Hancock & Holt, 2003)

	Organization	Project	Team	Personal
Financial	*Currency or interest fluctuation*	*Client budget changes*	*Underestimate consumables*	*Salary/benefits*
Physical	*Poor offices weaken public image*	*Untidy site*	*Team split between site and office*	*Health*
Technical	*Errant auditing system*	*Lack of modular, pre-assembly suppliers*	*Faulty machinery*	*Failure to link competencies with tasks*

Table 2. Wicked Risk Areas (D. Hancock & Holt, 2003)

	Organization	Project	Team	Personal
Cultural	*Conflicting strategic aims within joint venture*	*Personnel within organizational 'silos'*	*Multi-tasking team with differing competencies*	*Impact of work upon family*
Social	*Electoral change*	*Protestor and/or security sensitivity*	*Accountability to other teams*	*Aligning activity with personal ethics*
Temporal	*New technology speeding up industry 'clockspeed'*	*Unspecified client need meaning unclear critical path*	*Unrealistic project 'milestones'*	*How activity promotes/hinders career path*
Environmental	*Exhaustion of non-renewable raw material*	*Contaminated site*	*Pollution requires use of unfamiliar protective gear*	*Exposure to hazards*

Table 3. Summary of Tame and Wicked Problems (Batie, 2008)

Characteristic	Tame Problem	Wicked Problem
1. The problem	The clear definition of the problem also unveils the solution *** The outcome is true of false, successful or unsuccessful *** The problem does not change over time	No agreement exists about what the problem is. Each attempt to create a solution changes the problem *** The solution is not true or false—the end is assessed as "better" or "worse" or "good enough" *** The problem changes over time
2. The role of stakeholders	The causes of a problem are determined primarily by experts using scientific data	Many stakeholders are likely to have differing ideas about what the "real" problem is and what its causes are
3. The "stopping rule"	The task is completed when the problem is solved	The end is accompanied by stakeholders, political forces, and resource availability. There is no definitive solution
4. Nature of the problem	Scientific based protocols guide the choice of solution(s) *** The problem is associated with low uncertainty as to system components and outcomes *** There are shared values as to the desirability of the outcomes	Solution(s) to problem is (are) based on "judgments" of multiple stakeholders *** The problem is associated with high uncertainty as to system components and outcomes *** There are not shared values with respect to societal goals

Table 4. How BP's Risk Assessment Changes Are Associated with Wicked Problems

Risk Assessment Change Made by BP	Wicked Problem Associated with Risk Assessment Change	How Risk Assessment Change Addresses Associated Wicked Problem
Implementation of S&OR Team	1. Constantly changing	Promotes adaptability by assigning experts to monitor need for change
	2. Impossible to fully define the problem	
Enhancement of Education Structure	1. Multiple stakeholders with differing opinions	Addresses differing opinions by training multiple stakeholders together
Implementation of Recommendations from Bly Report	1. Multiple shareholders	New training programs that involve the participation of multiple shareholder input, and work to improve communication between shareholders
	2. Never stops being a problem	Continuous reviews and audits to address effectiveness, consistency, and rigor of risk management
	3. Complex	Improves the qualifications of personnel dealing with complexities

Table 5. 2010 BP U.S. Emissions Data

2010						
		Emissions By Gas				
Site	Location (State)	Carbon Dioxide (CO2)	Methane (CH4)	Nitrous Oxide (N2O)	Total Emissions	
BPXA Seawater Treatment Plant	Alaska	142792	56	83	142931	
BPXA Seawater Injection Plant	Alaska	175786	70	103	175959	
BPXA Northstar Prod Facility	Alaska	329324	134	202	329660	
BPXA Lisburne Production Center	Alaska	507916	201	297	508414	
BPXA Gathering Center #3	Alaska	303056	120	177	303353	
BPXA Gathering Center #2	Alaska	396700	157	232	397089	
BPXA Gathering Center #1	Alaska	429524	170	251	429945	
BPXA Flow Station #3	Alaska	560451	222	328	561001	
BPXA Flow Station #2	Alaska	420086	166	246	420498	
BPXA Flow Station #1	Alaska	417242	165	244	417651	
BPXA Endicott Production Facility	Alaska	559800	222	328	560350	
BPXA Crude Oil Topping Unit, Prudhoe Bay Operations Center, Tarmac Camp	Alaska	48384	167	38	48589	
BPXA Central Power Station	Alaska	673369	267	394	674030	
BPXA Central Gas Facility	Alaska	1651922	654	966	1653542	
BPXA Central Compressor Plant	Alaska	2400854	951	1405	2403210	
BPE GPRP Grasslands Gas Plant	North Dakota	49691	20	29	49740	
BPE CS Prairie Dog Booster	Wyoming	27027	11	16	27054	
BP Whiting Business Unit	Indiana	4685645	20381	9987	4716013	
BP Husky Refining LLC	Ohio	1278424	7164	3470	1289058	
BP Cherry Point Refinery	Washington	2519247	10059	7430	2536736	
BP American Production Company Pascagoula Plant and Destin Pascagoula Compressor Station	Mississippi	48615	19	29	48663	
		17625855	41376	26255	17693486	Overall Totals

Table 6. 2011 BP U.S. Emissions Data

2011						
		Emissions By Gas				
Site	Location (State)	Carbon Dioxide (CO2)	Methane (CH4)	Nitrous Oxide (N2O)	Total Emissions	
BPXA Seawater Treatment Plant	Alaska	129240	46	68	129354	
BPXA Seawater Injection Plant	Alaska	159317	56	84	159457	
BPXA Northstar Prod Facility	Alaska	364199	6159	222	370580	
BPXA Lisburne Production Center	Alaska	692037	17293	372	709702	
BPXA Gathering Center #3	Alaska	276500	110	162	276772	
BPXA Gathering Center #2	Alaska	383763	152	224	384139	
BPXA Gathering Center #1	Alaska	480799	190	281	481270	
BPXA Flow Station #3	Alaska	545322	194	286	545802	
BPXA Flow Station #2	Alaska	471158	165	244	471567	
BPXA Flow Station #1	Alaska	476506	168	248	476922	
BPXA Endicott Production Facility	Alaska	609289	9938	306	619533	
BPXA Crude Oil Topping Unit, Prudhoe Bay Operations Center, Tarmac Camp	Alaska	29327	168	28	29523	
BPXA Central Power Station	Alaska	779786	277	409	780472	
BPXA Central Gas Facility	Alaska	1894858	22068	1007	1917933	
BPXA Central Compressor Plant	Alaska	2722859	24029	1430	2748318	
BPE GPRP Grasslands Gas Plant	North Dakota	77363	19088	34	96485	
BPE CS Prairie Dog Booster	Wyoming	19761	8	11	19780	
BP Whiting Business Unit	Indiana	4659270	20001	9699	4688970	
BP Husky Refining LLC	Ohio	1321307	7232	3670	1332209	
BP Cherry Point Refinery	Washington	2414749	7857	5192	2427798	
BP American Production Company Pascagoula Plant and Destin Pascagoula Compressor Station	Mississippi	37256	1763	24	39043	
		18544666	136962	24001	18705629	Overall Totals

Table 7. 2012 BP U.S. Emissions Data

2012						
		Emissions By Gas				
Site	Location (State)	Carbon Dioxide (CO2)	Methane (CH4)	Nitrous Oxide (N2O)	Total Emissions	
BPXA Seawater Treatment Plant	Alaska	175218	62	93	175373	
BPXA Seawater Injection Plant	Alaska	217529	77	115	217721	
BPXA Northstar Prod Facility	Alaska	342415	14142	213	356770	
BPXA Lisburne Production Center	Alaska	691129	17020	373	708522	
BPXA Gathering Center #3	Alaska	300651	119	177	300947	
BPXA Gathering Center #2	Alaska	416408	165	245	416818	
BPXA Gathering Center #1	Alaska	415373	164	242	415779	
BPXA Flow Station #3	Alaska	601719	214	316	602249	
BPXA Flow Station #2	Alaska	494022	173	258	494453	
BPXA Flow Station #1	Alaska	439318	155	233	439706	
BPXA Endicott Production Facility	Alaska	673568	10479	339	684386	
BPXA Crude Oil Topping Unit, Prudhoe Bay Operations Center, Tarmac Camp	Alaska	27847	143	27	28017	
BPXA Central Power Station	Alaska	821717	291	428	822436	
BPXA Central Gas Facility	Alaska	1936211	22252	1026	1959489	
BPXA Central Compressor Plant	Alaska	2618173	23406	1377	2642956	
BPE GPRP Grasslands Gas Plant	North Dakota	81398	12956	34	94388	
BPE CS Prairie Dog Booster	Wyoming	16545	7	10	16562	
BP Whiting Business Unit	Indiana	4732195	22003	10358	4764556	
BP Husky Refining LLC	Ohio	1341008	6721	3440	1351169	
BP Cherry Point Refinery	Washington	2203241	13079	4896	2221216	
BP American Production Company Pascagoula Plant and Destin Pascagoula Compressor Station	Mississippi	37278	10628	22	47928	
		18582963	154256	24222	18761441	Overall Totals

Table 8. Total Emissions/Year

		Emissions			
		Carbon Dioxide (CO2)	Methane (CH4)	Nitrous Oxide (N2O)	Total Emissions
Year	2010	17625855	41376	26255	17693486
	2011	18544666	136962	24001	18705629
	2012	18582963	154256	24222	18761441

Table 9. Total Production

	Total production (MBOED)			
	2,010	2,011	2,012	2,013
Total	2,535.0	3,496.0	3,373.0	3,270.0
US	983.0	781.0	684.0	637.0

Table 10. Total Emissions/Production in U.S.

		Total Emissions/Production (MBOED) in US		
		Carbon Dioxide (CO2)	Methane (CH4)	Nitrous Oxide (N2O)
Year	2010	17930.6765	42.09155646	26.70905392
	2011	23744.77081	175.3674776	30.73111396
	2012	27168.07456	225.5204678	38.02511774

Table 11. BP Economic Annual Report Data

	Sales and Operating Revenues ($ million)					
	2008	2009	2010	2011	2012	2013
Total	361,143	239,272	297,107	375,713	375,765	379,136
US	23,620	16,072	19,967	19,840	16,166	14,981

	Profit (loss) for the year ($ million)					
	2008	2009	2010	2011	2012	2013
Total	34,283	25,124	-3,702	39,815	19,769	31,769
US	1,214	5,937	10,004	6,343	7,075	3,312

	Operating Costs					
	2008	2009	2010	2011	2012	2013
Total	0	0	0	0	0	0
US	326,860	214,148	300,809	335,898	355,996	347,367

	Profit (loss) for the year attributable to BP shareholders ($million)					
	2008	2009	2010	2011	2012	2013
Total			-4,064	25,212	11,017	23,451
US						

	Capital expenditures and acquisitions ($ million)					
	2008	2009	2010	2011	2012	2013
Total	30,700	20,309	23,016	31,959	25,204	36,612
US	16,046	9,865	10,370	8,931	10,541	9,176

	Number of Employees					
	2008	2009	2010	2011	2012	2013
Total	92,000	80,300	79,700	84,100	86,400	83,900
US	29,300	29,800	22,100	22,900	23,400	19,600

	Total production (MBOED)					
	2008	2009	2010	2011	2012	2013
Total	3,885	4,046	2,535	3,496	3,373	3,270
US	538	1,049	983	781	684	637

	Production of barrels of oil (thousand barrels per day)					
	2008	2009	2010	2011	2012	2013
Total	2,401	2,535	1,229	2,157	2,056	2,013
US	538	665	594	453	390	363

	Production of natural gas (million cubic ft. per day)					
	2008	2009	2010	2011	2012	2013
Total	8,334	8,485	7,332	7,518	7,393	7,060
Total (converted to barrels of oil)	1,484	1,511	1,306	1,339	1,317	1,257
US	0	2,157	2,184	1,843	1,651	1,539
US (converted to barrels of oil)	0	384	389	328	294	274

	Environmental expenses ($ million)					
	2008	2009	2010	2011	2012	2013
Total	1,100	66,600	52,500	77,400	22,400	2,460
US						

	Price of oil/per barrel/year					
	2008	2009	2010	2011	2012	2013
Total (world basket price)	94.45	61.06	77.45	107.46	109.45	105.87

	Production (USD)					
	2008	2009	2010	2011	2012	2013
Total	366,938	247,049	196,336	375,680	369,175	346,195

Table 12. Average Product Analysis 1

	Average Product Analysis 1					
	2008	2009	2010	2011	2012	2013
Total	0.01	0.02	0.01	0.01	0.01	0.01
US	0.02	0.10	0.10	0.06	0.08	0.05

Table 13. Average Product Analysis 2

	Average Product Analysis 2					
	2008	2009	2010	2011	2012	2013
Total	0.04	0.05	0.03	0.04	0.04	0.04
U.S.	0.02	0.04	0.04	0.03	0.03	0.03

Table 14. Savings Analysis

	Savings Analysis ($ million)					
	2008	2009	2010	2011	2012	2013
Total	365,838	180,449	143,836	298,280	346,775	343,735