Factors Underlying Companies Response to Supply Chain Disruption: A Grounded Theory Approach

Patrapa Chadist

A thesis submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy in Management

Submitted to:

Cass Business School, City University

May 2012

Table of Contents

List of Figures

List of Tables

Acknowledgement

It would have not been possible to write this doctoral thesis without the help and support of the kind people around me.

First and foremost, I would like to express my deepest and sincere gratitude to my supervisor, Professor ManMohan Sodhi, for his exceptional guidance, time, encouragement, patience and continuous support. Without him, this thesis would not have been finalised. One could not wish for a more understanding, helpful and motivated supervisor.

I also would like to show my gratitude to Dr. Son, Byung-Gak for his advice along my PhD journey. It has been an honour to be his first Ph.D. student; my thanks also to Professor Gianvito Lanzolla and Professor Michael Bourlakis for their valuable recommendations.

In addition, I would like to thank "YOU" - all my friends and PhD colleagues - for your support in all different ways.

Finally, I would like to thank my wonderful family for their boundless support from afar and Rolf Huber for nearly unlimited patience and bountiful advice.

Abstract

A wide range of recent man-made and natural disasters has demonstrated the importance of managing disruption risk in global supply chains. This research argues that supply chain disruptions are, de facto, unavoidable and consequently all complex supply chains can be considered inherently risky. This research focuses on a relatively unexplored issue in supply chain risk management, asking and answering the question of how companies specifically use time to respond to catastrophic events of low probability but high impact. Linking faster response lead-time with reduced impact, the goal is to identify and explore the underlying factors of managing disruption risk by answering how companies respond to supply chain disruptions. In reducing total response time by detecting the event, designing solutions, and deploying a recovery plan sooner after a disruption, the company can reduce the impact of disruption risk.

The research uses Grounded Theory methodology to extend an emerging framework on time-based supply chain risk management. Empirical data is used from a range of sources including interviews and corporate publications from the events faced by global pharmaceutical manufacturer during a pandemic in 2009. The emerging categories of possible factors in response time are further developed using data from the events surrounding the worst maritime oil spill in history in 2010 under the management responsibility of the Exploration and Production (Upstream) division of a global energy company and from an industrial accident in 2005 in the Refining and Marketing division of the same firm.

The research identifies four categories of factors that companies can focus on to reduce response time in the face of catastrophic events of low probability and high impact: *organisational structure*, *preparation*, *partnership* and *reserve*. The research derives new insights, presented as four propositions that relate the response time in managing supply chain disruption to negative or potentially positive impact.

Chapter 1
Introduction

1.1 Research Background

Supply chain risk is the probability of incurring a loss within the supply chain that is related to the logistics activities in companies' flows of material and information (Ritchie & Brindley, 2007).

Although awareness is increasing among practitioners and researchers, the concepts of supply chain vulnerability and its managerial counterpart, supply chain risk management (SCRM), are still in their infancy (Christopher et al., 2002). A number of researchers suggest that supply chain exposure to risk has increased in recent decades due to higher demand, globalisation of markets, market saturation and increased competition as well as shorter product life cycles. AMR Research found that more than 42% of the surveyed companies managed more than five different supply chains in 2006, mainly due to the need to produce multiple products for multiple markets. These developments have led to higher exposure to risks in the supply chain of global firms (Christopher et al., 2002). Supply chains must adapt to these forces to stay competitive but at the same time will thereby increase their exposure to different forms of risk (Christopher et al., 2002; Faisal et al, 2006; Hallikas et al., 2002; Handfield & Nichols, 1999; Sodhi & Tang, 2009).

Initiatives in supply chain optimisation – such as minimising stock – can exacerbate the likelihood or impact of unanticipated events, for example, sharp increase in demand, production or supply-side failure. Moreover, mitigation strategies addressing one type of risk can have an adverse affect on another type of risk to the supply chain (Chopra & Sodhi, 2004). This suggests managers must find a balanced approach between their strategies for supply chain management and for supply chain risk management.

Failure to manage supply chain risks effectively can have a major impact on an organisation (Mitchell, 1995). The negative impact is not only from financial loss but also reduction in product quality, delivery delays, damage to property and equipment, and loss of reputation among customers, suppliers and the public

(Cousins et al., 2004). As Hendricks and Singhal (2003, 2005) documented, not only can the failure to manage supply chain risks effectively lead to a sharp drop in an organisation's share price, which can be slow to recover, it can also generate conflict amongst the organisation's stakeholders.

There are many unexpected and unpredictable disruptions in the last few years that highlight the vulnerability of supply chains. Ericsson lost GBP 240 Million in 2000 due to fire at a supplier's semiconductor plant in Albuquerque, New Mexico and the lack of alternative supply channels. Apple lost a significant number of orders following supply interruptions due to an earthquake in Taiwan in 1999. Land Rover laid off 1,400 workers after their supplier became insolvent in 2001. The longshoremen's strike in California in 2002, and the outbreak of SARS in 2003, and 'triple play' disaster of earthquake, tsunami and nuclear crisis in northern Japan in April 2011 are further examples of events that paralysed supply chain flows. The impacts of such disruptions can be catastrophic. Disruption is inherently difficult or impossible to predict, whether due to man-made causes such as terrorism (World Trade Center attack in 2011), military action (Kuwait in 1990) or natural events such as hurricane (Katrina, destroying New Orleans in 2005) and disease (UK foot and mouth disease in 2001 and 2007 and recently the H1N1 Influenza pandemic in 2009) and have the power to disrupt or cause uncertainty in supply chains (Elliott, 2005; Peck & Juttner, 2002).

A disruption to supplies in one country can quickly spread through an entire global supply chain (Harland et al., 2003). There is evidence that economic, political and social developments over the past decade appear to be increasing the risk of supply chain disruptions as supply chains are getting longer and more complex and are involving more partners due to the increase in global sourcing (Hendricks & Singhal, 2005). A case in point is the sharp increase in world oil prices as a consequence of the disruption of US oil production brought about by hurricane Katrina (Elliott, 2005). Supply chain disruption can potentially be very costly, and Rice and Caniato (2003) stated that the financial impact of a supply chain disruption is difficult to predict.

The importance of supply chain risk management has been recognised by organisations and researchers because of the short-term effects (negative publicity, low consumer confidence, loss in market share) and long-term effects (stock prices

and equity risk) (Sodhi & Tang, 2009; Hendricks & Singhal, 2005). Seeing risk as an important issue in the supply chain, Harland et al. (2004) recommend that supply chain risk management should focus on positioning the organisation to try to avoid such events and to develop strategies to manage the impact of them should avoidance not be possible. If the supply chain risks can be effectively and efficiently managed, considerable benefits can accrue not only to companies and their shareholders but also to their suppliers and their end customers.

1.2 The General Problem Area

The concept of supply chain risk management emerged in the early 1980s. Kraljic published one of the first articles in this field entitled 'Purchasing must become supply management' in 1983 (Paulsson, 2004). As the field supply chain risk management is even today still in the development stage, most literature focuses on explaining the importance of supply chain risk management, defining what supply chain risk is, what are the sources of supply chain risk and how to manage risk.

Notably, there is no unified theory or framework defined on how organisations can manage supply chain disruption risk. In a complex business environment, unfavourable surprises and unexpected events are not just an exception but have become the norm (Ansoff, 1975; Perrow, 1984). Nevertheless, recent studies have revealed a lack of implementation of supply chain risk management (Juttner, 2005; Mitroff & Alpaslan, 2003). Moreover, the literature on supply chain risk is quite limited due in part to ambiguous taxonomy. Many publications attempt to clarify the definition of relevant terms in the area of applied risk management and security (Craighead et al., 2007; Harland, Brenchley & Walker, 2003; Ritchie & Brindley, 2007).

In the past several years, researchers have developed a number of different models to manage supply chain risks (Christopher, 2002; Chopra & Sodhi, 2004; Lee, 2004; Sheffi, 2005; and Tang, 2006), using a range of ideas and techniques to identify, analyse and mitigate the effects of disruption. Focus on risk has led to suggest a new approach to supply chain strategy which goes beyond, for example, cost reduction and time-based competition, to address product characteristics, production and distribution strategies, and a partnership approach to suppliers and customers (Chopra & Sodhi, 2004; Tang, 2006a). These strategies can be more

effective, and executed with lower negative impact, when deployed using time focussed risk management. This also suggests that early warning before an event, or the escalation of a disruption, can contribute to a more effective handling of catastrophic events.

1.3 Aim of the Research

Overall the goal is to contribute to theory building of supply chain risk management resulting in a framework and propositions for further study. Using a risk framework and the outcome of the research, the aim is to support general theory and specifically prescribe an approach to management of risk that explicitly incorporates the role of time. This could serve as the basis for further field validation and can also be assessed for the impact on theory building in related fields of supply chain risk management.

The specific goal is to understand companies' response to disruption. I seek to analyse, outline and categorise possible factors that underlie response. These are summarised as a set of propositions for further study, which can explore and validate specific drivers of event detection and response.

1.4 Potential Contribution

The contribution of this study is in providing a deeper understanding of the factors that organisations can manage to reduce the impact of disruption risk. By explicitly addressing the role of time reducing the impact of disruption, this contributes to the development of an integrated framework of supply chain risk management incorporating total supply chain cost, time and risk.

This research also adds to the existing literature on supply chain risk management by empirically exploring the ways in which the components of time create value for managing supply chain risk based on time-based risk management concept.

1.5 Structure of the Report

Chapter 1 – provides background information regarding supply chain risk management in order to set the scene for the study and gives an overview of the thesis.

Chapter 2 – presents an overview of relevant research on risk and risk management, business continuity, crisis management, risk and supply chain management, time-based management and theoretical approaches behind the research. The chapter aims to review the emerging knowledge of supply chain risk management and supply chain disruption to identify a research gap to be addressed by this study. Finally, the research gap, research questions and emerging conceptual framework on time-based risk management (Sodhi & Tang, 2009) are addressed. The framework is used to argue that if a firm can shorten its response time by deploying a recovery plan soon after a disruption, the firm can reduce the impact of the disruption by way of faster recovery. The time-based framework provides the structure and a lens with which to organize the data analysis, consistent with the methodology described in the next chapter.

Chapter 3 – provides an overview of the relevant research methodology for this study, Grounded Theory, along with perspectives in the literature in its evolution and options in application. This methodology is well suited for qualitative data analysis based on contemporary events. In this study, a Straussian approach to Grounded Theory is taken, which lends itself to the time-based risk management framework as a starting point for data collection and analysis. The methodology used can be viewed as abductive, building and validating the initial emerging structures derived from the initial study with data taken from subsequent sources. The three major data sources used in this study are presented in the following chapters along with the initial and revised findings.

For each event under study here, the causal relationship of decisions taken prior to the disruption and the event itself are investigated, with a particular focus on how the firms detected and responded to the event. Data is then analysed by coding through summarisation, reduced to group similar codes in major categories and finally synthesised to a set of propositions on factors underlying disruption response.

Chapter 4 – provides an introduction and background of the first exploratory case, that of a global pharmaceutical company (referred to in this study as PHARMA) during the H1N1 Influenza Pandemic in 2009. The novel Influenza strain, H1N1, commonly known as swine flu, had fast transmission but unknown mortality at the outset, resulting in a dramatic spike in demand for PHARMA's antiviral and related medicines. PHARMA's handling of the Influenza pandemic declared in April 2009 is reviewed by an analysis of interviews of key management, company internal and public documentation.

Chapter 5 – provides a detailed analysis of the qualitative data using Grounded Theory obtained from PHARMA. Data was taken from interviews, team conference calls and meetings, during the event, corporate reports and plans before and after the pandemic. Open coding was used to code and group similar actions and description of factors that companies should focus on to reduce response time. The four potential categories of factors that underlie the firm time-based response to handing such an events were discovered: Preparation (warning, stress test, modelling, planning and training), Partnership (external communication, relationship with competitors, government, agencies and business partners), Organisation (teamwork, internal communication, roles and responsibilities and learning), and Reserve (employee capacity, production capacity, supplier capacity, product design and solution design).

Chapter 6 – presents the first stage of the constant comparative analysis by looking in depth at how the BP Upstream division, its contractual suppliers and various government agencies responded to the Deepwater Horizon oil spill in the Gulf of Mexico in 2010.

Chapter 7 – describing the background and the analysis from BP Refining and Marketing divisions' handling of a fatal explosion at their Texas City Refinery in 2005, in which 15 workers were killed and 180 injured, resulting in an extensive review of BP and industry operations.

These two additional disruption events from BP serve to validate the initial categories and codes developed in PHARMA.

Chapter 8 – presents the confirmed core categories in detail. It discusses how the core categories, their properties (sub-categories), and links between categories were integrated. It also provides an explanation as to how these four categories affected response speed. Finally, it illustrates how these four categories in related with time-based risk management framework. The findings show that the presence – or lack of – these factors can have an impact on the response speed for the effective management of disruption. By giving examples of what actions the companies took at each stage shows that these factors can help the company reduce detection time, design time, and deploy time.

Chapter 9 – presents the conclusions of the study and four propositions that relate the response time in managing supply chain disruptions to have a negative or potentially positive impact. The propositions augment the existing knowledge related to response and support hypothesis testing for further research in the field of supply chain risk management. This concludes with a perspective of the implications of these findings from a theoretical and managerial view, along with the limitations of the study and recommendations for future research in the area.

Chapter 2
Literature Review & Research Question

2.1 Risk and Risk Management

2.1.1 Risk

The first known theoretical contribution to understanding risk was made by Blaise Pascal and Pierre de Fermat, who in the 17th century studied gambling from a mathematical perspective (Frosdick, 1997). Development of probability theory followed, based substantially on their initial mathematical work (Bernstein, 1996). For approximately the next 200 years, risk management continues to be mostly applied to gambling.

The insurance industry was the first to embrace risk management (Moore, 1983), which was then followed by a broader use across various industries and corporate functions in the mid-20th century (Grose, 1992; Snider, 1991). For example, risk management was applied to purchasing by Robinson et al. (1967) and their development of the Buy Grid model. More recently, transaction cost economics developed by Williamson (1979) highlighted the relationship between transaction cost risks and degree of uncertainty in the customer and supplier interaction, as increased dependency on a supplier could cause a supplier to act opportunistically by increasing prices. According to Moore (1983), risk consists of two basic components, namely the range of outcomes and the likelihood distribution of these outcomes. In Williamson's work, transaction cost economics is closely linked to Moore's definition of risk, exemplified by the supplier/customer relationship where, for example, a loosely controlled contractual relationship will have the tendency to increase opportunistic behaviour.

According to Zsidisin (2003), the concept of risk has been the subject of extensive studies in numerous business settings, such as managerial decision making (March & Shapira, 1987; Yates & Stone, 1992; Shapira 1995), strategy (Ruefli et al., 1999; Sitkin & Pablo, 1992), operations (Newman et al., 1993; Pagell & Krause, 1999),

accounting (Ash-ton, 1998; Baucus et al., 1993), finance (Ho & Pike, 1992; Chow & Denning, 1994) and distribution (Celly & Frazier, 1996).

Risk is not only about outcomes and likelihood of occurrences, but also about choices and behaviour when facing these (Bernstein 1996). The choices made in a supplier/ customer relationship and the level of integration can be mutually rewarding (Burnes & Dale, 1998; Burnes & New, 1996; Womack et al., 1990) however they can also be risky if opportunistic behaviour takes over (Cousins et al., 2004). Therefore risk – and the choices made when facing risk – comprises the fear of losing and the hope of gaining (Moore, 1983). Within organisations and their management practices, the negative aspects of risk have however been dominant (Hood & Young, 2005; March & Shapira, 1987).

The Royal Society (1992) defines risk as 'a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence', which is similar to Rowe (1980), Lowrance (1980) and Simon et al., (1997) definition that defined risk is a measure of the probability of unwanted negative consequence to arise from a specific event.

Sitkin and Pablo (1992, p.10) reflect this in their generalised definition of risk as being 'the extent to which there is uncertainty about whether potentially significant and/or disappointing outcomes of decision will be realized.'

Most definitions of risk encompass three common elements: (1) the likelihood of occurrence of a particular event or outcome; (2) consequences of the particular event or outcome occurring; and (3) the exposure or causal pathway leading to the event (MacCrimmon & Wehrung, 1986).

The first element of risk is the likelihood of occurrence, also called probability that can be measured in objective or subjective terms. Two schools of thought regarding risk likelihood or probability are found in the literature. In one view, risk can be treated scientifically as an observable, measurable factor (Lupton, 1999). From an objective perspective, risk is tangible and static in its form. It can be evaluated and analysed by using statistical methods and tools applied to known quantifiable data (Covello & Merkhofer, 1993). Others argue that risk is perceptive, subject to social context and interpretation with sensitivities determined by socio-political and

historical factors (Bernstein, 1996; Frosdick, 1997; Moore, 1983; Spira & Page, 2002; Yates & Stone, 1992).

Yates and Stone (1992:p.5), for example, see the argument that risk must be treated as subjective as it involves 'an interaction between the alternative and the risk taker.' They maintain that the nature of any potential loss, its significance and the estimated chance of its occurring, are personal to the individuals concerned, for example the result of risk-taking can be perceived as positive by some but negative by others. Since the likelihood and consequences are specific to the individuals, where each can benefit or lose according to their own context and hence perceive risk individually, risk must be subjective. Risk is not, therefore according to Yates and Stone, an objective factor in decision making.

Thomas Bayes, an English clergyman and mathematician, took a similar view. He viewed risk as a product of perceptions: 'probability is a number of expressing a state of knowledge or degree of belief that depends on the information, experience and theories of the individual who assigns it' (Covello, 1993: p.209). This perspective therefore requires information that is unrelated to the available data. When applying an objective view of risk, the evaluation of probability will be subject to fitting the real world into mathematical concepts and statistical methods (Vesely, 1984). This may result in a somewhat artificial interpretation of the real world to be matched with the structure and constraints of mathematical and theoretical models. But also the subjective view generates its specific challenges, namely that the risk and probability evaluation will be subject to the assumptions of the analyst and the interpretation of information. Hence analysts will typically arrive at different conclusions to the same information.

The second element of risk is the consequence of the particular event or outcome, which should not simply be regarded as only negative, since 'the essence of risk taking is the potential opportunity to produce positive outcomes' (Blume, 1971).

The causal pathway is the third element of risk, which is an understanding of the sources, cause and nature of factors that in turn influence the likelihood, nature and scale of consequences, whether positive or negative.

2.1.2 Risk and Uncertainty

In 1921, Knight established an important distinction between risk and uncertainty. From his book Risk, Uncertainty and Profit, situations displaying risk are those where decision-makers are faced with unknown outcomes but with known probability distributions before the event. In his view, risks can be anticipated and priced in competitive markets; therefore associated profits are competed away. Risk is measurable in the sense that estimates can be made of the probabilities of the outcome. On the other hand, uncertainty concerns the unforeseeable elements in markets, and by definition those elements are not fully priced or factored into a firm's decision. It is not quantifiable and the probabilities of the possible outcome are not known.

Slack and Lewis (2001) describe 'uncertainty as a key driver of risk but argue that managers are able to measure and change their exposure to risk through the development of prevention, mitigation and recovery strategies. Whilst these do not eliminate uncertainty, they do enable managers to reduce the risks which might arise from uncertainty.'

Knight (1921) viewed the superior source of profit to be random beyond the control of companies however Schoemaker (2002, p.12) argued, 'uncertainty might indeed create opportunities as the firm can be favoured by chance and organisations can be designed to profit from uncertainty through superior anticipation, flexible strategies, and dynamic monitoring.' Therefore, in summary risk can be measurable and manageable while uncertainty cannot.

2.1.3 Risk Management

The International Organisation for Standardisation (ISO) defined risk management in ISO31000: 2009 as 'coordinated activities to direct and control an organisation with regard to risk.' A list of risk management definition by numerous authors is presented in Table 1.

Risk management has become a main part of many organisational activities and its main aim is to help all other management activities achieve the organisation's aims directly and efficiently (Tchankova, 2002).

The actual process of risk management normally begins by assessing two factors: first, the likelihood of specific events occurring, and second, the consequences should the events actually occur (Cox & Townsend, 1998). Between academics there is a general consensus on the phases of the process of managing risk, whereas each phase or step sometimes is coined differently. A review of the literature by White (1995) suggests that the process of risk assessment in Figure 1 usually consists of three stages: (1) risk identification – determining all risk factors that are likely to occur on a project (2) risk analysis – understanding the likelihood and extent of the most significant risks and (3) risk evaluation – deciding on the most appropriate management response for each risk and which party is most appropriate to manage each of the risks identified.

The risk management process in ISO 31000 is illustrated in Figure 2, comprising of five key activities: communication and consultation, establishing context, risk assessment, risk treatment and monitoring and review (Table 2).

Year	Authors	Definition
1989	Dickson (1989)	The identification, analysis and control of those risks, which can threaten the assets, or earning capacity of an enterprise.
1992	The Royal Society	The making and implementing of decisions regarding risks and their subsequent implementation, and flows from risk estimation and risk evaluation. It focused on understanding risks and mitigating the impact of risks by reducing the likelihood of their occurrence and/or the avoidance of their consequences. To manage risk means to avoid, reduce, transfer or share risk.
1995	The British Standards Institution	The process whereby decisions are made to accept a known or assessed risk and/or the implementation of actions to reduce the consequences or probability of occurrence.
2000	Fone and Young	A general management function that seeks to assess and address risks in the context of the overall aims of the organisations.

Table 1: Definition of Risk Management

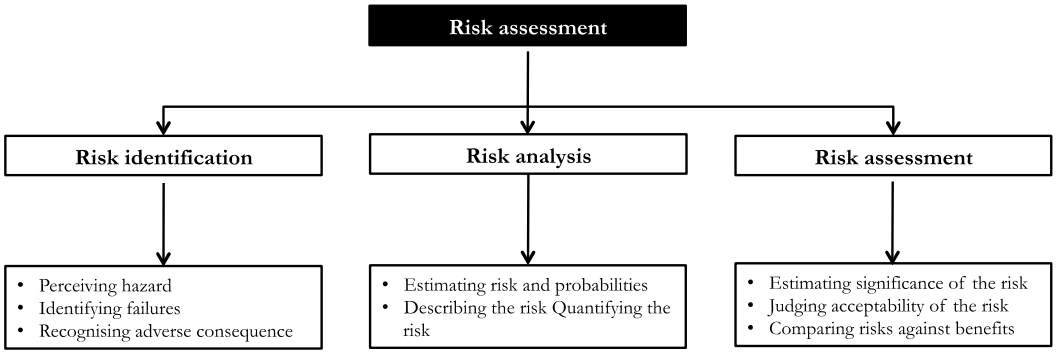


Figure 1: The Process of Risk Assessment

Source: White (1995)

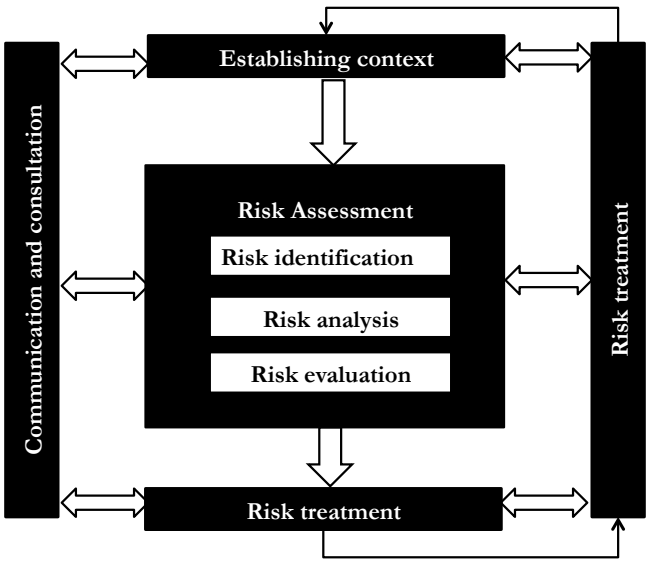


Figure 2: The Risk Management Process

Source: ISO 3100: 2009

Key activities	Description
Communication and consultation	Engaging internal and external stakeholders throughout the risk management process.
Establishing context	Setting parameters or boundaries around the organisation's risk appetite and risk management activities. The results of this context are risk management policy, processes, methods and reporting processes.
Risk assessment	Overall process of identifying, analysing and evaluating risks. Risk identification is a process of finding, recognising and describing risks. Identification techniques including brainstorming, work breakdown analysis, and expert facilitation. Risk analysis is a process to comprehend the nature of risk and to determine the level of risk. It considers possible causes, sources, likelihood and consequences to establish the inherent risk. Risk evaluation is a process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude are acceptable or tolerable.
Risk treatment	Process to modify risk. Risk treatment can involve avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk, taking or increasing risk in order to pursue an opportunity, removing the risk source or changing the likelihood.
Monitoring and review	Process of continual checking, supervising, critically observing or determining the status in order to identify change from the performance level required or expected, keeping the risk management framework relevant to the changing needs of the organisation and external influences.

Table 2: The Risk Management Process

Source: Adapted from ISO 3100:2009

2.2 Business Continuity

The disciplines of risk management and business continuity management (BCM) share similarities, but there are important differences found in the general consensus among practitioners. Whereas risk management has the primary focus on assessing and managing known risks, BCM has been developed primarily by practitioners to minimise the effects of unanticipated events on the firm's ability to meet customer requirements (Zsidisin et al., 2005). It is also focussed on keeping the business going and mitigating consequences no matter the type of event or risk that occurs with a possible negative impact on business activities (Hiles & Barnes, 2001).

Business continuity management is defined as '…the development of strategies, plans and actions which provide protection or alternative modes of operation for those activities or business processes which, if they were to be interrupted, might otherwise bring about a seriously damaging or potentially fatal loss to the enterprise (Hiles & Barnes, 2001).

According to CMI (2002), BCM includes crisis management (the overall process to manage an incident), disaster recovery (recovery of critical systems, applications, data and networks), business recovery (recovery of critical business processes) and contingency planning (recovery from impact external to the organisation).

There is, as mentioned an overlap between risk management and BCM but the definitions are being debated and one group of practitioners argues that risk management is a part of BCM whereas another claims the opposite. A third group claims that they are indeed distinct from each other. The consensus seems however to be that risk management is about responding to specific identified risks, while BCM is about responding to unknown risks and events.

Waters (2007) divided the process in BCM into six main steps: initiate the process of BCM; define the requirements of BCM and develop a strategy to achieve them; identify the risks and assess their probability and impact; prepare the business continuity plan; implement the business continuity plan; monitor and control the business continuity plan.

According to Christopher et al. (2002), the UK government is demanding that BCM processes are established across all departments and agencies following the terrorist attacks on the World Trade Center on September 11, 2001. Regulators also place demands on industry to establish effective risk management, specifically those risks which cannot be eliminated. There is also an acceptance that many of these risks are inherent within the supply networks. Accordingly, BCM can be considered as an effective tool in assisting in the management of these risks.

2.3 Crisis Management

A related field, Crisis Management, is covered by a number of academic authors in an extensive body of theory and literature (Elliott & Smith, 1993; Hazarika, 1987; Quarantelli, 1998; Reason, 1997; Smith, 1990).

In the organisational literature, crisis is defined as follows: 'an organisational crisis is a low-probability, high-impact event that threatens the viability of the organisation and is characterised by ambiguity of cause, effect, and means of resolution, as well as by a belief that decisions must be made swiftly' (Pearson & Clair, 1998 p.60).

The process of crisis management is often seen by some organisations in terms of the process of business continuity management (Elliott et al., 2002) and, as such, has a focus on the development of contingency plans to cope with a range of 'crisis' scenarios.

According to Smith (2005), the term 'crisis management' may itself be problematic as it could be seen to overemphasise the processes of contingency planning and business continuity. However, the 'crisis' literature can be seen to encompass work that is concerned with the prevention of crises as well as with the contingency responses that organisations can make to the threat of such risks. Thus, a definition of crisis depends on the context in which it is being used and the researcher's discipline (Preble, 1997).

Fink (1986, p.15) suggests that planning to avoid a crisis '… is the art of removing much of the risk and uncertainty to allow you to achieve more control over your own destiny'. According to Fink (1986, p.20-28), a crisis consists of four stages: (1) Prodromal [forerunning] crisis stage – the early warning stage when the organisation gets a first glimpse of the potential of the crisis to come; (2) Acute crisis stage – begins once the damage has begun; (3) Chronic crisis stage – begins when the organisation tries to recover from the crisis, identify its vulnerabilities and learn from the failures and success of its response; and (4) Crisis resolution stage – begins when the organisation comes back to normality and resumes full functionality.

Effective crisis planning aims at identifying the early warning signals for the crisis, even if occasionally the prodrome may be oblique and much harder to recognise, or is evident but no action is taken (Paraskevas, 2006).

2.4 Risk and Supply Chain Management

2.4.1 Supply Chain Management

It is clearly stated that logistics management is a part of supply chain management (SCM) from a definition of logistics modified by the Council of Logistics Management (1998) 'Logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements.'

The concept of supply chain management has been increasingly discussed among logistics practitioners and researchers since the mid-1980s (e.g. Houlihan, 1985; Jones & Riley, 1985) and lately companies have also started to work according to its principles. The term SCM first appeared in 1982, according to a literature review by Cooper et al. (1997). Since the early 1990s, SCM has been distinguished in academic studies from logistics management as focus has shifted from inventory reduction in the single firm to total network and inter-firm optimisation. Throughout the research literature there are two distinctive views on defining SCM. The first view extends the definition of traditional logistics management beyond single enterprise boundaries and the original focus on material movement. This view on SCM, found in many early logistics management textbooks, emphasises that 'operational effectiveness' is the key to competitive advantage (Bowersox et al., 1996).

Swaminathan et al. (1996) defined SCM as managing 'a network of autonomous or semi-autonomous business entities collectively responsible for procurement, manufacturing and distribution activities associated with one or more families of related products.'

On the other hand, the second view on defining SCM is from the wider perspective of integrated business processes and strategic management of the complete set of activities and organisations and their links, such as communication. This view of SCM was suggested by Porter (1985), in which linking different functions could create 'value'. In his view, value is added by improving information and control, coordinating related activities, and optimising total costs across multiple activities to reduce enterprise transaction costs rather than sub-optimising logistics or other functions. In line with Porter, Cooper et al. (1998) note that 'for companies to survive and prosper, they will need to operate their supply chains as extended enterprises with relationships which embrace business processes, from material extraction to consumption.'

Reinforcing this definition of SCM, Greis et al. (1997) defined SCM as 'an integrated group of strategically aligned organisations in the supply chain, focused on specific market opportunities. This idea of extended enterprise is based on mutual benefit which requires co-operation and collaboration among partners.'

This evolution in the definition of SCM has two primary drivers, according to Cooper et al. (1997): First is the shift toward process-oriented business management in place of the functional view of the organisation. Second, as mentioned earlier, is the significant difference in the perception of SCM as having a broader management scope than only logistics.

The second view of SCM definition carries more weight on strategic management and marketing perspective than the first view, which makes it widely accepted among researchers. According to Christopher (1992), a key characteristic of supply chain management is the coordination of activities between these interdependent organisations. He defines SCM from the above perspective as 'the management of upstream and downstream relationships with suppliers and customers in order to create enhanced value in the final market place at less cost to the supply chain as a whole.' Giunipero et al. (1996) defined SCM thus: 'in its broadest contest SCM is a strategic management tool used to enhance overall customer satisfaction that is intended to improve a firm's competitiveness and profitability.' By the same token, Mentzer et al. (2001) defined SCM as 'the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole.'

Given the definitions above, for the purposes of this research, the definition of Supply Chain Management by Tang (2005) is as follows: 'Supply chain management is the management of material, information and financial flows through a network of organisations (i.e. suppliers, manufacturers, logistics providers, wholesalers, distributors, retailers) that aims to produce and deliver products or services for the consumers. It includes the coordination and collaboration of processes and activities across different functions such as marketing, sales, production, product design, procurement, logistics, finance, and information technology within the network of organisations' (Tang, 2005). Figure 3shows the overall picture of supply chain flows.

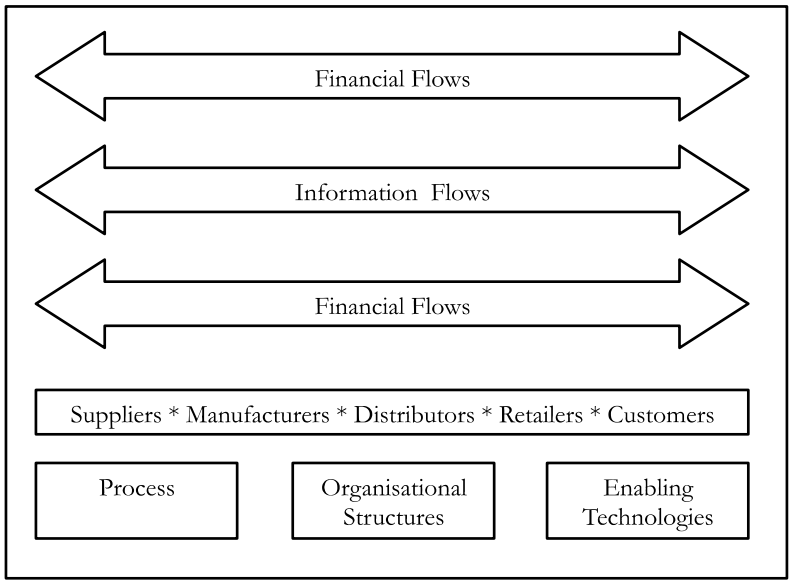


Figure 3: Supply Chain Management

According to Lambert and Cooper (2000) and Mentzer et al. (2001), a key component for Supply Chain Management is to share both risks and rewards between members of the supply chain.

2.4.2 Supply Chain Risk

Risky events intrinsically make the global supply chain and logistic network vulnerable. In the 1980s, the risk was said to be created by the inter-connected material flows, information and funds in the network of firms (Kraljic, 1983; Treleven, 1988). It was recently that the phenomenon triggered interest from many scholars and practitioners. An increasing amount of literature (e.g., Ritter, Barrett & Wilson, 2007; Sheffi, 2005; Zsidisin & Ritchie, 2009) provides case studies relating to the events that caused disruption of supply chain, logistics networks, and transportation and operations. Also, many publications propose best practices and risk management concepts that could help a company create more robust supply chains, logistics networks, and transportation operations.

There are two major factors underlying these increasing interests in the topic. First, the risk of unexpected adverse events with which firms must cope is increasing in terms of frequency, intensity and diversity (Coleman, 2006; Helferich & Cook, 2002). The potential for supply chain disruption as well as its magnitude has increased (Elkins et al., 2005) as shown in the crises and disasters which happened

in the past ten years such as the terrorist attack on the World Trade Center in 2001, Hurricane Katrina in 2005, the swine flu pandemic in 2009, and the earthquake and tsunami in Japan in 2011. These disasters reveal that many supply chain networks have a low level of preparedness and therefore force logistics managers to reconsider their supply chain security and risk management processes.

Second, the business model of modern supply chains, logistics networks, and transportation operations can increase the impact from unexpected adverse events to companies. For example, the logistic service provider industry has changed remarkably over the past 15 years. Increasing competition, globalisation of markets, and expansion of international trade have put more pressure on individual companies to increase collaboration with their supply chain partners. This makes supply chains more complex and also increases the level of dependency between supply chain entities. As a result, it increases the level of threat in supply chains to adverse events that could happen to any entity in supply chains (Kleindorfer & van Wassenhove, 2004; Sarathy, 2006). This idea is supported by literature in organisational science which states that companies have a greater tendency to be affected by accidents and disruptions because of their complex, tightly coupled, and technology-oriented processes (Lin et al., 2006).

Supply chain risk is predominantly used in both the literature on supply disruption as well as general concepts of various events, situations, potential threats, or uncertainties. Authors from different areas use the term risk to refer to different issues when addressing different audiences. Wagner and Bode (2009) commented that there is no right or wrong definition; there is just a more or less appropriate definition for each specific situation. The definition of risk can generally be interpreted in two ways: (1) risk as both danger and opportunity, and (2) risk as danger only (Mitchell, 1995).

The first notion sees risk as variability around the mean of a measure (Arrow, 1965). Therefore, there is both downside and upside potential.

In contrast, the second notion only perceives the downside potential of risk. The definitions of risk in most dictionaries will also see risk as having only negative consequences. In addition, many empirical studies find that this notion is more

consistent with perception as the majority of people tend to perceive solely the negative potential of risk (March & Shapira, 1987).

These two general views on risk have been discussed and applied when authors defined the term 'supply chain risk'. While Juttner, Peck and Christopher (2003) defined supply chain risk following the first notion of definition of risk, Harland, Brenchley and Walker (2003) defined supply chain risk as associated with the chance of undesired consequence such as danger, damage, injury and loss. According to the literature in the area, perceiving risk as purely negative is most suitable to the business reality. The consequences can be either indirect or direct, and can provide major or minor performance objectives (Bode et al., 2007).

Despite the lack of a generally accepted definition of risks in the supply chain (Baird & Thomas, 1990, p.26), March and Shapira (1987) put forward that risk is defined as 'variation in the distribution of possible outcomes, their likelihoods and their subjective values'. In the supply chain, the primary driver of risk centres on the disruption of the flow of information, materials, products and capital. These flows are interdependent and by definition extend beyond the boundaries of a single firm. To be effective, any approach to risk management in the supply chain must take into consideration the performance of these key management processes in a network of organisational entities. This approach acknowledges that objectives may not be aligned and therefore risk management should incorporate persuasion, negotiation and bargaining and reflect the mutual dependencies within and between organisational entities.

Supply chain risk is the probability of incurring a loss within a supply chain that is related to the logistics activities in companies' flow of material and information (Ritchie & Brindley, 2007). Likewise, Zsidisin (2005) defined supply chain risk as the potential occurrence of an accident or failure to seize opportunities with inbound supply in which the outcome results in a financial loss for the firm.

2.4.3 Type of Supply Chain Risk

Many frameworks for supply chain risk are found in the literature. According to Tang and Tomlin (2007), supply chain risks are categorised into six types: supply risks, process risks, demand risks, intellectual property risks, behavioural risks and political/social risks. Chopra and Sodhi (2004) extend this to nine categories of risk:

delays, systems, forecast, intellectual property, procurement, receivables, inventory, capacity and disruptions. Cousins et al. (2004) have a simpler model, suggesting that companies are exposed to two main types of supply chain: 'technological risk' – over-reliance on a single or limited source of a product, process or technology; and 'strategic risk' – over-reliance on a single or limited number of suppliers.

Other suggested categories of risk included environmental, demand and supply, process and control risks (Mason-Jones & Towill, 1998), and supply market, supplier, regulatory and supply strategy risks (Minahan, 2005). Johnson (2001) divides supply chain risks into supply risks (e.g. capacity limitations, currency fluctuations and supply disruptions) and demand risks (e.g. seasonal imbalance, volatility of fads, new products). Merna and Smith (1999) also give an extensive list of supply chain risks, which are strategic, natural, political, economic, physical, supply, market, transport, products, operations, financial, information, organisation, management, planning, human, technical, criminal, safety, environment and local permits.

Christopher et al. (2002) classified risks in supply chains into two different types: supply chain risks and external risks. 'Supply chain risks' arise from interaction between organisations along the chain. Such supply chain risks result from a lack of visibility, lack of ownership, chaos, just-in-time practice and inaccurate forecasting. On the other hand, 'external risks' arise from environmental uncertainties. Such risks include disruptions caused by strikes, terrorism and natural catastrophes. Thus, external risks are 'risks to the various links in the supply chains' (Souter, 2000). Although both have independent sources, simultaneous occurrence of both risks and the interactions between them intensifies damage to the supply chain.

Mason-Jones and Towill (1998) refine this model by describing the three categories: (1) Internal risks are inherent or arise directly from management decisions, or arise from operations within the organisation such as delays and breakdown; (2) Supply chain risks that arise from the interactions between members of the supply chain, external to the organisation, but within the supply chain, such as risk from suppliers or consumers; (3) Risks external to the supply chain that arise from interactions with its environment such as natural disaster, legislation pressure groups, wars, etc.

Waters (2007) stated that internal risks are generally less dramatic: 'Internal risks are the risks to operations that managers can control while the external risks are outside manager control. So managers cannot change the risk, but they can design operations that work as efficiently as possible within a risky environment.'

2.4.4 Supply Chain Risk Sources

The sources of supply chain risks are many, as different links of a supply chain are exposed to different types of risk. Faisal et al. (2006) pointed out that in 'a quest to become more agile and lean, organisations are becoming more dependent on outside support which also adds to the overall risk vulnerability.'

A study conducted by Cranfield University for the UK government (2002) defined supply chain vulnerability as 'an exposure to serious disturbance, arising from risks within the supply chain as well as from risks external to the supply chain.'

According to Christopher (1992), a number of factors that contribute to supply chain vulnerability are due to a focus on efficiency rather than effectiveness, the globalisation of supply chains, focussed factories and centralised distribution, the trend toward outsourcing, reduction in the supplier base, volatility of demand, lack of transparency and control procedures. Supply chains must adapt to these forces to stay competitive but at the same time increase their exposure to different forms of risk (Sodhi & Tang, 2009).

This is also supported by Hallikas et al. (2002) and Handfield and Nichols (1999), who state that we are living in an era of rapid change in product markets and technologies, and increasing customer expectations in terms of better products, quicker response time and lower prices.

The nature of supply chain disruption is diverse because it can occur from both inside or outside a supply chain, and its magnitude, attributes, and effect can vary greatly. Many scholars have tried to classify supply chain disruption in the form of taxonomies/typologies with the objective to distinguish between supply chain disruptions from other types of undesirable events in business (e.g., Calvinato, 2004; Chopra & Sodhi, 2004; Christopher & Peck, 2004; Norrman & Lindroth, 2004; Svensson, 2000). The categories of supply chain disruption are also called supply chain risk sources, as they are known sources and probabilities of supply

chain disruptions. Since different risk sources need different risk management activities, understanding the categories and nature of supply chain disruption is essential.

There are many classifications of supply chain disruptions proposed by different authors. For example, Svensson (2000) classified supply chain risk sources as quantitative and qualitative, Juttner (2005) proposed three types – supply, demand, and environmental, whereas Manuj and Mentzer (2008) delineated eight types – supply, operational, demand, security, macro, policy, competitive, and resource. Wagner and Bode (2009) reviewed other authors' classifications and summarised that supply chain risk sources have five categories: demand side; supply side; regulatory, legal, and bureaucratic; infrastructure; and catastrophic. This classification is generated from an empirical study of industrial firms and logistics services across Austria, Switzerland, and Germany (Wagner & Bode, 2010) The first two sources focus on risk sources that are internal to supply chain while the later three are risk sources that can also be external to supply chain. Various sources of supply chain risk are examined as follows:

Demand Side Risk

Downstream supply chain operations can cause supply chain disruption. This includes disruptions in product distribution to the end-customer caused, for example, by the strike of truck drivers (McKinnon, 2006), as well as the uncertainty of customer demand due to poor co-ordination in the supply chain and mismatch between a firm's projection and actual demands of customers. Demand side risk can create obsolescence of stock, shortage, and poor customer service due to unavailable product. Although addressing demand side risk is said to be an essential discipline of supply chain management, it is still present as a major risk source for many companies. In 2001, for example, the lack of communication among downstream supply chain partners forced Cisco Systems, which is a global manufacturer of communications equipment, to write off GBP 1.5 Billion in inventory (Spekman & Davis, 2004).

Supply Side Risk

A company should manage the risk of their supplier portfolio in order to minimise the risk from disruptions caused by supply side (Kraljic, 1983) especially when a company strongly relies on external sources for critical materials. The upstream side of a firm's supply chain can be a major source of supply chain disruption. These disruptions can be caused by suppliers, supplier relationships and networks, and purchasing activities. Additionally, such risks include production capacity constraints on the supply market, supplier business risks, change in technology and product design, and quality problems (Zsidisin, Panelli & Upton, 2000).

Supplier business risks are related to the discontinuity of suppliers that could cause the interruption or termination of the buyer–supplier relationship such as suppliers' financial problems, bankruptcy, insolvency, or consequences of supplier default (Wagner, Bode & Koziol, 2009). Suppliers' financial default or a supplier going out of business can cause serious problems to a buying firm such as in the case of Land Rover whose only supplier of chassis frames for its Discovery model, UPF Thompson, unexpectedly went bankrupt in 2001. It cost Land Rover GBP 35 Million to resume production (Lester, 2002). This type of disruption can also occur when the supplier is vertically integrated with a customer firm's competitors; the relationship may be automatically forced to be terminated (Chopra & Sodhi, 2004). In addition, when the switching cost for the buying company is high, the opportunistic behaviour of suppliers can be a source of supply side risk (Wagner & Johnson, 2004; Spekman & Davis, 2004). Finally, poor quality products or services of suppliers can also trigger a domino effect on goods or services delivered to the end customer (Zsidisin et al., 2000).

Regulatory, Legal, and Bureaucratic Risk

The regulatory, legal and bureaucratic risk is the legal enforceability and execution of laws, regulations, or policies that have an impact on the supply chain. The frequency and degree of changes in these rules can be the source of supply chain risk because a sudden change in these rules may lead to the violations of laws, or regulations.

Although little attention has been paid to supply chain risk from regulatory and legal issue, in many countries these factors have significant effect in setting up and operating supply chains. Hendricks and Singhal (2003) pointed out that the actions of authorities can create severe supply chain disruptions because it can affect the firm's ability to obtain permission to set up or operate a supply chain, as well as trade barriers such as embargoes, tariffs, local content constraints, or import/export quotas. Wagner and Bode (2008) conducted interviews and found that the major risk for inbound logistics in Russia is customs clearance. This is due to changing requirements regarding shipping documentation, possible time loss, standstill fees, as well as the unpredictable behaviour of customs authorities in Russia. As a result, many importing companies are forced to avoid the problem by using expensive customs brokers to assist the clearance process. Firms are facing more complex supply chains due to environmental legislation in many other countries, leading to an increase in supply chain costs.

Infrastructure Risk

Infrastructure risk refers to the risk occurring from a firm's infrastructure underlying its supply chain operations. This includes accidents caused by both human issue and technical problems related to the area of supply chain security such as machine breakdowns, equipment malfunction, disruption of electricity or water supply, labour strike, and vandalism (Chopra & Sodhi, 2004; Lee & Wolfe, 2003; Spekman & Davis, 2004). Firms have become increasingly dependent on information technology (IT) as well; therefore, IT-related problems can significantly affect supply chain management. These problems include hardware failures or software bugs, as well as problems created by human actions such as malicious software, or cyber-attacks. In addition, the Enterprise Resource Planning (ERP) systems, which allow a company's suppliers and customers to have direct access to databases and internal processes, can increase the chance of IT-related threats.

Catastrophic Risk

These events include natural disasters, epidemics, terrorist attacks, civil unrest, and socio-political instability (Kleindorfer & Saad, 2005; Martha & Subbakrishna, 2002; Swaminathan, 2003). Natural disasters such as tsunamis, earthquakes, hurricanes, and floods can be a severe threat to transportation systems and production facilities.

Due to the globalisation of markets and global-spanning of supply chain operations, local disasters have an increasingly indirect global consequence. Since 2001, there had been growing interest in the destructive impact from terrorism on companies' supply chains (Rice & Tenney, 2007; Sheffi, 2011) because it affects supply chains either directly in causing damage to logistics infrastructure as well as indirectly due to, for example, events such as port closures.

2.4.5 Supply Chain Disruption

The terms supply chain risk and supply chain disruption are generally used interchangeably. However, the definition of the term supply chain disruption has not been made explicit in the literature. Terms such as error, accident, hazard, operational failure, operational crisis, and disturbance have been used in the same context. Table 3 provides an overview of recent publications discussing supply chain disruption.

The literature on disaster research has spanned many fields such as marketing, management, organisational behaviour, psychology, sociology, political science and engineering (Pearson & Clair, 1998). As a result, the term organisational crisis and its attributive dimensions have various definitions (Hermann, 1963; Kovoor-Misra, Clair & Bettenhausen, 2001; Milburn, Schuler & Watman, 1983; Pearson & Clair, 1998). However, most of the definitions have agreed that organisation disruption consists of (1) an unforeseen triggering event, and (2) a consequential situation (Bilings, Milburn & Schaalman, 1980; Hermann, 1963; Kovoor-Mistra et al., 2001).

According to this, supply chain disruption is also said to comprise two components: (1) a triggering event which is an unexpected event that appears in the supply chain or its environment and causes the consequential situation; (2) a consequential situation which is the exceptional event that makes a company unable to pursue their normal business operation (Wagner & Bode, 2009).

What makes a supply chain disruption differ from risk is that a supply chain disruption is an obvious situation. Supply chain disruption is more closely related to organisational crisis, which needs immediate attention (Reilly, 1987) because the impact of the disruption is usually a function of time (Hermann, 1963). It can be distinguished by uncertainty of its cause, effect, and means of solution (Pearson & Clair, 1998). More importantly, it should be noted that supply chain disruption is

said to occur only if the involved actors identify the situation as unusual. Wagner and Bode (2009) said that because organisational response is triggered by actors' perceptions, not by fact, this made the nature of supply chain disruption very subjective. As a result, it is difficult to distinguish a supply chain disruption's beginning and ending.

Authors	Research Focus
Applequist, Pekny & Reklaitis (2000)	Develops a metric for evaluating supply chain projects with significant risk. The measure quantifies a risk premium used to measure return and risk on an investment in comparison with other investments.
Johnson (2001)	Enumerates lessons learned from manage supply chain risk in the toy industry. Risk mitigation techniques are presented in terms of managing demand and managing supply.
Sheffi (2001)	Discusses supply chain investments and re-organisation needed to prepare for terror attacks in terms of the challenges of dealing with the aftermath of a terror attack and managing supply chains with increase uncertainty.
Mitroff & Alpasan (2003)	Presents recommendations for proactive preparation if internal attacks.
Rice & Caniato (2003)	Discusses the need for security and resilience in supply-chained ideas to develop more secure and resilient supply chains.
Zsidisin & Ellram (2003)	Considers the influences of inbound supply chain risk and techniques to al within these risks based on the results of a survey.
Cavianato (2004)	Focuses on logistics risk in a supply chain and discusses the broadening definition of risk.
Chopra & Sodhi (2004)	Presents a high level categorisation of supply chain risks and their drivers with recommendations to improve risk preparedness.
Sinha, Whitman & Malzhan (2004)	Develops a methodology to mitigate risk in an aerospace supply chain based on a five-step IDEF0 model.
Zsidisin, Ellram, Carter & Cavinato (2004)	Presents findings of an empirical study on how purchasing organisations assess risk.
Hallikas, Karvonen, Pulkkinen, Virolainen & Tuomimen	Discusses a general risk management process for supplier networks.
Kleindorfer & Sadd (2005)	Develops a conceptual framework for managing supply chain disruption risk that includes the tasks of specification, assessment, and mitigation.
Peck (2005)	Presents a framework for understanding supply chain vulnerability and a discussion if the drivers if vulnerability.
Sheffi & Rice (2005)	Discusses the stages of a disruption and provides high-level recommendations for improving flexibility in the supply chain.
Zsidisin, Melnyk & Ragatz (2005)	Discusses the use of business continuity to manage purchasing and supply risk.
Sodhi (2005)	Presents two risk measures (demand-at-risk and inventory-at-risk) and two linear programming models to be used together to manage demand and inventory risk in consumer electronics supply chain.
Tomlin (2006)	Develop a supply chain model to investigate mitigation and contingency strategies and recommends when to use them based on firm with a single product and the option of two suppliers: one that is unreliable and the other that is reliable but more expensive.
Craigbead et al. (2007)	Present propositions that supply chain characteristics - density, complexity and node criticality and supply chain mitigation capabilities - recovery and warning affected the severity of supply chain disruption.

Authors	Research Focus
Sodhi & Tang (2009)	Present time-based risk mitigation concept. With this concept could enable companies to reduce impact of supply chain disruption.
Bode & Wagner (2010)	Present a framework for understanding the frequency of supply chain disruptions is a function of certain supply chain characteristics.

Table 3: Review of Literature Related to Supply Chain Disruption

Source: Adapted from Craighead et al. (2007)

Craighead et al. (2007) explicitly use the term 'supply chain disruption' to refer to 'unplanned and unanticipated events that disrupt the normal flow of goods within a supply chain, exposing the firms within the supply chain to operational and financial risks', (citing Svensson, 2000; Hendriks & Singhal, 2003; Kelindorfer & Saad, 2005; Stauffer 2003). Craighead et al. goes on to discuss two risk mitigation capabilities: (1) recovery capability which is defined as the activities in the supply chain to restore normal product flow, and (2) warning capability which refers to the ability of a supply chain participant to detect a pending or realised disruption and disseminate pertinent information about the event to relevant supply chain partners. In addition, they state that supply chain design characteristics such as density, complexity and node criticality can be expected to be positively related to supply chain disruption severity.

2.4.6 Supply Chain Vulnerability

The type of supply chain disruption and its magnitude alone are not the only determinants of the harm caused by supply chain disruption. The outcome of the disruption is also determined by the response capacity, and the susceptibility of supply chains is also significantly relevant to the harm and loss caused by supply chain disruptions.

Despite attempts to define and offer approaches to manage supply chain vulnerability, the concept is still considered to be unclear and insufficiently understood (Juttner et al., 2003; Peck, 2005). Christopher and Peck (2004) defined the term as 'an exposure to serious disturbance' (p.3). Bernes and Oloruntoba (2005) defined vulnerability as 'a susceptibility or predisposition to … loss because of existing organisational or functional practice or conditions' (p.519). Svenson (2000, 2002) stated that supply chain vulnerability is constructed of atomistic vulnerability, which is limited to a part of the supply chain such as a single firm, and holistic vulnerability, which covers the entire supply chain. Wagner and Bode's

(2009) definition of vulnerability is quite similar to Bernes and Oloruntoba's (2005); they described vulnerability as 'a function of certain supply chain characteristics which make the focal firm sensitive to disruptions' (p. 15) and explained that it can be, for example, a firm's mechanism that moderates the consequences of a supply chain disruption occurring in a firm. Therefore, supply chain vulnerability can be seen as the ability of a firm to absorb the supply chain disruption effects. The factors that could increase the degree and impact of supply chain disruption are aspects such as dependence on suppliers and clients (Wagner & Bode, 2006), supply chain complexity, supply chain density, node criticality (Blackhurst, Rungtusanatham & Handfield, 2007), sloppy management (Turner, 1994), eroded safety procedures (Reason, 1990), and complex technical systems or organisational processes (Perrow, 1984).

2.4.7 Supply Chain Risk Management

The concept of supply chain risk management was adapted from general business risk management concepts (Khan &Burnes, 2007; McCormack, 2008; Ritchie & Brindley, 2007), which aimed to 'eliminate, reduce, and generally control pure risks' (Waring & Glemdon, 1998:p3). The process of general risk management contains (1) risk identification; (2) risk assessment, which includes analysis of the impact and probability of the identified risk; (3) risk treatment; and (4) risk monitoring. If the amount of remaining risk after the risk management process is in line with a firm's procedure, the level of risk is considered optimal. When applying this concept to a supply chain context, the third stage referring to the practice and measure of risk treatment has to be made specific to the context of supply chain, therefore it can be considered as supply chain risk management (Tang, 2006).

According to Norrman and Lindroth (2002), 'supply chain risk management is to collaborate with partners in a supply chain, applying risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics related activities or resources.'

Christopher (2002), defined supply chain risk management (SCRM) as 'the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity.' He pointed out the four objectives of supply chain risk management. First, maintain the supply and

continuous availability of product. Second, decrease the supply chain's ability to cope with disruptions in the supply of products if necessary. Third, avoid possible domino effects throughout the chain. Last, make the supply chain more resilient to disruption.

Management of supply chain risks has over the years seen a myriad of approaches with different focus. Most approaches can however be grouped into the two broad categories of relationship management (Puto et al., 1985) and strategic/proactive purchasing (Smeltzer & Siferd, 1998). These two categories do, to some extent, overlap.

Puto et al. (1985) and Mitchell (1995) identify supplier relationship development as an important risk-reducing strategy, which includes loyalty to existing suppliers, the characteristics of the buying situation and the buyer's perception of the procurement problem. In addition, Zsidisin et al. (2000) and Zsidisin (2003) also support the importance of relationship management by advocating that partnership formation; strategic alliances and supplier development and performance systems are all activities that reduce risk.

Approaches	Authors
Purchasing partnerships	Ellram (1991a, b)
Multiple sources of supply VS single sourcing	Treleven and Schweikhart (1988), Kraljic (1983) and Zsidisin (2003)
Supplier quality/ auditing/ certification programmes	Smeltzer and Siferd (1998), Newman et al. (1993) and Zsidisin (2003)
Supplier improvement programmes	Smeltzer and Siferd (1998)
Closer working relationships with suppliers	Zsidisin et al. (2000), Zsidisin and Ellram (2003) and Eisenhardt (1989)
Communication and early involvement of suppliers in strategic decisions	Krause (1999)
Buffer	Newman et al(1993)
Strategic alliances	Zsidisin et al (2000)
Risk sharing/ knowledge transfer	Eisenhardt (1989), Zsidisin et al. (2000) and Krause (1999)
Focus on core competence	Zsidisin et al (2000)
Product differentiation	Lonsdale (1999)
Entrepreneurial/ risk taking	March and Shapira (1987) and Lonsdale (1999)
Proactive supply management	Smeltzer and Siferd (1998) and Kraljic (1983)

Table 4: Risk Management Strategy

Source: Khan &Burnes (2007)

Eisenhardt (1989) as well as Zsidisin and Ellram (2003) argue that agency theory can be applied to reduce supply chain risks, mostly via co-operation with the aim to create joint benefits and reduction of conflicts. In that context, improved

information sharing, where the aim is to create knowledge, will reduce the risk of opportunistic behaviour.

The category of strategic/proactive purchasing aims at overseeing the whole supply chain. This approach is less intimate than the relationship management approach, but the scope is also much wider. Monitoring and auditing of supply chain partners and their standards is a key activity in reducing risk, according to Smeltzer and Siferd (1998) and Newman et al. (1993). Mitchell (1995) and Zsidisin et al. (2000) advocate the use of multiple sourcing. Contrasting this view, Lonsdale (1999) favours increasing the variety of products rather than choosing multiple sourcing as a means of reducing risk.

As described above, there are different categories and approaches to managing supply chain risk. The field has however not matured, which can be seen in the broad range of conflicting views. For example, among the most commonly accepted risk reduction approaches are single sourcing and building long-term partnerships (Treleven & Schweikhart, 1988). On the other hand, single sourcing can lead to over-dependence on one supply source and increasing vulnerability to opportunism (Zsidisin, 2003; Kraljic, 1983). And the same wide range of views is expressed when it comes to the effectiveness of building long-term relationships. One group of academics advocate that it does reduce supply chain risk (Zsidisin, 2003; Eisenhardt, 1989; Ellram, 1991a; Ellram, 1991b), whereas another group argues against this approach (Smeltzer & Siferd, 1998; Pilling & Zhang, 1992; Lonsdale, 1999).

Mitchell (1995) sees that one explanation for the lack of maturity in the field is that the very different views of supply chain risk management are by nature situational. Newman et al. (1993) provide a case in point, which is the use of buffers. In the short run the use of buffers can be effective in reducing risk but in the long run risk may increase as it is expensive and creates production inefficiencies as well as increasing the risk of creating outdate stocks.

General risk management is a discipline that is fairly developed, especially in the financial field. It is however striking that general risk management literature as well as the associated tools and techniques have not found their way into how supply

chain risk management is being approached (Cousins et al., 2004; Kraljic, 1983; Robinson et al., 1967; Williamson, 1975; Williamson, 1979).

Further development of theoretical and practical supply chain risk management appears to be possible, especially if the research agenda focuses on the following three areas. First, supply chain risk management should take into account the work that has been done within general risk management and in particular within financial risk management. Second, supply chain risk management needs to be more firmly rooted in understanding how companies actually do manage supply chain risk and why they do it in a chosen way. Third, based on research into the two previous topics, improved theory and models of supply chain risk management can be developed.

Supply chain management faces the challenge of balancing risk profile and cost minimisation. Risk can probably not be completely eliminated but it can in most cases be reduced significantly. The risks in the supply chains can often be mitigated if companies can understand the variables having an impact on risk management in the supply chains. Some of the variables that enable risk mitigation are information sharing, aligning incentives, risk sharing and corporate social responsibility (Chopra & Sodhi, 2004; Speckman & Davis, 2004; Faisal et al., 2006).

2.5 Time Based Management and Response

The importance of time as a competitive parameter has over the last two decades made its way into the literature addressing how to compete effectively. Time based competition is essentially about compressing time of the important activities of the firm, i.e. responding to customer needs, introducing new products faster than competitors, reducing time in the production and delivery process, and by doing so a significant competitive advantage can be established (Stalk, 1988; Stalk &Hout 1990; Blackburn, 1991).

One of the main reasons for the emergence of time-based competition is that customers feel increasingly time starved, providing a major opportunity for companies that can exploit time as a competitive parameter (Tucker, 1991). In his work Tucker viewed time as a major driving force of change.

A number of companies are today categorised by competing on time and the characteristics are that they employ structurally different methods to manufacturing and product innovation and development (Stalk, 1988; Stalk & Hout, 1990; Blackburn, 1991), they think of themselves as part of an integrated system of suppliers and customers (Stalk & Hout, 1990) and they create more information that is also shared more openly and rapidly with important stakeholders.

The benefits of successful time-based competition are similar to those of most other successful competitive strategies, namely increase in productivity, ability to command a price premium, ability to gain market share, high customer loyalty and the ability and willingness to cannibalise own products (Stalk, 1988; Stalk, 1990; Blackburn, 1991; Daniels & Essaides, 1993).

Time-based competition can be seen as a managerial focal point that guides the decisions and directs the company towards time-sensitive customer segments by merging principles of traditional strategic schools of thought with flexible and lean manufacturing principles.

The literature on time-based competition in combination with supply chain management appears, however, to be very limited and thus provides for a research agenda that takes this important aspect into account.

There are nevertheless scientific models, such as the epidemic model and fire model, as well as anecdotal evidence to support a conjecture that the magnitude of the problem triggered by the event increases exponentially over time.

The simple form of epidemic model is the 'Exponential Model' by Thomas Robert Malthus (1766–1834). This model can be explained as follows:

Let I(t) be the number of people infected at time t. In this case, the rate of infection can be defined by the differential equation: $dI(t)/dt = kI(t)$, where the parameter $k>0$. This differential equation yields: $I(t) = I_0e^{kt}$, where I_0 is the number of people infected at time 0. Therefore, the number of people infected grows exponentially overtime.

A similar model is a fire model called the 'Elliptical Fire Spread Model' presented by Arora and Boera (2005). They assumed that the area burned is taken to be elliptical

in shape with the point of ignition at one of the foci. By assuming that the fire is spread linearly over time along a two-dimensional space, they show that the total area burned grows as a squared function of time elapsed since the start of the fire. Thus, the total area burned grows exponentially over time.

2.6 Existing Theories

2.6.1 Normal Accident Theory

The normal accident theory (NAT) was proposed by Charles Perrow with the objective of explaining the reason that makes socio-technical system fail based on the analysis of the US nuclear power plant near-disaster (Perrow, 1984). The theory suggested that the probability of occurrence and the severity of systems accidents are determined by two system characteristics:

The first characteristic is 'interactive complexity of the system': a supply chain is a socio-technical system, which Simon (1962) explained is a complex system because there are many elements interacting in a non-simple way, making it more difficult to manage and control. According to NAT, complexity becomes dangerous when the interactions among the components of the system are nonlinear because nonlinear interaction leads to unpredictable event sequences. Many small failures can interact and produce unexpected, unfamiliar events.

The second characteristic is 'tight coupling of the elements in the system': the systems, which contain interrelated components that have time-dependent processes, possible substitutions, and minimal slack or buffer, are tightly coupled systems (Galbraith, 1973; Perrow, 1984). Although tight coupling systems generally have higher efficiency and performance standards, loosely coupled supply chains are able to absorb environmental changes, failures, or unexpected system behaviours. In tightly coupled systems, a change in one component may trigger a fast and strong change in other components in a kind of domino effect. Thus disruptions can spread rapidly through the system.

According to this, a system with high levels of interactive complexity and high levels of tight coupling is vulnerable to accidents because when the two characteristics are combined, it becomes impossible to predict and protect the ways

in which the system could fail. The accidents are hence inevitable; it can be concluded that in such systems, accidents are normal.

NAT stated that supply chains with a high degree of interactive complexity and tight coupling have higher frequency of supply chain disruption. However, some literature (Hopkins, 1999; Wolf, 2001) argues that the level of tight coupling is difficult to subject to empirical test.

There is no consensus on the definition of supply chain complexity. There are two dimensions of supply chain complexity, which are information processing and technology (Vachon & Klassen, 2002). Choi and Krause (2006) assumed that supply chain complexity has three drivers: (1) the quantity of suppliers, (2) the diversity among the suppliers, and (3) the inter-relationships among the suppliers. According to literature in organisational design, there are three dimensions of complexity: vertical complexity, horizontal complexity and spatial complexity (Daft, 2006). These can be applied to the context of supply chain. Vertical complexity can refer to the number of tiers in the upstream supply chain. Horizontal complexity refers to the number of suppliers. Spatial complexity can refer to the geographical dispersion of the supply base (Choi, Dooley & Rungtusanatham, 2001; Choi & Hong, 2002; Vachon & Klassen, 2002). It can be summarised that these three dimensions amplify the complexity of supply chain and, therefore, increase the uncertainty and diminish transparency, which lead to higher exposure to supply chain disruptions (Choi & Krause, 2006).

2.6.2 High Reliability Theory

Rijpma (2003) pointed out that Perrow's (1984) NAT can be overly pessimistic in concluding that accidents are inevitable in systems with interactive complexity and tight coupling. High reliability theory argues that the likelihood of normal accidents can be reduced by organisational and structural precautions (Roberts, 1990). The theory examines the characteristic of organisations that show strong ability in dealing with unexpected events and concludes that although organisations may have interactive complexity and tight coupling in the supply chain, they can be successful if they possess the characteristics of highly reliable organisations.

The empirical test of high reliability theory is not very precise nor consistent. For example, redundancy was suggested to help organisations buffer the impact of

unexpected situations and reduce mistakes (Roberts, 1990). In contrast, redundancy was also found to backfire in some critical situations (Sagan, 2004). Another recommendation was that the right training should be able to reduce the impact of crisis situations. However, other studies argue that training can also diminish flexibility, which results in an organisation's lower ability to respond to crisis situations (Price, 1977).

Therefore, Bode and Wagner (2010) suggested that the focus should be made on the characteristics that have been repeatedly accepted to enhance reliability such as decentralised decision making (Roberts, Stout & Halpern, 1994). When the supply chain is decentralised, the information and decisions regarding the supply chain are generated closer to the suppliers, making the organisation able to respond to warning signals and disruptions better (Bode & Wagner, 2010).

2.6.3 Transaction Cost Theory

In essence deals with the basic question of how to organize economic activity: should activities be based within the hierarchy or should activity outcomes be obtained through the open market? Coase (1937) explained that transaction costs are incurred from activities in the open market and in particular related to cost of searching and finding information, bargaining and decision costs and policing and enforcement costs. Insights from the transaction cost perspective are suitable for making decision about governance and understanding motives of other partners.

In this study, the goal is to understand the speed of response in Detection, Design, and Deployment. Presuming the supply chain transactions cross the firms internal (divisional, cross functional) and external boundaries (suppliers, customers, logistics), risks may be present and transaction cost theory suggests that such differential costs, of whatever nature, could be factored into a model of risk response.

If, for example, events that lead to catastrophic failure are less visible, that is, take longer or are more expensive to Detect, then a Transaction Cost theory may suggest a different organization boundary will be more robust. At a minimum, greater focus on such external relationships will be beneficial; the classic example of Nokia versus Ericsson could be studied from this perspective. Both firms outsourced chip production of common, key component – typical in an environment of rapid

change, tremendous specialization and large investment – to Philips Electronics. Nokia proactively sought information on the status of the Philips factory after a small but devastating fire; Ericsson relied on the information it was given. Such an event within either firm, it could be surmised, would be better communicated and result in a different risk / response pattern.

Other differences, for example in engineering or management culture, internal versus external to the firm can also have an impact on the Design or Deployment time in reacting to an event. Transaction Cost theory potentially provides an additional dimension to time response. In this study, one could consider this dimension as a starting point for exploratory questions or to assure completeness of the data, may explicitly identify participants whose role or expertise provide insight from across the organizational boundaries.

2.6.4 Agency Theory

Agency theory deals with how relationships are organized when it is based on a principal-agent type of transaction (Eisenhardt; 1989), and enables control and coordination via highlighting the importance of monitoring and creating incentives (Child et al., 1998). Especially within knowledge-based economies there is evidence of a theory related to increasing returns (Arthur; 1989). Arthur's main point was that "if technological ecologies are the basic unit of strategy in the knowledge-based world, players compete by building webs… that amplify positive feedback to the base technology".

In economics, the principal-agent problem treats the difficulties that arise under conditions of incomplete and asymmetric information when a principal hires an agent. There are two problems arising. The first is the agency problem that occurs when (a) the desires or goals of the principal and agent conflict and (b) it is difficult or expensive for the principle to verify what the agent is actually doing. The problem here is that the principal cannot verify that the agent has behaved appropriately. The second is the problem of risk sharing that arises when the principal and agent have different attitudes towards risk. The problem here is that the principle and the agent may prefer different actions because of the different risk preferences (Eisenhardt, 1989).

Risks in supply chain become more obvious when viewed using agency theory. For example, the supplier (agent) of a critical component make take a less-robust, cost-minimizing approach to manufacturing in order to win a procurement contract, however leaving its customer (principal) disproportionately exposed should a manufacturing disruption occur. Information sharing between and agent and principle become a key objective of the principle; this can be extended to consider the time / risk relationship for supply chain.

Agency theory may also provide additional insight in the management of disruption in the supply chain. Information asymmetry can distort the perception of risk or potential consequence of disruption, in particular where asymmetric and non-linear financial or other impact is faced by participating firms. For example, where a very large, well-funded firm has outsourced a particular task to a much smaller partner, collapse of the common supply chain could leave the larger partner liable to greater litigation and penalties, even if the smaller firm were contractually and in practise the responsible party. Conflicting incentives on production speed versus quality may motivate a firm to withhold crucial information if such information is only revealed – potentially through catastrophic failure – at a much later stage. Counterfeit aircraft components, for example, have been root cause of several air disasters, when such components were sold and installed by a subcontractor to the airline at high profit long before the accident occurs. In this study, agency theory could potentially provide an additional research guide for understanding the perception of catastrophic risk and the resulting management systems in terms of the time-based framework. This additional dimension requires saturation of concepts, which may be visible at a contractual level between firms, however, rather than within the management perspective of individual participants, which are the focus of data collection here. Agency theory could be applied to test, in future research, to the propositions developed in this study.

2.7 Research Gap

The literature in supply chain risk has proposed a number of different approaches to the management of supply chain risk (Chopra & Sodhi, 2004; Christopher & Peck, 2004; Elkins et al., 2005; Lee & Wolfe, 2003; Martha & Subbakrishna, 2002; Rice & Caniato, 2003). While Kleindorfer and van Wassenhove (2004) propose that supply chain risk management activities comprise supply-demand coordination

activities and activities for managing disruption risks, Tang (2006) proposes that the management of supply chain risk should focus on four areas: supply management, demand management, product management, and information management. Wagner and Bode (2009) propose a different approach to supply chain risk management by stating that the management should focus on cause-oriented measures (the prevention or elimination of supply chain disruption) and effect-oriented measures (the attempt to reduce the impacts from supply chain disruptions when they occur).

Further, certain existing supply chain risk management literature has focused on prescribing effective recovery plans for reducing the impact of disruption after an event occurs (Christopher, 2002; Chopra & Sodhi, 2004; Lee, 2004; Sheffi, 2005; and Tang, 2006). Sodhi and Tang (2008) argue that these strategies can improve recovery if the firm can deploy their strategies during or soon after the event occurs.

Literature in other fields of scientific research has documented the role of time as a surrogate measure of the impact of a disruption, for example in the spread of disease or forest fire (Richads, 1995; Janssens, 2000; Arora & Boer (2005). Specifically, the impact of a natural disruption tends to initially increase exponentially with time and then eventually taper off.

In addition to these natural disruption models, there are hazard analysis reports related to supply chain management showing that the magnitude of problems associated with many hazards (fire, terrorism, earthquake, etc.) tend to grow super linearly over time (Anderson et al., 2002).

The time-based paradigm was first highlighted explicitly in the supply chain management literature in the late 1980s by Stalk (1988) who noted that traditional manufacturing focussed on achieving low production cost through the utilisation of low-cost labour. Attention then shifted to specialisation and exploiting production competency. Time-based competition emerged as the competitive paradigm during the 1990s, which mandates a strategy of customer responsiveness and rapid new product introduction, along with competitive quality and cost. The essence of time-based competition involves compressing time in every phase of the product creation and delivery cycle. The claim is made that in today's business, only time-

based firms will be able to meet such customer demands and respond quickly to changing consumers' needs (Stalk, 1988; Stalk & Hout 1990; Blackburn, 1991).

As discussed in the literature review, time plays a vital role in logistics and operations research. There is much existing time-based literature in traditional production/ operations management research such as time-to-market, just-in-time manufacturing, product innovation, role time in customer service and satisfaction, etc. Yet one issue that remains relatively unexplored is time in risk management perspective – namely, how companies leverage time in managing disruption risk. Thus, a research gap exists in addressing how time-based risk management can be used as a strategy to response supply chain disruption by reducing the impact of disruption risk in the supply chain.

This research therefore is concerned with the external risk that arises from disruptions to normal activities. It is also known as 'disruption risk', which refers to the major disruptions caused by natural and man-made disasters such as earthquakes, floods, hurricanes, outbreaks of disease, price rises, strikes, problems with trading wars, terrorist attacks or economic disruptions, and financial irregularities such as currency evaluation (Sodhi, 2004; Tang, 2005; Kleindorfer & Saad, 2005; Waters, 2007).

The business impact associated with disruption risks is harmful, costly and greater than others. This research argues that supply chain disruptions are unavoidable and, as a consequence, that all supply chains are inherently risky; accordingly, companies should seek to respond faster to a disruption in their supply chain.

Sodhi, Son and Tang (2012) have argued that the supply chain risk literature has understudied response as following:

Definition gap: there is not enough agreement on the nature of supply chain risk.

Process gap: between (1) identification (2) assessment (3) mitigation and (4) response, there has been proportionally much less attention on response, whether to operational risks or to disruptions (catastrophic risks)

Methodology gap: empirical research in the OM literature is proportionally less represented in the literature on supply chain risk

Specifically, firms need to identify the factors in the speed of response in order to prepare and act faster in the management supply chain disruption. In this research, disruption risk is being the potential of an unplanned, internal or external event of low probability but high impact that occurs in the supply chain. This unplanned event creates sudden, sharp, and significant impact on the ability of supply to meet demand, resulting in major disadvantage or potential loss for the firm.

2.8 Research Question

As introduced in Chapter 1, this research seeks to fill the gaps in the supply chain risk management by conducting an empirical study to explore how global companies manage response time to minimise the impact of disruption on the supply chain. The primary research question is

'What factors underlie companies response to supply chain disruption?'

Underlying the theory that greater response speed can reduce the impact of disruption, I presume a model where impact increases hyper linearly over time until some point where material damage to the firm and its environment has occurred. This can include among other things the impact on internal human life and resources, systems and supply chain, and financial loss, also external factors such as customer defection, reputation, and regulatory and legal action against the firm.

Motivated by Sodhi & Tang (2009), I considered response as detection, design and deployment.

Therefore, in order to answer the primarily research question, the following aspects are considered in each case:

- How did the company respond to supply chain disruption?
- How did the company detect and communicate information about the disruption and what did the company do to reduce detection time?
- How did the company design and select possible solutions to address the disruption and what did the company do to reduce design time?
- How did the company deploy their selected solutions? What did the company do to reduce the deployment time?

2.9 Research Framework

Supply chain disruption can be costly and damaging to the firm. Costs can be measured in financial metrics such as drop in market capitalisation (Hendricks & Singhal, 2003a; Kilgore, 2004), but also in terms of lost reputation, deteriorating competitive position, increased or restrictive regulation, loss of internal capacity and so forth, with wide-ranging impact across the organisation and its supply chain.

As stated by Perrow (1984) in his widely referenced work on Normal Accident Theory, accidents become inevitable if a system exhibits: (1) interactive complexity and (2) tight coupling. Linear interaction leads to a predictable and comprehensible sequence of events, while non-linear interactions (interactively complexity) lead to unexpected event sequences. Herbert A. Simon (1962) characterised a complex system as being 'made up of a large number of parts that interact in a non-simple way'. From this perspective, supply chains can be viewed as complex and according to some theories such as normal accident theory, disruption is inevitable.

Certain characteristics of the supply chain (density, complexity, node interactivity) are stated in some literature to have a positive correlation with the severity of supply chain disruption (Craighead et al., 2007). Other definitions of supply chain complexity in the literature include Choi and Hong (2002), who consider vertical complexity, horizontal complexity, and spatial complexity in terms of parallel, sequential span and geographic disperse supply chain stages. Vachon and Klassen (2002) looked at complexity in terms of information processing and technology. Choi and Krause (2006) illustrate a different approach focussing primarily on supply complexity: (1) the number of suppliers, (2) the differentiation among the suppliers, and (3) the inter-relationship among the suppliers in the supply base.

As stated in earlier in section 2.6.1 and section 2.6.2, the proponents of High Reliability Theory view Normal Accident Theory as too 'pessimistic', and believe that appropriate design can reduce or even eliminate system and supply chain failure. They state that redundancy of unreliable components, decentralised decision-making, 'culture of reliability', training, and learning from previous accidents can reduce or eliminate failure (Rijpma, 2003; Roberts, 1990; Sagan, 2004; Price, 1977).

Bode and Wagner (2010) test the complexity proposition that Craighead et al. (2007) propose and confirm that the degree of supply chain complexity influences the occurrence and magnitude of supply chain disruption. They also find that Normal Accident Theory and High Reliability Theory seem to be meaningful theories for understanding the causes of supply chain disruption. Faster product and technology life cycles, increased use of manufacturing, distribution, and logistics partners, greater customer expectation and regulatory complexity are resulting in more complex and longer supply network relationships, which make the supply chain more complex. In addition, due to the globalisation of markets and supply chain operations, local events increasingly have indirect global repercussions. Certain types of risks – of human or natural origin – remain difficult if not impossible to predict in frequency, magnitude or both; events in Northern Japan triggered by an offshore earthquake in 2011 provide ample evidence of local impact on global supply chain operations.

Global supply chains are by nature unavoidably complex and de facto vulnerable to disruption. In this research I consider an intersection of probability and impact, and leverage a time-based risk management framework (Sodhi & Tang, 2009) to better address disruption through faster response.

At a high level, supply chain risk = probability (of an event) x business Impact (or severity) of the event (Brindley, 2004).

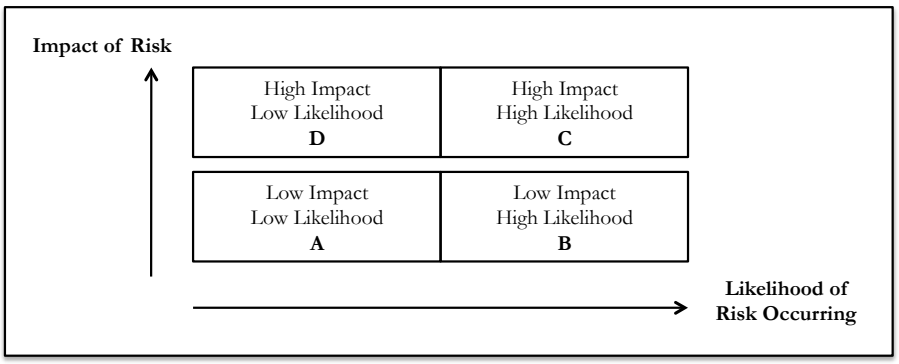


Figure 4: Classification of Disruption Risk

Figure 4 shows a straightforward risk matrix measured on two dimensions – 'the impact of risk' and 'likelihood of risk occurring'. Probability can be further

understood to be low frequency (for example, from the 'millennium bug' in software systems from two-digit date recording in the transition from the year 1999 to 2000) and/or low likelihood (natural events, terrorist attack, failure from obscure or complex interdependency internal to a system). Impact can be further understood in terms of high-impact of known magnitude (for example, due to 72 hour closing of US airspace in September 1999) or high-impact of unknown magnitude (for example, ongoing nuclear crisis in Japan during early 2011).

Most companies develop plans to protect against recurring, low impact risks in their supply chains. Many, however, all but ignore high-impact, low-likelihood risks. For instance, a supplier with quality problems represents a common, recurrent disruption. Without much effort, the customer can demand improvement or find a substitute. In contrast, in regions where earthquakes are rare, preparedness to prevent major disruption may be weak or uneven. This research will focus on Box D – high impact but low likelihood – where risk management must seek to mitigate the losses due to high-impact events in the supply chain. It is also important to minimise exposure in general to such events, which is mainly done by designing appropriate structures and a robust business/operating model. Such high-impact events of high likelihood (Box C) – the drivers for which can be identified – are typically addressed in the design of the supply chain. High-impact events with low likelihood (Box D) or unknown origin – referred to here as catastrophic events that can cause supply chain disruption – cannot be easily avoided due to their unpredictable nature and unpredictable locus in the supply chain as well as potentially prohibitively high cost of detection and avoidance.

This research extends a framework on time-based risk management whose premise is that faster response to disruption in the supply chain will reduce impact. Figure 5 illustrates the framework along a time dimension to structure the research. This framework for time-based risk management is developed by Sodhi and Tang (2008). They state that this approach has been used assessed with 'anecdotal examples of companies rather than detailed case studies'. I will extend the approach through analysis of data from three contemporary events in details in order to study the importance of time in established risk management processes.

In the 3D framework, elapsed time can be divided into three stages, which Sodhi and Tang (2008) abbreviate as 3D. The 3D framework divides a company's

response lead-time (R1) into three sequential components – the first component is 'Detect' (D1), which is defined as the time between the moment an event has occurred and the time at which the firm recognises the fact that the event has occurred. The second component is 'Design' (D2), which is defined as the time between the detection of an event and the time at which a specific recovery plan is designed. The third component is 'Deploy' (D3), which corresponds to the time between the design of the recovery plan and the time at which the firm has deployed the solution. After deployment, the time it takes to effectively restore the supply chain operation is denoted the recovery lead-time (R2).

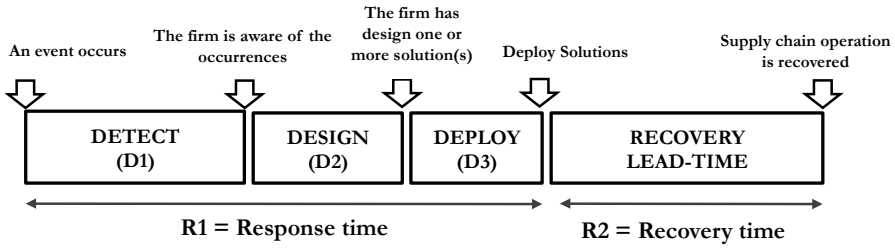


Figure 5: Time Dimensions in Time-Based Risk Management Framework

Source: Sodhi & Tang (2009)

According to Sodhi and Tang (2008), faster deployment of a recovery plan via shortening the response lead-time R1 can enable a firm to reduce supply chain risk significantly. Figure 6 shows the effect when reducing R1; the magnitude of the problem caused by the disruption is smaller. It is also plausible that the recovery lead-time (R2) is shortened because the recovery plan is deployed sooner. Thus, the response lead-time (R1) is essential for managing supply chain disruption.

Various risk management models ascribe increased vulnerability of a supply chain to its characteristics, such as density or interactivity between supply chain nodes. Sodhi and Tang (2008) goes further and illustrates interrelationship between risk mitigation strategies, where one risk mitigation strategy addressing certain risk types can in fact increase vulnerability to another.

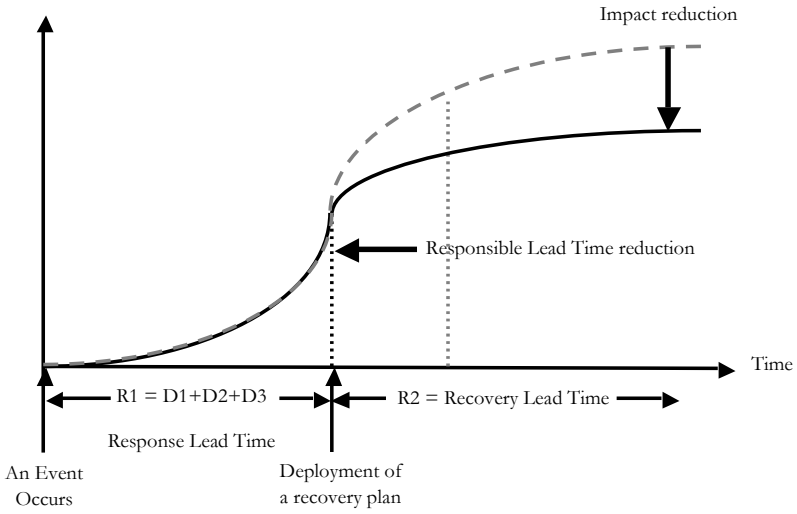


Figure 6: The Effect of Reducing Response Lead Time

Source: Sodhi & Tang (2009)

Adapting a complexity model of supply chain risk (Criaghead et al., 2007) and time-based risk management framework (Sodhi & Tang, 2008), I illustrate an overall framework for this research. The research conceptual framework is provided in Figure 7, highlighting elements of analysis in bold. The three elements of response time in this framework are assumed to drive increased an impact of supply chain disruption. The goal of the research is to understand how companies view and use detection time, design time and deploy time in order to respond to supply chain disruptions. The identification and characterization of the factors underlying the response time from empirical analysis of the real-life cases are the primary contribution of this research. These are indicated as F_1, F_2, F..., F_n in Figure 7 – The research conceptual framework. Table 5 shows definitions used in this research to support case analysis.

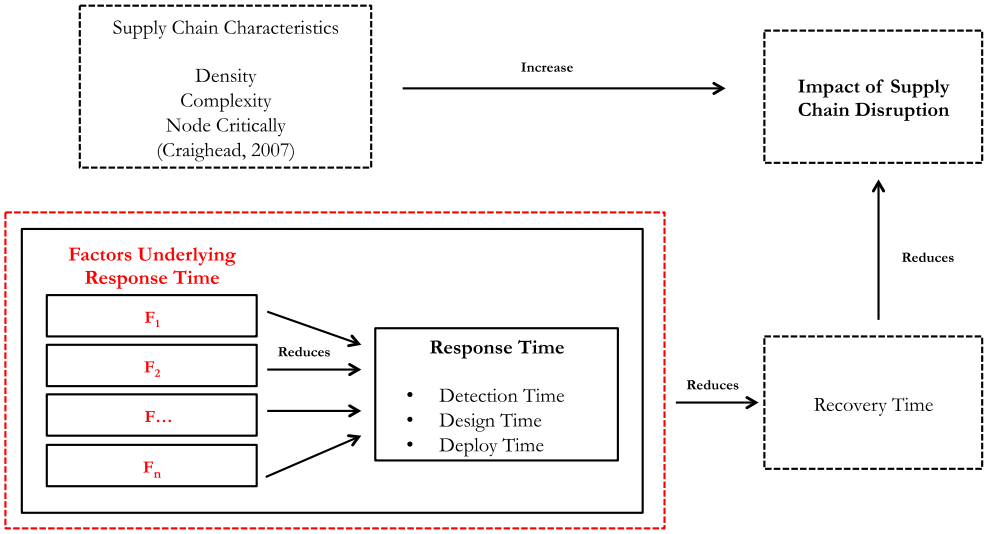


Figure 7: The Research Conceptual Framework

Term	Definition
Disruption Risk	The potential of an unplanned, internal or external event of low probability but high impact that occurs in the supply chain. Such an unplanned event could create sudden, sharp, and significant impact on the ability of supply to meet demand, resulting in major disadvantage or potential loss for the firm.
Supply Chain Disruption	Unplanned events that may occur in the supply chain, which might affect the normal or expected flow of materials and components (Adapted from Svensson, 2000; Hendricks & Singhal, 2003; Kleindorfer & Saad, 2005; Craighead *et al.*, 2007).
Response Lead Time	The elapsed time between detection of an event and substantial implementation of an appropriate response (Sodhi & Tang, 2009).
Detection Time	Elapsed time between the occurrence of an event and the moment a firm recognises the occurrence of – or the initial impact of – the event (Sodhi & Tang, 2009).
Design Time	Duration between detection of an event and definition of possible solutions, based on existing concepts and methods or new solutions, which can restore normal supply chain operations (Adapted from Sodhi & Tang, 2009).
Deploy Time	Duration between start and completed implementation of a selected solution that is successful in significantly restoring supply chain operations (Sodhi & Tang, 2009).
Supply chain characteristics	Strategic and operational structure of the supply chain, including strategies for efficiency and speed as well as strategies for risk management. (Craighead et al., 2007; Bode & Wagner, 2010).
Recovery time	Total duration between an event and the return of the supply chain to normal and planned flow of products (Sodhi & Tang, 2009).
Recovery capabilities	Recovery capability or the interactions of supply chain entities and the corresponding coordination of supply chain resources to return the supply chain to a normal and planned level of product flow (Craighead et al., 2007).

Table 5: Definition Used in the Research

Chapter 3
Methodology

This study employs classic Grounded Theory methodology (Glaser & Strauss, 1967; Glaser, 1978, 1992, 1998, 2001, 2003, 2005; Strauss and Corbin, 1990). As a research strategy, Grounded Theory is well suited for exploration and study of unstructured natural phenomena through extensive and iterative data collection and analysis.

3.1 Grounded Theory Methodology

Glaser and Strauss introduced Grounded Theory in their seminal book "The Discovery of Grounded Theory", published in 1967. Their approach to qualitative analysis was developed during an observational field study of nurses and hospital staff on their work with near-death patients. Strauss and Corbin (1990, p.24) later provided a succinct definition:

> *"A qualitative research method that uses a systematised set of procedures to develop and inductively derive Grounded Theory about a phenomenon."*
>
> *Strauss & Corbin (1990, p.24)*

Creswell (2002, p.439) further defines Grounded Theory as a "systematic, qualitative process used to generate a theory that explains, at a broad conceptual level, a process, an action, or interaction above a substantive topic."

The objective is to develop an account of a phenomenon that identifies the major constructs - in Grounded Theory terms 'categories', their relationships, context and process, providing a theory of the phenomenon which goes further than just a descriptive account (Morse & Richards, 2002; Becker, 1993). This allows one to "organise many ideas from analysis of the data" (Strauss, 1967, p.23). Strauss and Corbin (1990, p.24) emphasized the need to develop theory "that was faithful to and illuminated the area under study."

Theories derived in this approach may also relate to existing theories, and are not necessarily developed in isolation. This allows Grounded Theory to be used to extend and explore current understanding of the phenomenon. In this study, a

time-based risk management framework provides the context and lens through which the mechanisms of risk management are to be discovered.

Strauss (1967, p.22-23) summarised Grounded Theory procedures as the systematic analysis of documents, interview notes, or filed notes by continually coding and comparing data that produced a "well constructed theory." Viewed this way, the theory is inductively derived from the phenomenon under study. The data collected and analysis are intrinsically linked with the derived theory. Unlike other scientific methods, in which the researcher collects data to test an existing theory, Grounded Theory allows the theory to emerge directly from qualitative data. In this sense, the emergent theory is 'grounded' in the data. As Strauss and Corbin (1994, p.274) noted, "the major difference between this methodology and other approaches to qualitative research was its emphasis upon theory development," and not on the descriptive or narrative aspects of qualitative analysis.

Grounded Theory is structured from three basic elements: concepts, categories and propositions. Concepts are the most basic component of Grounded Theory. Theory development is based on these units of analysis, not directly from the underlying data. In a definition of concepts used by Corbin and Strauss (1990), these are "words that stand for groups or classes of objects, events, and actions that share some major common property(ies), though the property(ies) can vary dimensionally." They emphasize the conceptualization of data:

> *"Theories can't be built with actual incidents or activities as observed or reported; that is, from "raw data." The incidents, events, happenings are taken as, or analysed as, potential indicators or phenomena, which are thereby given conceptual labels. If a respondent says to the researcher, "Each data I spread my activities over the morning, resting between shaving and bathing," the researcher might label this phenomenon as "pacing." As the researcher encounters other incidents, and when after comparison to the first, they appear to resemble the same phenomena, then these, too, can be labelled as "pacing," Only by comparing incidents and naming like phenomena with the same term can the theorist accumulate the basic units for theory."*
>
> *Corbin and Strauss (1990, p.7)*

Categories – or themes - of related concepts form the second element of Grounded Theory. Corbin and Strauss (1990) defined categories as a "higher-level concepts under which analysts group lower-level concepts according to shared properties. They represent relevant phenomena and enable the analyst to reduce and combine data." Thus:

> *"They (categories) are generated through the same analytic process of making comparisons to highlights similarities and differences that is used to produce lower level concepts. Categories are the "cornerstones" of developing theory. They provide the means by which the theory can be integrated. We can show how the grouping of concepts forms categories by continuing with the example presented above. In addition to the concept of "pacing," the analyst might generate the concepts of "self-medicating," "resting," and "watching one's diet." While coding, the analyst may note that, although these concepts are different in form, they seem to represent activities directed toward a similar process: keeping an illness under control. They could be grouped under a more abstract heading, the category: "Self Strategies for Controlling Illness"*
>
> *Corbin and Strauss (1990, p.7)*

Propositions make up the third component of Grounded Theory, which serve to express the relationships between a category and its concepts and between categories. In the original paper, these where originally referred to as 'hypotheses' (Glaser and Strauss, 1967). As Whetten (1989, p.42) pointed out, 'propositions' involve conceptual relationships, whereas 'hypotheses' suppose quantifiable relationships. Accordingly, the term propositions is chosen here, given the conceptual nature of the conceptual relationship which are evident but not be directly measurable.

Concepts, categories and propositions are developed iteratively, as new data is incorporated and the emerging theory adapted and refined. Unlike other methodologies, Grounded Theory does not engage in the linear testing of an existing theory, in contrast, it is:

> *"…Inductively derived from the study of the phenomenon it represents. That is, discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory should stand in reciprocal relationship with each other. One does not begin with a theory, and then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge.*
>
> *(Strauss and Corbin, 1990, p.23.)*

3.2 Grounded Theory and Qualitative Research

Grounded Theory has its roots in two philosophical schools of thought, namely logical positivism and pragmatism. Influential until the late 1970's, positivism is based on the application of formal logic to underpin an empirical understanding of the world, where scientific truths are verifiable claims. Pragmatism (from the Greek

'pragma' meaning 'act' or 'deed') describes the process in which theory can be extracted from practise and applied back, resulting in 'intelligent practice'.

Combining these philosophies, Glaser and Strauss (1967) defined qualitative research using techniques such as: "Simultaneous data collection and analysis coding, creating categories for data, comparative analysis of data, theory development during data collection and analysis, detailed categories, establish properties for categories, and identify relationships between categories, theoretical sampling to make research more robust and literature review written after data analysis instead of drive the research."

Using this approach, Grounded Theory, according to Strauss and Corbin (1990, p.19), qualitative research can 'uncover and understand what lies behind phenomenon about which little is known'. Their work provided greater philosophical credibility to qualitative research, in contrast to methodology relying, for example, on quantitative methods such as statistical sampling. Selecting between qualitative and quantitative research methods has been stated as one of the most challenging decisions for researchers in the early stage of their research, with a simple but logical answer to this suggested by Ellarms (1996): 'it all depends on the researcher's skill and the nature of the research question.' Grounded Theory is a general method of analysis that accepts qualitative, quantitative, and hybrid data collection from surveys, experiments, and case studies (Glaser, 1978).

Since research in logistics and supply chain management is a relatively new discipline, there are few well-established research templates in the field. Mentzer et al. (1995) also said 'there is little to guide logistics research in how to adopt a rigorous research process that manifests theory development.' Therefore, they proposed a logistics research framework within the positivist approach, which offers a comprehensive perspective on the logistics research process.

The logistics research framework presented by Mentzer and Kahn is a continuous process that integrates three research stages which are: (1) idea generation to substantive justification, (2) theory construction to methodology and (3) methodology to conclusions and future research.

Grant (2001) stated that Mentzer's logistics research framework (1995) 'is consistent with the nature of positivist and quantitative enquiry that consists of idea generation, literature review, hypothesis formulation, data collection and analysis, and discussion.' Thus, it is appropriate when descriptive or causal research is undertaken.

In the period after they created the concept of Grounded Theory, numerous publications sought to further investigate the underlying philosophical foundation and procedures used in Grounded Theory (Glaser, 1978, 1992; Glaser and Strauss, 1968; Straus and Corbin, 1990; Wester and Peters, 2004). Strauss joined with Corbin in the 1990s to support use of predetermined categories in Grounded Theory and address issues in validity and reliability of theory development.

While Strauss & Glaser (1967) evidently used logical positivism in the development of Grounded Theory, others argued that the assumptions and methods were more closely related to hermeneutics (Parker, L.D. and Roffey, B. (1993) and Laws, K. and McLeod, R. (2004). Hermeneutics is the study and theory of interpretation, typically applied to areas of social research of written, spoken and non-verbal communication in religion, literature and law.

Babbie (2001) contrasts hermeneutics in social sciences as "interpreting social life by mentally taking on the circumstances, views and feelings of the participants", describing Grounded Theory simply as "a term used in reference to the creation of theory based on observation more than education". Strauss and Corbin (1990) implicitly acknowledged the hermeneutic and phenomenological foundations of Grounded Theory when they stated:

> *"Data collection, analysis and theory stand in reciprocal relationship with one another. One does not begin with a theory, and then prove it. Rather, one begins with an area of study and what is relevant to that area of study is allowed to emerged."*
>
> *Strauss and Corbin (1990, p.23)*

Table 6 show the sets out the key distinctions between logical positivism, hermeneutics, and Grounded Theory.

More recently, Charmaz (2006) argued that Grounded Theory should use an interpretivist approach, referring to her method as the 'constructivist' Grounded

Theory model. Positivist and interpretive work can co-exist, the former seeking to understand social relationships, in this case the managerial and operative context of risk management, the latter seeking to understand the social mechanisms that underpin tailored approaches to risk understanding and risk management in the specific cases used for this study. 'It seeks to describe many perceived realities that cannot be known a priori because they are time- and context-specific. Thus, research is actually an emergent process. As perceived realities change, the research design adapts … the interpretivists conduct research in a natural, changing environment' (Hudson et al., 1988). Charmaz' interpretivist approach allows Grounded Theory methodology to have greater flexibility, particularly relevant here when observation of the PHARMA and events are made as the situations evolve.

Positivism	Hermeneutics	Grounded Theory
Defines the world as objects	Resists objectification	Accounts for processes that can change the coded 'meaning' of observed phenomena.
Objectification seeks explanation	Seeks understanding	Seeks understanding based on interrelationships between conditions, meaning and action
Objectification seeks dissection and reduction	Seeks respect for the whole	Avoids reductionism b using conditional matrices and transactional systems
Truth is to be found in "agreement" by verification	"Truth" is revealed phenomenological	"Truth" is approximated by the researchers creative engagement with systematic, interactive data collection, analysis and validation process.
"Meaning" is to be found in closed definitions	"Meaning" is to be found through interpretation that allows future layers of interpretation	"Meaning" is found through interpretation that allows future levels and categories of interpretation and "explanation"

Table 6: Positivist, Hermeneutic and Grounded Theory Assumptions

Source: Parker, L.D. & Roffey, B. (1993)

To summarize, Grounded Theory methodology has three major design patterns:

1. Systematic design (Strauss and Corbin, 1998): In systematic design, propositions are developed through a sequence of data collection, coding, and the visual representation of categories that group and relate codes. This enables construction of a specific set of verifiable set propositions from pre-existing vantage point based on qualitative data.

2. Emerging design (Glaser, 1992): In emerging design, the relationship between categories is emphasized and explored by the researcher, with very open approach to theory development.

3. Constructivist approach (Charmaz, 1990, 2000, 2006): The constructivist approach emphasizes the meaning and interpretation of data by the participants and the researcher, allowing subjective view of events and their relationships specific to the situations and data sets under study.

3.3 Grounded Theory and Abductive Research

In general, there is a lack of formal discussion on research approaches in logistics literature. The central approaches in Western research traditions have been those of deduction and induction (Kirkeby, 1990). The deductive research follows a conscious direction from a general law to a specific case (Andreewsky and Bourcier, 2000; Taylor et al., 2002).

According to Arlbjorn and Halldorsson (2002), deductive research is suitable for testing existing theories, not creating new science, whilst the inductive research approach moves from a specific case or a collection of observation to general law or from fact to theory. Accordingly, inductive research is generally appropriate in developing new theories. Figure 8 compares deductive and inductive research process.

C.S. Pierce introduced the concept of abduction as a method of deriving a theory from underlying facts and observations (Cunningham, 1998, p.833). Abduction is often referred to in the literature with the same meaning as 'reduction' (Emery and Emery, 1997). As one of main proponents of Pragmatism, his defining work on abduction takes a key role in this methodology. Distinct from deduction and induction, abduction is focussed on the iterative interpretation of data to derive explanations for the observed facts. Abduction applies derived propositions to the observed facts 'tending to make them applicable in any way to other circumstances than those under which they are observed' (Peirce, 1955, p.150), in other words, an inference starting with observed facts and linking logically backward to potential cause.

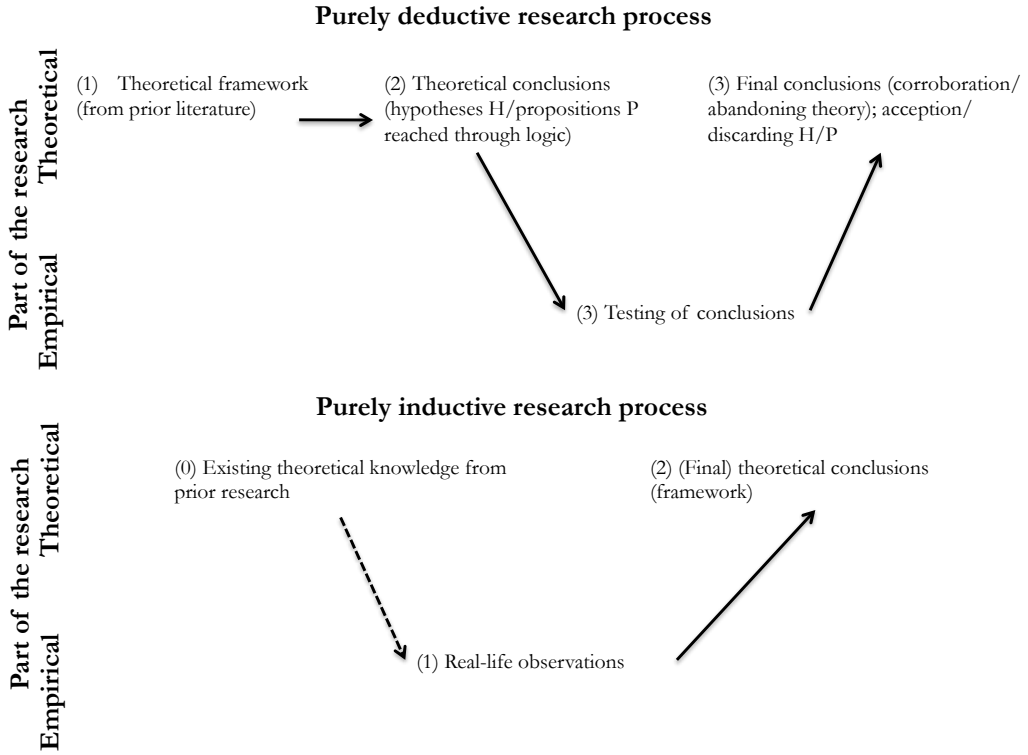


Figure 8: The Purely Deductive and Inductive Research Process

Sources: Kovacs and Spens (2005)

According to Cunningham (1998, p.833-4), abduction is the appropriate method for making sense of new (or unfamiliar) situations. Abduction is essential to development of reasoning, in that 'all thought would be totally impossible in a universe in which abduction was not expectable' Bateson (2002, p.134), in one view.

The differences between induction, deduction, and abduction is classically illustrated in Table 7 with simple hypothetical example, that of a bag of beans, white or black, provided by Shank (1998, p.847):

Deduction	
Rule	[It is true that] All the beans from this bag are white
Case	[We know that] These beans are from this bag
Result	[Certainly, it is true that] These beans are white
Induction	
Rule	[We know that] These beans are from this bag
Result	[We have observed that] These beans are white
Rule	[Probably, then] All the beans from this bag are white
Abduction	
Result	[We have the experience that] The beans are white [but this experience lacks any real meaning for us].
Rule	[The claim that] All the beans from this bag are white [is meaningful in this setting].
Case	[Therefore, it is both plausible and meaningful to hypothesize that] These beans are from this bag.

Table 7: The Method of Deduction, Induction and Abduction

Source: Shank (1998, p.847)

3.3.1 Abduction within Grounded Theory Approach

Within the Grounded Theory approach, the importance of abduction has been recognised by Coffey and Atkinson (1996, p.155) stating that 'abductive reasoning' lies at the heart of 'grounded theorising.' Furthermore, they state that:

> *"Our important ideas are not 'in' the data, and however hard we work, we will not find those ideas simply by scrutinising our data ever more obsessively. We need to work at analysis and theorising, and we need to do the intellectual, imaginative work of ideas in parallel to the other tasks of data management."*
>
> *Coffey and Atkinson (1996, p.155)*

Thus, abduction is a type of inference that operates bottom up: individual facts are collected and connected together in order to develop hypotheses. An observed phenomena is the starting point (Coffey and Atkinson, 1996), which at first pass suggests the exclusion of formal theory Coffey and Atkinson (1996, p.157) allow for formal theory in this approach

> *…We can also recognise that theories usefully can be thought of as heuristic tools. In other words, we use concepts, theories and ideas constructively and creatively…Regularities in data – whether of form or content – must be associated with ideas that go beyond those data themselves.*
>
> *Coffey and Atkinson (1996, p.157)*

As pointed out earlier, much of the logistics research has a positivist approach and has been criticised for lack of focus on theory development (Stock, 1997; Kovacs &Spens, 2005). Kovacs and Spens (2005) proposed that an abductive research

process (Figure 9) is an appropriate tool to further theory development in business logistic research. The abductive approach resonates with the fact that significant advances in science typically follow neither a pattern of pure deduction nor of pure induction (Kirkeby, 1990; Taylor et al., 2002).

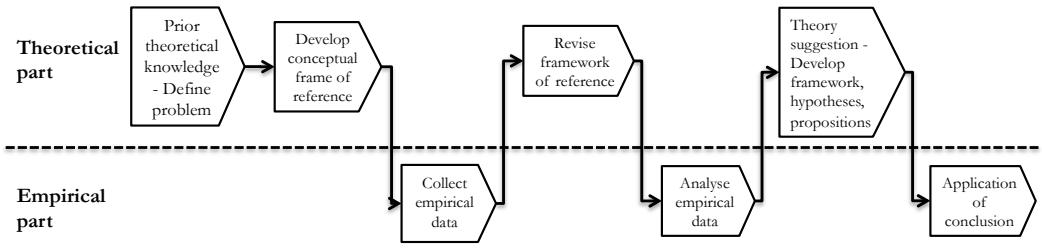


Figure 9: The Abductive Research Process Applied in This Research

Source: Adapted from Dubois and Gadde (2002) and Kovacs and Spens (2005)

The abductive approach leads to new insight about existing phenomena by examining these from a new perspective. This way of creating knowledge is found in logistics research that borrows theories from other scientific fields (Arlbjorn and Halldorsson, 2002; Stock, 1997). In addition, abduction works through interpreting or re-contextualising individual phenomena within a contextual framework, and aims to understand something in a new way, from the perspective of a new conceptual framework (Danermark, 2001; Dubois & Gadde, 2002).

It has been shown that case studies commonly use abductive reasoning (Alvesson & Skoldberg, 1994; Dubois & Gadde, 2002). Rather than focusing on generalisations and/or their specific manifestations only, the abductive approach is concerned with the particularities of specific situations that deviate from the general structure of such kinds of situations (Danermark, 2001). As such, it helps to determine which aspects of a situation in the case studies are generalisable and which only pertain to the specific situation itself.

Following Hudson (1988), this research on how companies respond to supply chain disruption can be seen in a 'natural and changing environment', with events unfolding during course of the study.

The abductive research process based on the ideas of Dubois and Gadde (2002) and Kovacs and Spens (2005) is appropriate because it leads to simultaneous data

collection, theory development and theory-building elements, precisely the approach taken in this study.

3.3.2 Different Proponents of Grounded Theory Building Process

Grounded Theory is a research method that operates almost in a reverse fashion from traditional research. Rather than beginning with a hypothesis, the first step is data collection, through variety methods. From the collected data, key points are marked with a series of codes extracted from the text. The codes are grouped into similar 'concepts' in order to make them more workable. From these concepts, 'categories' are formed, which are the basis for the creation of a 'theory'. This process contradicts the traditional model of research, where the researcher chooses a theoretical framework, and only then applies this model to the phenomenon to be studied (Alan, 2003).

Table 8 shows the different between two schools of thought – Strauss and Corbin (1998) and Glaser (1978) – specifically in data analysis phase.

	Strauss and Corbin (1990)	Glaser (1978)
Initial coding	**Open Coding** Use of analytic technique	**Substantive coding** Data dependent
Intermediate phase	**Axial coding** Reduction and clustering of categories (paradigm model)	**Continuous with previous phase** Comparisons, with focus on data, become more abstract, categories refitted, emerging frameworks.
Final development	**Selective coding** Detailed development of categories, selection of core, integration of categories	**Theoretical** Refitting and refinement of categories which integrate around emerging core
Theory	Detailed and dense process fully described	Parsimony, scope and modifiability

Table 8: Data Analysis: Strauss and Glaser Compared

Source: Heath and Cowley (2004)

The Ground Theory steps outline by different authors is illustrated in. In general the process of Grounded Theory often starts with researcher decide if a Grounded Theory is a best addresses to the research problem, identify a process to study and seek and access to the data. Then conduct theoretical sampling and code data by using selective coding to develop theory. Once the research has emergent theory then they have to validate the theory before writing a Grounded Theory research report.

Technique 1	Technique 2	Technique 3	Technique 4	Technique 5
Strauss and Corbin (1990)	**Glaser (1978)**	**Odis E. Simmons (2003)**	**Naresh R.Pandit (1996)**	**Randall and Mello (2011)**
Phase 0: Preparation	**Phase 0: Preparation**	**Phase 0: Preparation** Minimising preconceptions. No preliminary literature review. General research topic, but no predetermined research 'problem'	**Phase 0: Research design** Step 1: Review of technical literature (definition of research question, definition of priori constructs) Step 2: Selecting cases (focuses efforts on theoretical useful cases not random sampling)	**Phase 0: Research problem and opening research question**
Phase 1: Data collection Collecting data via interviews, observations, videos, documents, drawings, diaries, memoirs, newspapers, biographies, historical documents, autobiographies, and other sources not listed here.	**Phase 1: Data collection** Collecting data by intensive interviews often combined with participant observation. But, any type of data can be used including quantitative.	**Phase 1: Data collection** Collecting data by intensive interviews, participant observation or from secondary sources.	**Phase 1: Data collection** Step 3: Developing rigorous data collection protocol - create case study database, empty multiple data collection methods, qualitative and quantitative data) Step 4: Entering the field – overlap data collection and analysis, flexible and opportunistic data collection methods. Step 5: Data ordering – arraying events chronologically to facilitate easier data analysis.	**Phase 1: Data collection initial coding** Initial pilot interview is developed and an archival review is conducted
Phase 2: Data analysis 'Open coding' – use of analytic technique 'Axial coding' – reduction and clustering of categories (paradigm model) Final development stage is 'Selective coding' – detailed development of categories, selection of core, integration of categories Theory stage is detailed and dense process fully described	**Phase 2: Data analysis** 'Substantive coding' –data dependent 'Continuous with previous phase' – comparison, with focus on data, become more abstract, categories refitted, emerging frameworks 'Theoretical' – refitting and refinement of categories with integrate around emerging core Theory stage is parsimony, scope and modifiability	**Phase 2: Data analysis** Relating data to ideas, the ideas to other ideas. 'Substantive coding'- Summarising empirical substance 'Open coding '- coding for anything and everything 'Selective coding' – occurring when core variable and major dimensions and properties have been discovered 'Theoretical coding' – conceptualizing how the substantive codes may relate to each other as 'hypotheses' to be integrated into the theory	**Phase 2: Data analysis** Step 6: Data relating to the first case 'Open coding' – develop concepts, categories and properties 'Axial coding' – develop connections between a category and its sub-categories 'Selective coding' – all forms of coding enhance internal validity Step 7: Theoretical sampling – literal and theoretical replication across case (go to step 2 until theoretical saturation) Step 8: Reaching closure – Theoretical saturation when possible	**Phase 2: Initial memos raise codes to tentative categories**
Phase 3: Memoing Writing records of analysis	**Phase 3: Memoing** Memos are theoretical notes about the data and the	**Phase 3: Memoing** Memos are the theorizing write-up of ideas about codes and their	**Phase 3: Literature comparison** Step 9: Compare emergent theory with extant literature	**Phase 3: Data collection focused coding**

	conceptual connection between	relationships.	Comparisons with conflicting with frameworks to	
Technique 1	**Technique 2**	**Technique 3**	**Technique 4**	**Technique 5**
	categories. The memo process runs parallel with the coding and analysis process to capture the research's emergent ideation of substantive and theoretical codes and categories.		improve construct definitions, and therefore internal validity Comparisons with similar frameworks to improve external validity by establishing the domain to which the study's finding can be generalised	
Phase 4: Theoretical sampling Data collection based on concepts that appear to be relevant to the evolving story line	**Phase 4: Theoretical sampling** Process of data collection for generating theory whereby the analyst jointly collects, codes, and analyses his data and decides what data to collect next and where to find them in order to develop his theory as it emerges.	**Phase 4: Sorting and theoretical outline** Conceptual sorting of memos into an outline of the emergent theory, showing relationship between concepts (not data sorting).	**Phase 4: Write up your theory**	**Phase 4: Memos refine conceptual categories**
Phase 5: Constant comparison Comparing incident with incidents in order to classify data is not difficult to comprehend.	**Phase 5: Constant comparison** Comparing incidents applicable to each category Integrating categories and their properties Delimiting the theory Writing the theory	**Phase 5: Write up your theory**		**Phase 5: Theoretical sampling of hypothesized relationships**
Phase 6: Theoretical saturation The point in analysis when all categories are well developed in terms of properties, dimensions, and variations. Further data gathering and analysis add little new to the conceptualization, though variations can always be discovered.	**Phase 6: Theoretical saturation** The point where no additional data are being found			**Phase 6: Sorting memos, Theoretical coding, Adopting categories**
Phase 7: Write up your theory	**Phase 7: Write up your theory**			**Phase 7: Integrating memos diagram concepts, Saturation**
				Phase 8: Emerge Theory
				Phase 9: Further theoretical sampling if needed

Table 9: Grounded Theory Steps Outlined by Different Authors

3.4 Glossary of Grounded Theory

Grounded Theory has evolved over the last 40 years; below is a short glossary of key terms used for this study shown in Table 10.

Term	Definition
Axial coding	Process by which categories are related to subcategories at the level of properties and dimensions. This type of coding consists of intense analysis done around one category a time, in terms of the Strauss and Corbin paradigm items (e.g., coding, actions/interactions, and consequences).
Basic social processes (BSP's)	One type of core category, often best visualized when the category involved multiple concepts linked together in a larger social process – all BSP's are or involve core variables, but not all core variables are or are part of BSP's. The primary distinction between the two is that BSP's are processural – they have two or more clear emergent stages in a temporal sense.
Coding paradigm	Analytic tool Strauss and Corbin devised to help integrate structure with process. When using the paradigm one codes for core phenomena, conditions, actions/interactions, and the consequences of those actions/interactions.
Categories	Abstract, higher order concepts under which other concepts can be grouped through an underlying shared uniformity. Categories name patterns in the data. They have analytic power because they can be used to explain and predict behaviour in a phenomenon.
Categories	Abstract, higher order concepts under which other concepts can be grouped through an underlying, shared uniformity. Categories name patterns in the data. They have analytic power because they can be used to explain and predict behaviour in a phenomenon.
Coding families	Sets of interrelated theoretical codes. For example, the "cultural family" includes social norms, social values, social beliefs, and social sentiments.
Conditions	Term used in Grounded Theory to refer to context. Sets of events that create the situations, issues, and problems within which a phenomenon is manifest and help explain the behaviour of individuals or groups. Types of conditions include casual, intervening, and contextual conditions.
Conceptual ordering	Organisation of data into categories according to their properties and dimensions.
Conditional matrix	A diagram used to track or contemplates the various levels of influence on a phenomenon as well as the implications on those levels of the phenomenon.
Constant comparison	Investigation of similarities and differences across incidents recorded in the data. A technique used to generate concepts and their properties based on repeated patterns of behaviour. Comparisons are made within and across data sources.
Core category	Central category of the phenomenon about which the theory is concerned. May not necessarily be a category originally sought at the beginning of the research study. Explains the majority of the behaviour in a phenomenon.
Dimension	Range along which properties of a category vary. Used to provide parameters for the purpose of comparison between categories.
Formal theory	Theory that is developed for a conceptual area of inquiry at a high level of generality (scope). Formal theory develops through the generalisation and modification of substantive theory as it is applied to different areas of inquiry.
Process	Sequences of evolving action/interaction taking place over time and that are related to changes in structural conditions.
Properties	General or specific characteristics or attributes of a category, which allow a category to e defined and given meaning.

Term	Definition
Selective coding	To delimit coding to only those variables that relate to the core variable that has emerged from the study. The analyst links related and subordinate categories to a core category in sufficiently significant way to assist in the formulation of theory.
Structure	Social conditional context in which a phenomenon is located. Social structure creates the context for action and interaction, and as such is inexorably linked to process.
Substantive theory	Theory that is specific to time and place. May eventually be extended to a formal theory if becomes supported across multiple contexts.
Theoretical memos	Written ideas of the researcher concerning codes and their inter-relationships within a phenomenon.
Theoretical sampling	Process of data where the analyst collects, codes, and analyses data and decides what data to collect next and where to find them based entirely upon the emergent theory.
Theoretical saturation	Point at which no new information appears to emerge during coding and subsequent data collection; i.e., when no new properties, conditions and so on can be attributed to a category.
Theoretical sensitivity	Researcher's knowledge, understanding, and skill, which foster the generation of categories and properties and increase the ability to relate them to emergent theoretical codes.

Table 10: Glossary of Grounded Theory Terms

Source: Mello and Flint (2009)

3.5 Case-Based Research and Grounded Theory

This study uses Grounded Theory methodology with data from three cases. The benefits and context in which this methodology can be used in combination with case research are discussed below.

Case-based research has consistently been one of the most powerful research methods in operations management, particularly in the development of new theory (Voss et al., 2002). Eisenhardt (1989) also argues that case studies are especially helpful when building theories or frameworks.

According to Yin (2003) and Mukherjee et al. (2000), exploratory case study is particularly useful when there is uncertainty in the definition of constructs. Since the purpose of this research is to describe and learn from current management practice and applies the case methodology to actual events in business life, case study was an appropriate way to provide data to Grounded Theory methodology because 'a case study is an empirical enquiry that (1) investigates a contemporary phenomenon within its real life context, especially when (2) the boundaries between phenomenon and context are not clearly evident' (Yin, 2003, p.13).

This is confirmed as well by Eisenhardt (1989) who argues that using case data to build Grounded Theory has major strengths as follow:

1. Theory building from case studies is likely to produce novel theory; this is so because 'creative insight often arises from juxtaposition of contradictory or paradoxical evidence' (Eisenhardt, 1989, p.546). The constant comparative method of real-world data inevitably reveals conflicts with dogmatic, rigid thinking, forcing the researcher to review inherent bias and adapt his thinking (p. 546).

2. The emergent theory 'is likely to be testable with constructs that can be readily measured and hypotheses that can be proven false' (Eisenhardt, 1989, p.547). Due to the close connection between theory and data, it is more likely that the theory can be tested and expanded by subsequent studies.

3. The 'resultant theory is likely to be empirically valid' (Eisenhardt, 1989, p.547). Validity is maintained from the start through the constant comparison of data with emergent theory. 'This closeness can lead to an intimate sense of things' that 'often produce theory which closely mirrors reality' (Eisenhardt, 1989, p.547).

Stuart et al. (2002) also suggest that case studies are an appropriate research methodology to map the field of supply chain management, as they allow identification and description of critical variables. Moreover, case studies should not be seen as a methodology appropriate only to understand the preliminary stages of theory development but also to provide a means of refutation of, or extension to, existing concepts because of their observation richness (Stuart et al., 2002).

Case research and Grounded Theory are consistent in a number of dimensions. Data from these studies are obtained from real-world, natural settings; the emergent theory is derived from actual managerial practice. The abductive nature of Grounded Theory methodology allows exploration of 'how' concepts are linked, supporting the development of causal relationships. Lastly, these support exploration of issues in an area that has not been extensively studied before. As

discussed earlier, the role of time in management of catastrophic risk in supply chain is minimally covered by existing research.

Grounded Theory moves beyond descriptive case research toward development of theoretic constructs and propositional relationships (Charmaz, 2006). As she points out, this analytical method supports investigation of social processes and structure. The effectiveness and efficiency therefore depends on the availability and richness of data from observing human activity (Charmaz, 2006).

When using Grounded Theory methodology with data derived from case research, utmost care must be considered to ensure that principle of case study research do not distort true emergence for the theory generation (Glaser, 1998, pp.40-2). For example, Yin (1994, p.28) states theory development prior to the collection of any case study data is an essential step in doing case studies.' This statement, perfectly valid for some case study research, contravenes a key principle of Grounded Theory. Therefore, it is advised that when combining case study and Grounded Theory, the researcher must clearly specify which methodology is driving the investigation. Advancement of a supply chain management theoretical structure requires an aggregate approach based upon inductive techniques. Grounded Theory provides an inductive method for creating aggregate level theory through in-depth investigations within and across organisation (Charmaz, 2006; Glaser, 1992; Glaser & Strauss, 1967).

In addition, supply chain research often involves phenomena with complexity. I believe that grounded theory approach is an appropriate choice of methodology for this study because it makes the findings more robust and possibly makes it easier to detect similarities and differences.

Grounded Theory also emphasises gaining deep insights into social phenomena that are problematic for the people involved. Though deep immersion in the daily worlds of supply chain managers and gaining access to their thoughts, feeling and behaviours as they go and about solving the problems they encounter, researchers can gain insights into social aspects of supply chain management that other methodologies are less likely to tap into. Such insights are imperative in furthering our understanding of supply chain management phenomena and in developing useful theories (Randall, Wesley and Mello John E., 2006).

It is helpful to consider what Grounded Theory is and what it is not (Table 11)

What Grounded Theory is …	What Grounded Theory is NOT …
• Constant comparison & theoretical sampling - Collection of data and analysis go hand-in-hand - What data to collect next depends on the theory constructed thus far • Study of inter-subjective experience - More suited to efforts to understand how actors construct meaning out of inter-subjective experience (Suddaby, 2006) • 'Everything is data'	• Theory testing with a case study • Theory building with 'raw data' • An excuse to avoid reading up on the extant literature • A study of the actors' "inner lives" • Content analysis through word counts • A formulaic approaches to data (or to data gathering) • A descriptive account

Table 11: What Grounded Theory Is and What It Is Not

3.6 Step-by-Step Guide to Grounded Theory in this Research

Previously I have shown the differing approaches in theory building presented by several researchers. In this study, I have chosen the process based on Strauss and Corbin (1990), specifically in the data analysis phase employing an abductive approach.

All the interpretations of Grounded Theory methodology, the Strauss and Corbin (1990) approach was chosen for several reasons:

1. The focus of this study is on managerial decision-making. As stated by Lehmann, the Straussian approach is more effective for studies of individuals than research involving organisations, political systems, or technical issues (Lehmann, 2001a, p.9).

2. Strauss permits the notion of initiating the study with a general idea or framework of concepts in place, e.g. the 3D framework, while Glaser believes that an 'empty mind' should be the starting point to avoid bias and prejudice which might mask potential concepts and categories.

3. The approach Strauss takes can used structured questioning, leading to a more focus emergence and development of propositions; Glaser's approach presumes that theory should emerge entirely from the study.

Differences between the two approaches of Strauss and of Glaser are summarized below in Table 12.

GLASERIAN	STRAUSSIAN
Beginning with general wonderment (an empty mind)	Having a general idea of where to begin
Emerging theory, with neutral questions	Forcing the theory, with structured questions
Development of a conceptual theory	Conceptual description (description of situations)
Theoretical sensitivity (the ability to perceive variables and relationships) comes from immersion in the data	Theoretical sensitivity comes from methods and tools
The theory is grounded in the data	The theory is interpreted by an observer
The credibility of the theory, or verification, is derived from its grounding in the data	The credibility of the theory comes from the rigour of the method
A basic social process should be identified	Basic social processes need not be identified
The researcher is passive, exhibiting disciplined restraint	The researcher is active
Data reveals the theory	Data is structured to reveal the theory
Coding is less rigorous, a constant comparison of incident to incident, with neutral questions and categories and properties evolving. Take care not to 'over-conceptualise', identify key points.	Coding is more rigorous and defined by technique. The nature of making comparisons varies with the coding technique. Labels are carefully crafted at the time. Codes are derived from 'micro-analysis, which consists of analysis data word-by-word'.
Two coding phases or types, simple (fracture the data then conceptually group it) and substantive (open or selective, to produce categories and properties)	Three type of coding, open (identifying, naming, categorising and describing phenomena), axial (the process of relating codes to each other) and selective (choosing a core category and relating other categories to that)
Regarded by some as the only 'true' Grounded Theory method	Regarded by some as a form of qualitative data analysis (QDA)

Table 12: The Difference between the Glaserian and Straussian Approaches to Grounded Theory

Onion (2006)

Table 13 depicts this Grounded Theory process, emphasizing the constant comparison process which considers and compares the multiple concepts articulate by study participants to those concepts derived from theoretical memos, memos recorded during analysis, documents, and relevant literature and online sources. I selected three cases for study to seek theoretical similarities and differences in order to develop the higher order concepts, which explain behaviours and response (Gephart 2004; Glaser 1978).

Four analytic (and not strictly sequential) phases of Grounded Theory building were identified in this study: research design, data collection, data ordering, data analysis, literature comparison and write up. Within these phases, ten procedures or steps were followed. These phases and steps were evaluated against four research quality criteria: construct validity, internal validity, external validity and reliability.

Briefly, construct validity is enhanced by establishing clearly specified operation procedures. Internal validity is enhanced by establishing causal relationships whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships. In this sense, internal validity addresses the credibility or "truth value" of the study's findings. External validity requires establishing clearly the domain to which to study's findings can be generalised. Here, reference is made to analytic and not statistical generalisation and requires generalising a particular set of findings to some broader theory and not broader population. Finally, reliability requires demonstrating that the operations of a study – such as data collection procedures – can be – repeated with the same result.

			Description	Output
Phase 1 Research design	**Step 1**	Preparation	Minimizing preconceptions and preliminary literature review, define general research topic but no predetermined research problem.	General research problem & opening research questions
	Step 2	Case selection	Selecting the case – theoretical selection, not random sampling.	Case(s)
Phase 2 Data collection and data ordering	**Step 3**	Develop rigorous data collection protocol	Deviating real-life observation, interview, lecture, seminar, expert group meeting, newspaper, article, internet, mail, field notes or note taking.	
	Step 4	Entering the field	Overlap data collection and analysis to speeds analysis and reveals helpful adjustments to data collection.	
	Step 5	Data ordering	Arraying events chronologically to facilitate easier data analysis.	
Phase 3 Data analysis	**Step 6**	Analysis data *Open coding* *Axial coding* *Selective coding* *Memoing*	Analysis data relating to the first case by coding Develop concepts, categories and properties Develop connections between a category and its subcategories Integrate categories to build theoretical framework. All forms of coding enhance internal validity. Theorizing write-up of ideas about codes and their relationships.	Emerging core categories Properties, Sub-categories
	Step 7	Theoretical Sampling	Deciding what data to collect next and where to find that data in order to develop the theory as it emerges. Literal and theoretical replication across cases - keep going back to step 2, this process continues until no new properties or dimension are emerging.	
	Step 8	Constant comparison	Comparing incident with incidents for similarities and differences in order to classify data is not difficult to comprehend.	
	Step 9	Theoretical Saturation	Reaching closure when further data gathering and analysis add little new to the conceptualization.	Saturated core categories
	Step 10	Theoretical sorting memos Theoretical coding	Conceptual sorting of memos into an outline of the emergent theory, showing relationship between concepts. Defining hypotheses or proposition, suggesting new theory in final conclusion	Hypothesis, proposition – Emergent Theory
Phase 4 Literature comparison and write up	**Step 11**	Integrating the literature	Compare emergent theory with extent literature (comparisons with conflicting/similar frameworks).	
	Step 12	Validation your theory	Checking whether your new theory fit, relevance, workability and modifiability.	
	Step 13	Write up your theory	Writing research report	

Table 13: The Process of Building Grounded Theory in This Study

PHASE 1: Research Design

Step 1 – Preparation

The first step is in designing the research program, defining the overarching methodology and scope of study. Easterby and Smith define research design as:

> *"…The overall configuration of a piece of research: what kind of evidence is gathered from where, and how such evidence is interpreted in order to provide good answers to the basic research questions(s)."*
>
> *Easterby – Smith et al. (1990, p.21)*

Definition of the basic research question, as stated in the introduction to this study, is the first step in Grounded Theory. The scope must be narrow enough to provide focus and feasibility; the scope must be broad enough to allow flexibility as the study evolves and support discovery of unanticipated concepts. Existing supply chain risk management literature, however limited, provides an initial structure and scope (as per Charmaz, 2006; Glaser, 1992; Glaser 1998). For this perspective, the literature focuses, but does not constrain, or presuppose, the direction of the investigation. Here, I am using 3-D time framework developed by Sodhi and Tang (2008) to focus the research design.

Step 2 – Case Selection

After basic research questions have been generated and the research is scoped and focused, the second step is in case selection and identification of the starting case. Cases (the principal units of data in this research) were selected to fulfil requirements of theoretical sampling:

> *The process of data collecting for generating theory whereby the analyst jointly collects, codes, and analyses his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges.*
>
> *Glaser and Strauss (1967, p.45)*

Accordingly,

> *Unlike the sampling done in quantitative investigations, theoretical sampling cannot be planned before embarking on a Grounded Theory study. The specific sampling decisions evolve during the research process itself.*
>
> *Strauss and Corbin (1990, p.192)*

Yin (1994) suggested three principles of data collection that can help deal with the problems of establishing the construct validity and reliability of the case study evidence. These principles are (1) use of multiple sources of evidence (evidence from two or more sources, but converging on the same set of facts or findings); (2) creation a case study database (a formal assembly of evidence distinct from the final case study report), along the lines of the Straussian approach; and (3) maintain a chain of evidence in order to increase the reliability of the information in a case study (explicit links between the questions asked, the data collected, and the conclusions drawn). Grounded Theory is consistent with these principles.

The context for my investigation is PHARMA's handling of the H1N1 Influenza pandemic declared on 11 June 2009, with analysis of first-hand interviews of key management, company internal documents and publically available news and additional documentation from key players. The novel Influenza strain, H1N1, commonly known as swine flu, had fast transmission but unknown mortality at the outset, resulting in a dramatic spike in demand for PHARMA's antiviral and related medicines.

PHASE 2: Data Collection and Data Ordering

Step 3 – Develop Rigorous Data Collection Protocol

In this step, a data collection protocol is developed employing multiple data collection methods to establish the cases database. In Grounded Theory methodology, both of qualitative and quantitative data can be used. Data can come from (1) collecting observations of the area directly from the events under study (2) accessing public or private records of various types (e.g. news report, survey, government or organisation document, online sources, etc. (3) interviewing individuals or participating in group discussion, face to face or remotely (e.g. telephone, text chat) or asynchronously such as with email (Glaser, 1964 and Glaser, 2008).

For the PHARMA case, selected as the primary case, data was gathered through company visits from 2009 to 2010. Triangulation was used to ensure research reliability by obtaining the same piece of information from different sources: semi-structured interviews, internal documents, direct observation (McCutcheon and Meredith, 1993) and media. A semi-structured interview tool was developed to

collect data on the three above-mentioned dimensions. No fixed vocabulary was used to ask questions, assuring that the conversation developed at its own pace (Sutton and Callahan, 1987). I followed Yin's (1994) and Eisenhardt's (1989) suggestion of executing the case study by conducting interviews, face to face or via telephone, with key informants from different divisions along the PHARMA supply chain.

To ensure broad dimensionality in the data as suggested by Glaser and Strauss, 1967; Glaser, 1992, 1978; Charmaz, 2006), I engaged line managers, employees, supervisors and executives at multiple levels in the supply chain, while also cutting across functionally by interviewing R&D and manufacturing management

At this step, an initial pilot interview is typically developed, and an archival review is conducted to ensure the target participants represent a sufficiently rich with the phenomena under study.

Step 4 – Entering the Field

The step initiating field research include preparation work such as selecting and appropriate company sites and groups to interview, identifying participants and obtaining access to key documents, contacting participants and gaining their consent.

I used the interview protocol as show in Table 14 to conduct semi-structured telephone interviews with high-level site directors, sending them the planned interview questions in advance. The first goal of each interview was to understand their perception on supply chain risk and supply chain disruptions. The questions also explored their view on whether the company was aware of vulnerabilities in the supply chain and how they leveraged time in their management of supply chain disruptions.

I then conducted semi-structured face-to-face interviews with senior supply chain managers and executives. This used the time-based risk management framework (Sodhi & Tang, 2009) to understand how PHARMA and its executives viewed and used time to respond to the H1N1 Influenza pandemic. The interview questions submitted to the executives are shown also in Table 14.

Apart from face-to-face and interview, data was collected from direct observation, participant-observation (meeting and conference calls) and archival records and documentation both from internal sources (presentations, reports) and external sources (internet, news, press released). The data source, data collection methods and data content of PHARMA are summarised in Table 15.

Aspects	Questions
Supply chain design	• What are general design principles of the global supply chain of the company?
Risk management strategy	• What risk mitigation policies and strategies are in place today? o What governance has been established to: o Manage update of disruption catalogue (risk map) o Review contingency plans o Monitor occurrence of disruptions, and finally o Initiate and carry out contingency plans? • How are contingency plans being tested and how often?
	• Can you describe any previous significant disruptions to the supply chain that the company experienced? • What internal disruptions have PHARMA experienced and what were the lessons learned?
Current event	• How did the company become aware, and in retrospect were there any warning signs? How does the firm prepare for this type of risk? • How is the occurrence of a disruption detected and communicated to initiate contingency plans? • What was the initial impact of the current event? • What contingency plans does PHARMA have to manage major supply chain disruptions for the Hematol product line? • Who is responsible for the plan and execution? • What changes in the products, supply chain or other approach did the company consider to respond to the event? • What was the role of time in determining the response of the supply chain disruption? • How quickly could the actions enable the company to meet the supply chain objectives?
Time-Based Risk Management	• Does company explicitly set time targets or metrics for measuring response speed in handling the pandemic? • What was the role of time in managing the response? • Does company think that by shortening detection time, solution design lead-time and solution deployment time it can reduce supply chain impact or gain greater advantage?
Learning from the event	• What went well in responding to the event? What could have been done better?

Table 14: Final Interview Protocol

PHARMA		
Data Source	**Data Collection Methods**	**Data Content**
Key Informants	Semi-structured telephone and face-to-face interviews with: • Manufacturing and Supply BCP lead • Division BCP Lead(s) • Environment, Health and Safety Head • Process Owner • Primary Procurement Manager • Manufacturing Strategy Manager(s) • Project Manager(s) • Primary Logistics Manager(s) • Site Logistics Head(s) • Site Production Head(s) • Site Head(s) • R&D Manufacturing Manager (s)	Telephone Interview • Perceived probability and impact of potentially severe disruption. • Preparation and testing of business continuity plans. • Decision making process during a disruption. • Experience from previous supply chain events. Face to Face Interview • Steps taken to organise and initiate first response. • Mechanisms used to accelerate creation, evaluation and deployment of possible solutions. • Strategies to communicate and coordinate the status of the situation and the organisational response. • Lessons learned and incorporated in risk management strategies after the event with regard to reaction speed.
Archival Records	Presentations by: • Chief Executive Officer • Value Stream Leader, Manufacturing and Supply Pandemic Lead • Manufacturing and Supply BCP lead • Manufacturing Strategy Manager(s) • Project Manager(s) • Site Logistics Head(s) • Global Quality Assurance(s)	• Global procurement process and strategy • Risk management process • H1N1 Influenza pandemic executive review

Table 15: Data Sources, Data Collection Methods and Data Contents from PHARMA

Step 5 – Data Ordering

The fifth step involves data ordering. Yin (1989, p.119) suggested to array events chronologically to facilitate analysis, an obvious dimension for this study on time response time:

> *"The arraying of events into a chronology permits the investigator to determine causal events over time, because the basic sequence of a cause and its effect cannot be temporally inverted. However, unlike the more general time-series approaches, the chronology is likely to cover many different types of variables and not to be limited to a single independent or dependent variable"*
>
> *Yin (1989, p.119)*

In this study, a timeline was created to visualise the sequence of events and the response to these events.

PHASE 3: Data Analysis

Step 6 – Initial Data Analysis

Coding and Categorising Data

After data was collected and collated, an initial categorization was made to identify common concepts. Three sequential types of coding are used in the Straussian approach to Grounded Theory, namely open coding, axial coding and selective coding, where the output of one is the input to the next in a non-iterative fashion. This research process is summarised in Figure 10 with a definition of each step in the process and how this is implemented in the study.

Open Coding

The first step, open coding, is the initial analysis stage that deals with identification, naming, labelling, description and categorization of phenomena suggested by the data. Glaser (1978) coined the term by characterizing the process as 'running the data open', meaning the extraction of categories and properties from the underlying data. The output of labelling and categorization are concepts, forming the basic element used in Grounded Theory.

Open coding is implemented by memoing, in which notes are recorded of the interpretation of the data. Basic questions are asked on key attributes, such as where, how, who, when. This forms the initial stage of constant comparative analysis. Specific data is compared with the partial or complete data set, to express similarities and differences for purposes of categorization and labelling (Glaser, 1992; Glaser Strauss, 1967).

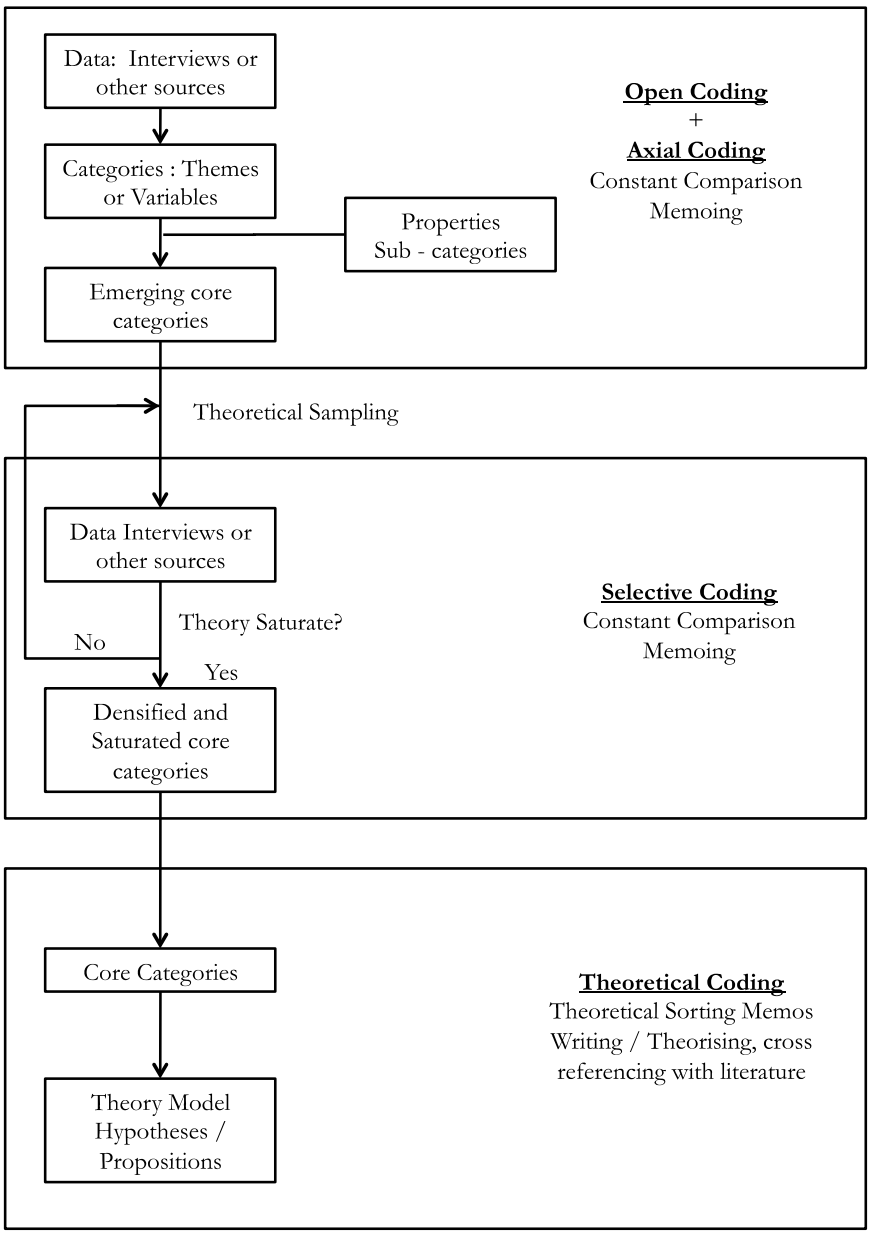


Figure 10: Data Analysis Process in This Research

In this step, data is coded in multiple ways (Glaser 1978), from smaller elements – word-by-word – or larger elements, such as complete narratives. Patterns can hereby emerge without bias, unrestricted by preconceived ideas and critically, 'grounding' the patterns directly in the underlying data.

As the open coding process continues, codes are grouped into categories and subcategories (Glaser 1992). The categories group codes and concepts with similar properties. The researcher may begin to identify a major concept that underlies all observation, and propose this as a core category. A core category encompasses the

variations of data across the complete study, and can be used to explain the behaviour and actions of participants.

Open coding therefore provides the overall theme, core categories and subcategories in which the coded data can be structured. This is used for further data collection or 'theoretical sampling', which is used to make the structure more robust. In this study, interview text was labelled and used to guide subsequent data collection and interviews. Approximately 200 codes were identified through open coding. Some codes are more descriptive in nature, and in other instances repetitive; these would be collapsed into a subcategory after additional theoretical sampling. Table 16 shows an example of developing categories from concepts in this study.

By grouping concepts into categories, the number of elements needed to express the structure of analysis can be made more manageable. In this case, Box 1 provides an overview of how concepts were integrated into higher-level categories. For example, various concepts could be identified as supporting the *create integrated response team*, whereas other could be identified as supporting the category of *establish frequent communication with supply chain partners.*

Category	Concepts
Preparation	Alarm, Delay, Information, Modelling, Monitoring, Notification, Scenario Planning, Testing, Training, Validation
Partnership	Agencies, Communication, Competition, Expertise, Government, Industry Corporation, Partners, Press, Publicity
Organisation	Communication frequency, Education, Experience, Learning, Roles, Responsibilities, Structure, Team

Table 16: An Example of Developing Categories

Axial Coding

In the next stage, axial coding is used to structure the categories and sub-categories along one or more properties and dimensions to make the relationships between the codes explicit and provider greater coherence to the initial analysis (Strauss and Corbin (1990, 1998; Strauss, 1987).

Box 1: Examples of open coding generated from PHARMA case

"No one organisation or country, or ground, can meet the pandemic challenge alone. All partners…must work together to put in place a robust and effective global response".
My initial coding for this excerpt was *coordination with international agencie*s. This excerpt later recorded as *establish frequent communication with supply chain partners.* (a code that emerged as a sub-core category in my emergent theory. In this case, establish frequent communication emerged as a property of creates integrated response team.

Another excerpt, "We are talking to them about a range of issues, trying to understand exactly what this new virus is, exactly how the WHO and CDC believe this may develop so we can response to their need more quickly and efficiently." Initial coding was *coordination with international agencie*s; later re-coded as *establish frequent communication with supply chain partners.*

Another example from data collection in PHARMA and open coding was, "We created an online electronic database for information sharing. These include risk management plans and our strategic plan". Initial coding for this except was *Establish online team room for document sharing* which also later re-coded as *Create integrated response team.*

A further example, "…during the first three months of the pandemic, we were held on a daily basis meeting with site directors and supply chain managers…" Initial coding was *create frequent communication with site directors*; later re-coded as *create integrated response team.*

Strauss (1987, p.64) sees axial coding as building "a dense texture of relationship around the 'axis' of a category." This would be typically support identification of a major category, as the variation in the data and therefore codes can be expressed along a dimension in axial coding. Creswell states the objective to be sorting, synthesis and organizing the potentially large amount of data, allowing the codes to be 'reassembled' in new ways. Links between categories and their subcategories and relationships among them become visible (Strauss and Corbin, 1998). By re-integrating the concepts which emerged from open coding, axial coding can begin to provide answers such as 'who, where, when, why, what impact, etc.' They suggested using scientific terms to make the links between categories more visible, emphasizing causal relationships as part of an overall framework. This has the following elements: (1) "causal conditions" – the context in which the phenomena was observed, and events leading up to the phenomena (2) "actions / interactions" – the way that participants responded to events or reacted to problems and (3)

"consequences" – the intentional or unintentional outcome or impact of the actions taken. Strauss and Corbin document the conditions for (1) with questions such as "why, where, for what reason, when" etc. (2) Action/interactions are answered by knowing who and how something was done. Lastly (3) Consequences are determined by answering questions of 'what happens or what impact'.

Looking back at their original study in 1967 which looked at how nurses dealt with near death patients, axial coding showed that the main concept under study was 'pain', the causal condition was 'arthritis', the 'action' was 'taking drugs', and the consequence was 'pain relief'.

Table 17 illustrates the conditions, actions and consequence of several examples in this study, showing the link between categories and subcategories and illustrating how these are related.

For example, A, B, C, D and E are the outcome from the open coding stage, each dealing with how communication can affect response time after supply chain disruption. The examples A, B, C, D relate to external communication, therefore they fall into the core category of 'partnership'. While E also deals with communication for same objective, it falls into 'organisation' category as an internal issue.

Selective Coding

In the next stage, output from axial coding is used for selective coding; where the core categories representing the main phenomena under study are explicitly identified and other (sub-) categories are placed in relation to create an integrated theoretical scheme.

The focus is usually on a limited number of categories, which seem to best encapsulate the major aspects of the phenomena under study. Once the core category(ies) has been identified, it is used to guide incremental data collection and further theoretical sampling (Glaser 1978). Similar to open coding, selective coding uses a process of constant comparison, considering the (dis)-similarities of new data to existing categories and properties of categories.

In contrast, however, to open coding which uses substantive codes (i.e. original data such as quotes or statements from the participants in their own words and language), selective coding uses analytical and abstract codes leading to conceptual labels for categories. (Glaser 1978).

Example(s)	A	B	C	D	E
Pattern recognition	Coordination	Coordination	Coordination	Coordination	Coordination
The phenomenon of interest	Communication	Communication	Communication	Communication	Communication
The causal conditions	Need to understand and control external suppliers	Government plays major role in policy and demand	Public and press have a vital role in responding to crisis	Internal agencies need?	Organisation want desire for business
The action strategy	Establish direct line of communicatio n with external suppliers	Proactive contact with governments to anticipate orders and allocate stock proportional to need	Increase frequency of press and public communications	Coordination with international agencies e.g. CDC and WHO	Modify organisation hierarchy to shorten lines of communication
The consequence	Improved speed and reduce risk, reduce deploy response time	Improved understand of order, reduce design and deploy response time	Lower risk, reduce design and deploy response time	Improved understanding of external parties, reduce detection, deploy and deploy response time	Reduced design response time and deploy response time.
The sub-core category	Establish frequent communicatio ns with supply chain partners	Establish frequent communications with supply chain partners	Establish frequent communications with supply chain partners	Establish frequent communication s with supply chain partners	Shorten lines of communication s within the organisation
The core category	Partnership	Partnership	Partnership	Partnership	Organisation

Table 17: An Example of Basic Form of Generic Relationship of Axial Coding in This Study

Selecting coding allows filtering and codification of the data, which are likely to be most relevant to the emerging concepts. Only selective data is needed, for example specific sections of an interview transcript needed to explore existing codes. Interview questions and data collection techniques can be continuously refined to focus on the objective of theoretical saturation of the existing conceptual structure.

Memoing

One of the important stages in ascribing meaning to the coding is a technique referred to as memoing, central to the coding process: 'the theorising write-up of ideas about codes and their relationship as they strike the analyst while coding' (Glaser, 1978, p.83). Glaser emphasized that the memoing process is essential in Grounded Theory:

> *"The writing of theoretical memos is the core stage in the process of generating Grounded Theory. If the researcher skip this stage by going directly to sorting or writing up, after coding, she is not doing Grounded Theory".*
>
> *Glaser (1978, p.83)*

As a theoretical framework begins to emerge in axial coding and reinforced in selective coding, memos are used to document hypothesized relationships between concepts, and provide evidence for how these relationships were developed by Charmaz (2006).

The basic goal of memoing is "to develop ideas with complete conceptual freedom" (Holton, 2007), without restriction, hence produced throughout the coding process and development of the ultimate theoretical framework. During process of comparison and conceptualisation, memos document the theoretical foundation relating codes to underlying data (Glaser, 1978; Urquhar, 2001). Memos provide intellectual freedom, flexibility, and enhance creativity in developing the overall framework. Stated by Holton, they are also a key to further data collection, coding, and analysis in selective coding (Holton, 2007). Box 3 shows a few examples of theoretical memos from this study.

Step 7 – Theoretical Sampling

In theoretical sample, the emerging theory is used as a guide on where and how to collect and coding additional data. Holton (2007) recommends:

> *The decisions concerning initial collection of data, further collection cannot be planned in advance of the emerging theory. Instead the researcher can only discover where next to collect data by first coding the initial data and then looking for comparison groups by which to saturate the emerging codes and their properties. By identifying emerging gaps in the theory, the researcher will be guided as where and how to collect the next sources of data.*
>
> *Holton (2007)*

As categories emerge from data in PHARMA case, I then chose to sample data from BP Deepwater Horizon and BP Texas Refinery cases, which could strengthen my emerging theory in defining the properties of the categories, and revalidate the relationship of core categories and sub-categories derived from initial analysis. The data sources of these two cases were determined in step 2.

Step 8 – Constant Comparison

Constant comparison is an analytic process of comparing different pieces of data for similarities and differences against a growing set of abstracted data. This process is essential for testing emerging concepts but also addressing the risk of bias from the researchers inherent starting perspective and limitations in conceptualization. The process evolves from the initial coding of interviews and data, to hypothesizing a relationship based upon one set of interviews or data from other sources), and then testing those relationships interpretation of follow-on data collection (Charmaz, 2006; Glaser and Strauss, 1967).

This emphasizes consistency and relevance of concepts derived from multiple data sources. Considering the commonality and variance between these three cases (e.g. global firms but different industries), this is of importance to assure stability of the emerging theory in further study. Constant comparison also helps enrich the properties and scope of the emerging categories.

In this study, this process continues from open coding to selective coding. The initial coding, which I had from the first case - PHARMA, leads to new interviews. During this process, my conceptual categories are refined. Constant comparison continued until the core and related categories were sufficiently saturated and further coding and constant comparison produced no meaningful further concepts.

Box 3: Examples of memos

During this study I have written over hundreds memos capturing the conceptual and methodological development of my theory. These memos ranged in length from a few lines to a page. In early memos I may record my hypotheses that 'preparation' and 'organisation' were categories and have closed relations. While another memo might question if "integrated response team" belong in partnership or organisation category. Another memo might query if organisation thinks time is important factor in general and can it lead to the better way in their mitigation plan? The following offers a few samples of memos written in conjunction with the category, Preparation.

Memo 1: Because of organisation optimisation in PHARMA ('Agile' programme), people who were explicitly named as a role in the pandemic response team are no longer in the same position. PHARMA resolved this problem afterward by defining a generic role of participation in the response structure. This was incorporated in revised and updated roles and responsibilities and document in a RACI diagram.

Memo 2: From an interview with a PHARMA logistic manager, the pandemic event seems to be more than ever in the public eye and daily reports of pandemic death as headlines across the world.

Memo 3: After re-reading fieldnotes from interviews with a plant manager, PHARMA has put additional reserves in place. Within a few weeks, they are able to secure all the ingredients, sourcing globally and immediately ramping up production. This reminds me of the contrast between Nokia and Ericsson in their response to the event of a fire at a Philips semiconductor factory. Ericsson decided to let the delay take its course, while the Nokia supply chain manager monitored the situation closely and immediately implemented contingency plans (securing components used to make chips for mobile phone from other suppliers) which resulted in more effective response.

Memo 4: The first call that was made by the site director in BP was the first action by BP to instructor second in command to inform the Washington BP base lobbyist of the event. It is parallel to PHARMA proactive establish direct communication with government and international agencies such as WHO in the same topic. It stands in contrast to the public perception that BP was hiding information in the early days of the Deepwater Horizon Oil Spill disaster.

Step 9 – Theoretical Saturation

After the repeated visit and interviews at PHARMA, the marginal improvement to the theoretical framework was small. As found Martin and Turner (1986, p.149), they said, "by the time three of four sets of data have been analysed, the majority of useful concepts will have been discovered".

Step 10 – Theoretical Sorting Memos and Theoretical Coding

Theoretical Sorting Memos

Theoretical sorting of memos is a key to formulating the theory for presentation or writing (Glaser, 1992). Glaser said it starts to put the data previously analysed during open coding into a theoretical framework. During the sorting process connections are made between categories and properties. For example, memos concerning condition affecting the phenomenon can be sorted together to help bring to surface similarity in incidents (or consequences) based on comparable condition.

Theoretical Coding

Theoretical coding occurs when core categories have become saturated. Theoretical codes conceptualised the interrelation of substantive codes by generating hypotheses to be integrated into theory. Theoretical coded emerged from open coding and theoretical memos. The results

Theoretical sorting of memos is a key to formulating the theory for presentation or writing (Glaser, 1992). Glaser said it starts to put the data previously analysed during open coding into a theoretical framework. During the sorting process connections are made between categories and properties. For example, memos concerning condition affecting the phenomenon can be sorted together to help bring to surface similarity in incidents (or consequences) based on comparable condition.

Theoretical codes conceptualised the interrelation of substantive codes by generating hypotheses to be integrated into theory. Theoretical coded emerged from open coding and theoretical memos.

In this study, having achieved theoretical saturation of my core concept and related categories, I proceeded to review, hand sort, and integrate those memos related to the core, its properties, and related categories. As I began to sort (read) memos and look for relationship between the various concepts, theoretical codes began to emerge. I formalised and systematised the findings into propositions that explained

what factors underlie response times. The emergent theory, which is the outcome of this study, will be explained in detail in Chapter 7– findings of the research.

PHASE 4: Literature comparison and write up

Step 11 – Literature comparison

The eleventh step is to compare the emerged theory with the existing literature and assess similarities and differences with a view on how such arise. Eisenhardt (1989, p.545) states:

> *"Overall, trying the emergent theory to existing literature enhances the internal validity, generalizability, and theoretical level of the theory building from case study research…because the findings often rest on a very limited number of cases."*
>
> *Eisenhardt (1989, p.545)*

As discussed earlier, literature on risk management in supply chain is relatively limited in scope and depth. Nevertheless, reading the relevant literature increases sensitivity to concepts – at the same time keeping in mind the 'open approach', which seeks to avoid bias.

For example, in my study, the literature review which are relevant to the main category and the emerging theory such as supply chain disruption, supply chain risk management, time-based management, supply chain partnership raised the theoretical level and help to improved construct definition, as suggested by Eisenhardt (1989).

Step 12 – Validation the theory

From the nature of the Grounded Theory process, validity is essentially inherent but validation can check whether the new theory has 'fit', 'relevance', 'workability' and 'modifiability'.

By fit, an evaluation is made on how well the concepts represent the observed phenomena, as outcome to rigorous application of constant comparison of multiple events contributing to the representation of a concept.

By relevance, a view is formed on how meaningful the concepts are to participants or to the cohort they represent. Certainly, the concepts identified here can be readily tested in further work against other industries – there is no scarcity of cases of supply chain disruption.

By workability, the applicability of concepts across a range of scenarios is understood. As the inputs are phenomena from real-world situations, which express considerable variability, the workability of theory and concept structure is critical to make the work meaningful.

With modifiability, the theory can be extended and adapted when new insight is generated through comparison with further data. This validation in the study is explained more in the closing chapter – 'Conclusion.' - of the study.

To validate my constructs (categories) and the relationships I looked at two disruption at BP the oil company. The disruption at BP Upstream, which experienced a catastrophic oil containment event in 2010, was selected. After a sequence of design changes by BP and missed warnings by its contracting partners, the Deepwater Horizon drilling platform lost control of the 15,000-foot deep exploration well at Macondo Prospect in the Gulf of Mexico. An eruption of oil and gas on the rig exploded, killing 11 and destroying the platform, starting a three-month effort to cap the well and the largest oil spill in American waters. Estimates of damage climbed exponentially; BP faced possible collapse, a lengthy moratorium on offshore drilling shutdown the industry and penalties of GBP 20 Billion where filed against BP and its partners.

The second disruption is from the BP company was selected, exploring the background, cause and response to an explosion at its Texas City refinery in which 15 workers were killed and 180 injured, resulting in an extensive review of BP and refining industry operations. BP has paid out more than GBP 1.2 Billion in compensation by late 2010.

For the BP Deepwater Horizon and BP Texas City cases, data were collected from secondary sources, as access to direct interviews was constrained by ongoing investigations and litigation. Data was collected from official government sources as well as from print news media, company reports and on the Internet. Data and

reports used here are from the US government (National Commission report to the President, Department of Energy, Department of Justice, and the Department of the Interior) and BP internal and public reports. Data included sworn testimony by direct participants in the events from formal and judicial investigations; these are in the public record. The data source, data collection methods and data content of BP are explained in Table 18.

The three disruptions are shown in Table 19 and the similarities and differences of these three cases are shown in Table 20 in order to underpin the relevance of the cases to the research objectives.

Step 13 – Writing the report

Writing of the report is the concluding step of the process. The key objective is to make the relationships explicit and clear, where relevant through graphical representation of the core categories, subcategories and contributing foundation of codes and observations.

BP Deepwater Horizon	
Data Source & Collection Methods	**Data Content**
Reported by • BP – Internal BP Investigation • National Commission on the BP Deepwater Horizon oil spill and offshore drilling • President, Global Business Lines and Chief Health, Safety and Environmental Officer Halliburton • The Joint United States Coast Guard/ The Bureau of Ocean Energy Management • Energy Policy Research Foundation • U.S. Department of Homeland Security, United States Coast Guard • Congress of the United States • Det Norske Veritas (DNV)	From the company and external investigation reports. • Industry and organisational background contributing to the event. • Factual sequence and likely root cause of the disruption. • Assessment of initial and ongoing response including corrective and preventative steps taken by the company. • Perspective on environmental and external impact. • Audio transcripts From company and external websites. • Perceived cause and impact of the disruption, as experienced during the event. • External perception of liability and consequences to the firm.
BP Texas City	
Data Source & Collection Methods	**Data Content**
Reported by • BP – Internal BP Investigation • U.S. Chemical Safety and Hazard Investigation Board • Environmental Protection Agency • U.S. Occupational Safety and Health Administration • Texas Commission on Environmental Quality • The BP U.S. Refineries Independent Safety Review Panel	From the company and external investigation reports. • Industry and organisational background contributing to the event. • Factual sequence and likely root cause of the disruption. • Assessment of initial and ongoing response including corrective and preventative steps taken by the company. • Perspective on environmental and external impact. From company and external websites. • Perceived cause and impact of the disruption, as experienced during the event. • External perception of liability and consequences for the firm.

Table 18: Data Sources, Data Collection Methods and Data Contents from BP

Case	PHARMA Response to 2009 H1N1 Pandemic	BP Deepwater Horizon Oil Spill, 2010	BP Texas City Refinery Fire, 2005
Notification of the event	• On 24 April 2009, the WHO announced an outbreak of H1N1 virus in Mexico and the United States. • On 25 April 2009, the WHO called the flu pandemic problem "a public health emergency of international concern." • On 11 June 2009, the WHO declared the first global Influenza pandemic in 41 years. • On 10 August 2010, The WHO declared pandemic is over. The world has now entered the "post pandemic period".	• On 20 April 2010, an explosion on the BP-leased Deepwater Horizon Gulf of Mexico platform exploded.	• On 23 April 2005, several explosions and a fire occurred during start up of the isomerization unit at the BP in Texas City. The explosions occurred when a distillation tower flooded with hydrocarbons and was over pressurized, causing a geyser-like release from the "blowdown drum" vent stack.
Impact of event	• WHO reported laboratory confirmed cases of pandemic Influenza H1N1 2009, including over 18036 deaths. • CDC estimated an average of 57 million people have been infected with H1N1 and an average 257,000 cases resulted in hospitalizations. • Pandemic Influenza risk triggers other across the company e.g. regulatory controls, sales and market regulations, global political and economic conditions etc. • Effect on several supply chains (Nicole, Hematol, consumer products, antibiotic etc.) • Potential loss of revenue, reputation, R&D investment (GBP 3.2 Billion) and market position.	• 11 workers were killed and many injured. • 4.9 million barrels of spilled in the Gulf. • Moratorium on drilling in the Gulf for six months and extensive new regulations. • BP fines estimated at USD 20 – 40 Billion.	• 15 Workers were killed and 180 other were injured. • Impacted on the World oil market - world oil prices jumped to USD 61 a barrel on the day after an explosion, raised concerns about energy supplies toward the end of 2005. • BP refineries were investigated and BP was fined numerous times by OSHA. • BP has paid out more than GBP 1.3 Billion in compensation.
Description of the risks	• Lack of stock availability to meet demand in the market. • Unable to produce business or medically critical products. • Loss of life; absentee on worker. • Strike in France & Shut down of the plant Mexico • Reputation risk.	• Largest accidental marine oil spill in the history of the petroleum industry. • Environmental. • Loss of life. • Loss of reputation risk. • Fines. • Litigation. • Right to drill. • Government contracts (e.g. Pentagon)	• As the third largest refinery in the US, disruption risk can have effect on the global oil supply petroleum. • Loss of life. • Fines. • Litigation.

Case	PHARMA Response to 2009 H1N1 Pandemic	BP Deepwater Horizon Oil Spill, 2010	BP Texas City Refinery Fire, 2005
Examples of Action taken/ insights solution	• Ramp up production to 24/7. • Recruiting contingency workers. • Redesign supply chain – shifting manufacturing capacity. • Develop production extension. • Accelerate approval process for existing products. • Accelerate vaccine development. • Simplify packaging for easier in high volume production.	• Setup Central command / incident management team. • Modelling of impact. • Develop and attempt portfolio of well-control solutions like top kill, containment dome, and relief well. • Develop and attempt oil recovery and oil spill techniques. • Create spill-response company with competitors.	• Create organization analysis (Fatal accident investigation report) • Engineering and plant analysis. • Simulation and modeling of impact. • Culture and safety review.
Parties Involved	• Suppliers & distributors. • Primary, secondary and third party manufacturing. • Government & International authorities. • Press and public communication. • Consumers/patients.	• Transocean – drilling rig operator. • Halliburton – cement contractor. • Federal, state and local governments. • The Bureau of Energy (BOEMRE) • Coast Guard. • Industry partners and competitors.	• Environmental Protection Agency. • U.S. Occupational Safety and Health Administration. • Texas Commission on Environmental Quality, Internal BP investigation. • Texas City citizens. • Plant workers and management.
Issues encountered	• Establish framework or pandemic management organization. • Preparedness plan in place but not in use – out of date, lack of clarify role & responsibilities. • Problems in line of communications. • Highly variable and uncertain demand.	• Missed early warning signs. • Long delay between detection and countermeasures. • Poor simulation modeling resulted in massive over investment of certain oil spill remedies. • No process and procedures in place for handling Deepwater oil spills. • Many parties involved in legal issues.	• Missed early warning signs. • Not learning from past events. • Documents are is out of date since merger of BP with Amoco. • Policies are ignored / plant layout is unsafe. • Failed alarms. • No effective notification system.

Table 19: A Fact Sheet of Three Disruptions

	Description
Similarities	• Challenges in distinguishing disruptive events from normal events. • Organisational 'apathy' regarding potentially disruptive risks. • Communications barriers during and after event. • Initial 'chaos' during first phase as awareness of the event builds. • Surge in widespread demand for information. • Exponential acceleration of impact when business-as-usual control mechanisms failed to isolate the disruption ('shape') • Balance between general fear of greater impact and need to manage perception of the event (control panic). • Global supply chains and organisation. • Multi-player / multi-geography • Complex supply chain / systems. • Significant impact to the organisation locally and globally. • Potential of catastrophic impact outside the organisation / industry. • Fast response required. • Long-term recovery cycle. • Aspect of government regulation and reputation risk. • Political interests during later phases of the disruption and in long-term 'learning' process.
Differences	• Speed and absolute duration of the event. • Scale of the permanent impact after the event. • Upside and downside opportunity. • Scale of potential impact on human lives (15 killed, 180 injured in BP approximately 18,000 swine flu deaths, 11 people killed in BP oil spill -

Table 20: Similarities and Differences of Three Disruptions

Chapter 4
PHARMA H1N1 Influenza Pandemic

4.1 Introduction

Influenza and other pandemics are infrequent but can have a dramatic impact on health for a large population. In previous generations, millions died in multiple waves of Influenza outbreaks in a relatively short period. Although most humans and animals suffer only mild symptoms, some variants are highly contagious or, such as the recent avian flu, deadly.

Uncertainty about the deadliness and spread of illness makes it difficult to predict the impact of an epidemic or pandemic, and with infrequent occurrences, planning for such a global outbreak is a challenging exercise.

A major pharmaceutical firm such as PHARMA (one of top five pharmaceutical companies in the world in term of revenue) must act quickly to protect its supply chain. A local or widespread outbreak can disrupt production and logistics for critical medicines relied upon by specific groups of patients, and obviously hamper the broader response for the production of Influenza medicines.

Fast and convenient travel in recent times has accelerated the spread of Influenza between countries and continents;; however, better modelling, science and communication present an opportunity to detect earlier, coordinate more effectively and respond faster. PHARMA plays a key role in minimising the humanitarian impact of such occurrences, at the same time there is a potential upside revenue opportunity that can reward years of investment in antiviral medicines.

Even so, there is always the risk of over-reacting to potential outbreaks, as seemed evident during the 'false alarm' epidemic in 1973 in the US, which led to unprecedented government involvement in vaccinating a large percentage of the population, despite only a handful of deaths early in that outbreak. Managing the critical supply, sales and political relationships is challenging when governments are regulators and influencers as well as important customers. According to Wolfgang Wodarg, head of health at the Council of Europe, the makers of flu drugs and

vaccines influenced the decision of the World Health Organisation (WHO) to declare a pandemic. Talking after the 2009 swine flu pandemic, Wodarg said, "This led to the pharmaceutical firms ensuring 'enormous gains', while countries, including the UK, 'squandered' their meagre health budgets, with millions being vaccinated against a relatively mild disease[1]."

In this chapter explained how PHARMA deal with unexpected/adverse events and the risk of disruption to PHARMA supply chain. It focuses on PHARMA's approach to supply chain risk management, in particular, discussing in depth, its planning and preparation for flu pandemic, the production of Nicole Influenza treatment, vaccine and the significant investment in PHARMA.

4.2 Company Overview

PHARMA is one of the world's leading research-based pharmaceutical and healthcare companies, and is "committed to improving the quality of human life by enabling people to do more, feel better and live longer". With a firm foundation in science, PHARMA discovers, manufactures and distributes vaccines, prescription medicines and consumer health products. Headquartered in the UK, PHARMA employs over 100,000 people in 117 countries and the pharmaceutical group includes 108 plants located in 41 different countries.

In 2000 two leading pharmaceutical companies merged to form PHARMA. After mergers and acquisitions PHARMA had a 7% share of the global pharmaceutical market, accounted for 26% of all vaccines sales and 17% of all anti-infective[2].

According to PHARMA released 2009 annual reports, PHARMA was the fourth largest pharmaceutical company worldwide by revenue with sales of GBP 28.4 Billion. Of that, sales in the care and pharmaceutical business were GBP 23.7 Billion (of which vaccines sales were GBP 3.7 Billion) and consumer healthcare sales were GBP 4.7 Billion.

---

[1] Macrae, F. (2010)
[2] Oxfam (2001)

PHARMA Products

PHARMA is known as a leader in respiratory central nervous system, AIDS/HIV and anti-infective research. The company's products are divided into three main areas: prescription medication, vaccines and consumer healthcare.

1. Prescription Medication (GBP 27.3 Billion)

The bulk of PHARMA's revenues come from the sale of prescription medications. PHARMA has medications in many different therapeutic categories, including cardiovascular, respiratory and the central nervous system. Some of its most important prescription products are:

- Hematol/Enatol (GBP 5 Billion): This product is a long-acting bronchodilator, meaning it opens up a patient's air passage through an anti-inflammatory taken through an inhaler. Hematol/Enatol is approved to treat asthma and chronic obstructive pulmonary disease. In 2004, it was estimated that approximately 20 million Americans (between 5 and 10%) have asthma. There is clearly a large market for treatments. Although there are no indications that the number of cases of asthma is growing, there has been no marked decrease either. Hematol/Enatol is the highest selling respiratory product worldwide; it is a main driver for the strong growth in PHARMA's revenue.
- Seria (GBP 771 Million): This product is metabolic product for the treatment of diabetes. It is used to level insulin levels and is effective at mitigating type II diabetes.
- Antivirals (GBP 4.2 Billion): PHARMA's antivirals treatments include an Herpes treatment, HIV treatment, and Nicole Influenza treatment. In 2009, the total antiviral sales grew by 12%.

2. Vaccines (GBP 3.7 Billion)

PHARMA is dominant in the vaccine market, supplying approximately one-quarter of all vaccines worldwide. Its vaccines are used to immunise a wide range of ailments including hepatitis (hepatitis A and hepatitis B), meningitis, Influenza and various childhood illnesses.

3. Consumer Healthcare (GBP 4.7 Billion)

PHARMA's consumer healthcare products include over-the-counter medications, nutritional supplements and oral care products. Some of the major products include a well-known toothpaste brand, toothpaste specifically for sensitive teeth, gastro-intestinal ailments and products to help users quit smoking. The portfolio includes a well-known product in a line of glucose energy and sports drinks of which sales rose 7 % to GBP382 Million in 2009.

PHARMA Supply Chain

The Manufacturing and Supply Chain (MSC) is responsible for PHARMA's supply chain quality, performance and customer service. MSC supports the commercial ambitions of PHARMA by delivering quality medicines and consumer products to patients and customers around the world. More than 29,000 people work in MSC across PHARMA in a network of 77 sites in 33 countries.

The scale of manufacturing in PHARMA is large, with the manufacture of over four billion packs per year in 28,000 different presentations including tablets, creams and ointments, inhalers, injections, liquids and sterile solutions supplied to more than 150 markets. As stated in the PHARMA annual report 2009, MSC spent over GBP 3.7 Billion on production in 2009.

PHARMA's supply chain is complex with over 75,000 suppliers worldwide. These range from major strategic relationships with suppliers that manufacture active pharmaceutical ingredients (APIs), intermediates, raw materials and packaging for PHARMA medicines through to local contracts for goods or services such as office equipment, cleaning and security. According to the 2008 annual report, PHARMA operates a procurement operation that spends over GBP 2 Billion annually with external suppliers. Importantly, PHARMA takes specific steps to protect its supply chain from disruption, as reviewed below.

PHARMA Risk Management

PHARMA is committed to having an effective risk management process across all business units. This enables management to operate a risk-based approach to establishing internal control systems to effectively mitigate or control significant

risks. PHARMA's risk management approach can be categorised into two levels: corporate level and business unit level.

Corporate Level

According to PHARMA's Corporate and Social Responsibility Report 2009, an internal control framework (Figure 11) integrates ethics and compliance with the day-to-day management of the group. This framework supports line management in the identification and mitigation of significant risks, among which are potential compliance failures.

The framework includes the Risk Oversight and Compliance Council (ROCC), as well as sector and other business unit risk management and compliance boards. The ROCC is chaired by PHARMA's corporate compliance officer and it includes several corporate executive team (CET) members and heads of department with internal control risk management, assurance, audit, and compliance responsibilities. The ROCC reports to the audit committee of the PHARMA Board and the CEO, and will also report to the CET. The reporting line to the audit committee provides a mechanism for the executive management if irregularities are identified.

PHARMA's Risk Management and Legal Compliance Policy further clarify the roles and responsibilities of people in the company's internal control framework. CET members are formally responsible for establishing an appropriate risk management structure within their business units to identify and mitigate significant risks.

PHARMA continues to improve its risk management process. The ROCC meets regularly to review and assess significant risks and mitigation plans, providing an oversight of internal controls to ensure compliance with applicable laws, regulations and internal PHARMA policies.

> *"Each business unit must review significant risks at least once a year and include identifying operational risks, legal compliance risks and risks to the achievement of strategic goals and objectives. This ensures that significant risks connected with changes in management direction and the external environment is identified. Business units are corporate functions are required to present annually to the ROCC and Audit and Risk Committee detailing risk management and compliance approach, provide a balanced assessment of the status of internal controls over key risks, and highlight any significant compliance issues."*
>
> *PHARMA Corporate Responsibilities Report (2010)*

Table 21 shows the most significant risks facing PHARMA are listed below based on the annual CET risk workshop in 2009.

Business Unit Level (Manufacture and Supply Chain Level)

Risk management is an essential component of PHARMA's system of internal control and governance and is regarded as good management practice throughout its business. PHARMA states a need for a systematic, standardised and effective approach to risk management to ensure that responsibilities for managing risks are clearly stated, understood and accepted as well as to ensure that the business objectives are achieved. This can also establish appropriate mechanisms for communication, reporting and the escalation of risk.

PHARMA's basic approach to supply chain risk management is a five-step process (Figure 12). The risk management process includes risk identification, risk assessment, risk analysis, risk treatment and risk monitoring.

Significant risks facing PHARMA
1. Risk that R&D will not deliver commercially successful products.
2. Patent infringement litigation.
3. Potential changes in intellectual property laws and regulations.
4. Weakness of intellectual property protection in certain countries.
5. Risk of substantial adverse outcome of litigation and government investigations.
6. Product liability litigation.
7. Anti-trust litigation.
8. Sales and market regulations.
9. Third party competition.
10. Governmental and payer controls.
11. Regulatory controls.
12. Risk of interruption of product supply.
13. Risk of concentration of sales to wholesalers.
14. Global political and economic conditions.
15. Taxation and treasury.
16. Pandemic Influenza.
17. Environmental liabilities.
18. Accounting standards.
19. Failure of third party providers.
20. Protection of electronic information and asserts.
21. Alliances and acquisitions.
22. Attraction and retention.

Table 21: Significant Risk Facing PHARMA

Source: PHARMA Corporate Responsibility Report (2009)

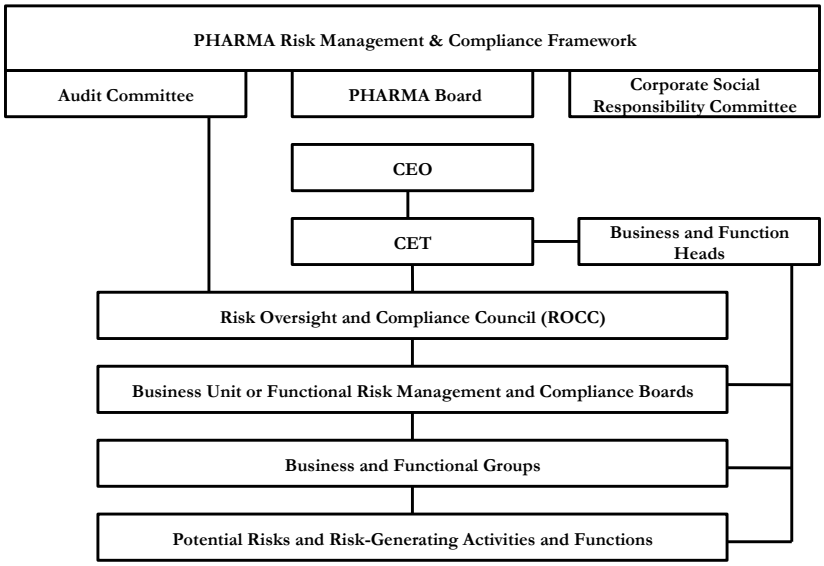


Figure 11: PHARMA Risk Management and Compliance Framework

Source: PHARMA corporate responsibility report, 2009

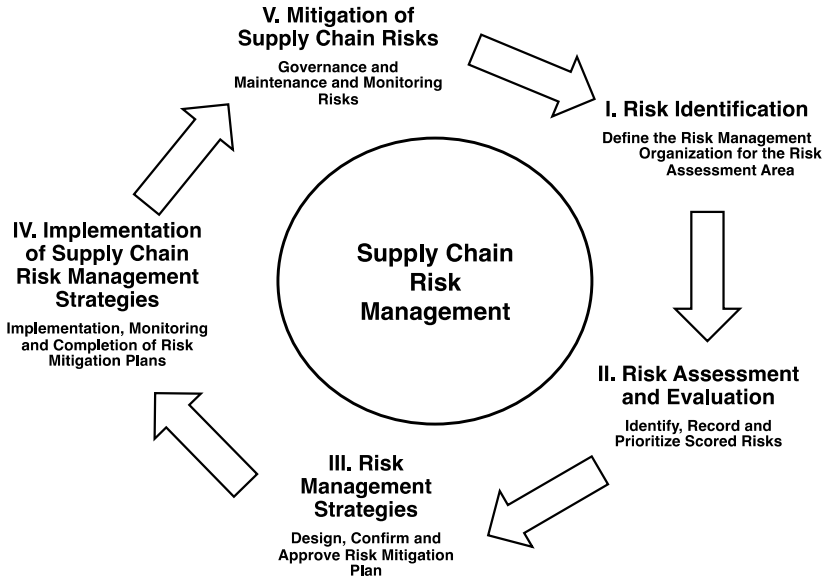


Figure 12: PHARMA's Basic Approach to Supply Chain Risk Management

Source: PHARMA

MSC defines the risk management requirements regarding identifying, accessing, prioritising, mitigating, monitoring and communicating risks. MSC and global functions must incorporate the process steps, decisions and approval points shown in the risk management process map in (Figure 13).

I. Define the risk management organisation for the risk assessment area.

The activities and areas in which this risk management process operates in MSC is known as the risk assessment area and defined by senior executive management.

II. Identify, record and prioritise scored risks

The risk identification processes consider past and present events in addition to potential future events or changes that could occur within the risk assessment area. Initially, PHARMA identifies and analyses its supply chain risks by mapping the supply chain, looking at suppliers as well as products and services. PHARMA distinguishes between five levels of the probability of an event occurring Table 22.

III. Design, confirm and approve risk mitigation plan

At this stage, the approved mitigation plan must be included in the risk register as well as mitigated consequence (score), mitigated likelihood (score), mitigated index value and escalation. A risk register or risk analysis that is used for identifying, analysing and managing risk contains are shown in Table 23. The risk score is calculated by multiplying the impact by the likelihood: I (impact) x L (likelihood) = R (risk score)

PHARMA categorises overall risk score and recommends response in four levels (Figure 14).

- Ensure mitigation and contingency remain valid (score 1–2).
- Consider further mitigation or contingency (score 3–4).
- Increase mitigation or strengthen contingency (score 6–10).
- Increase mitigation and strengthen contingency (score 12–16).

IV. Implement, monitor and complete risk mitigation plans.

At this stage, a mitigation plan owner starts the implementation of the risk mitigation plan and defines the key milestones for the measurement of the delivery of the plan to be monitored in the risk register. However, the risk owner determines the appropriate frequency for the review of the risk mitigation plan based on the severity of the risk and timing of key milestones.

V. Governance and maintain

There is a defined process for reporting, communicating and escalating risks including the communication of the plan's progress for review and approval. At the end of this stage, the risk register must be maintained and reviewed by the risk team annually.

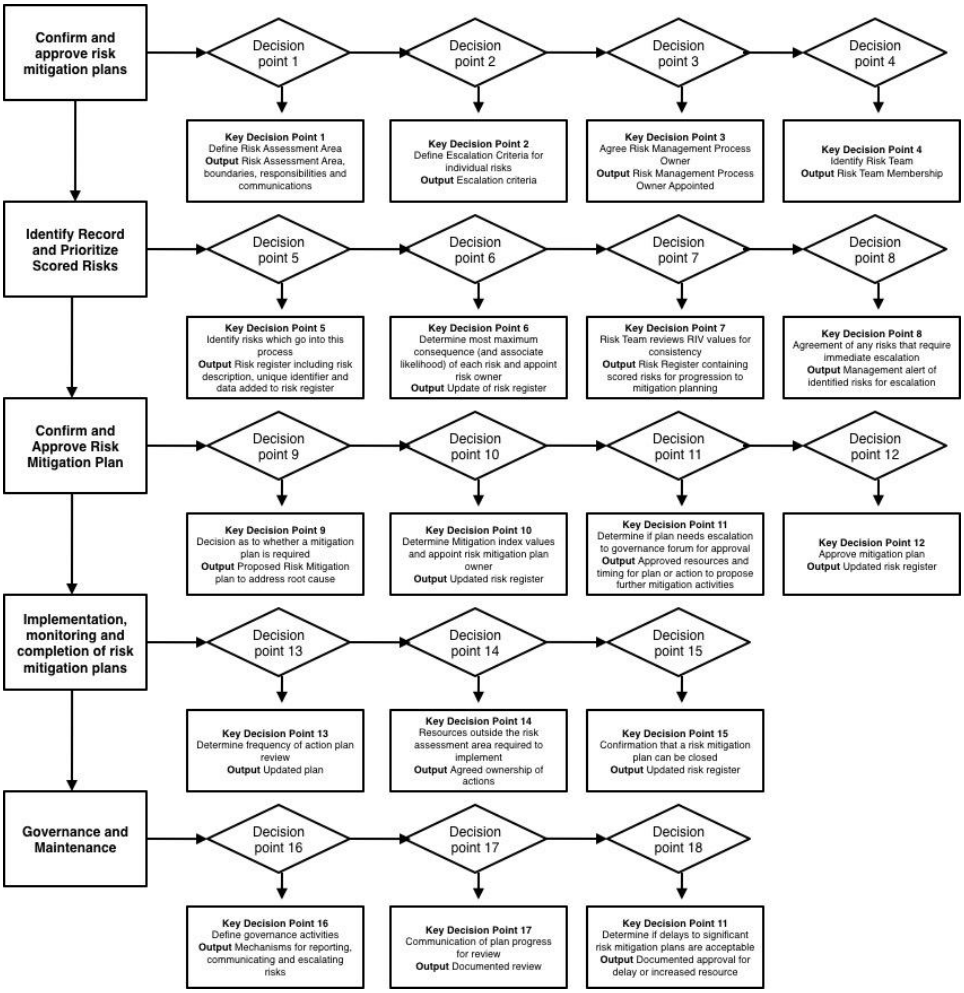


Figure 13: Process Map

Source: PHARMA

Category	Product Quality and Compliance	Environment, Health and Safety	Business
	Patients and customer Company and shareholder Regulators	Injuries or illness potential Environmental impact	Cost Supply Reputation

Likelihood Score	1-Rare	2 - Unlikely	3-Possibly	4-Likely	5-Almost certain
Frequency: How often might/ does it happen?	Once in 50 years	Every 5-10 years	Every 1-5 years	One or more times per year	Significant number of times per year

Impact Score	1-Insignificant	2-Minor	3- Moderate	4- Major	5- Catastrophic

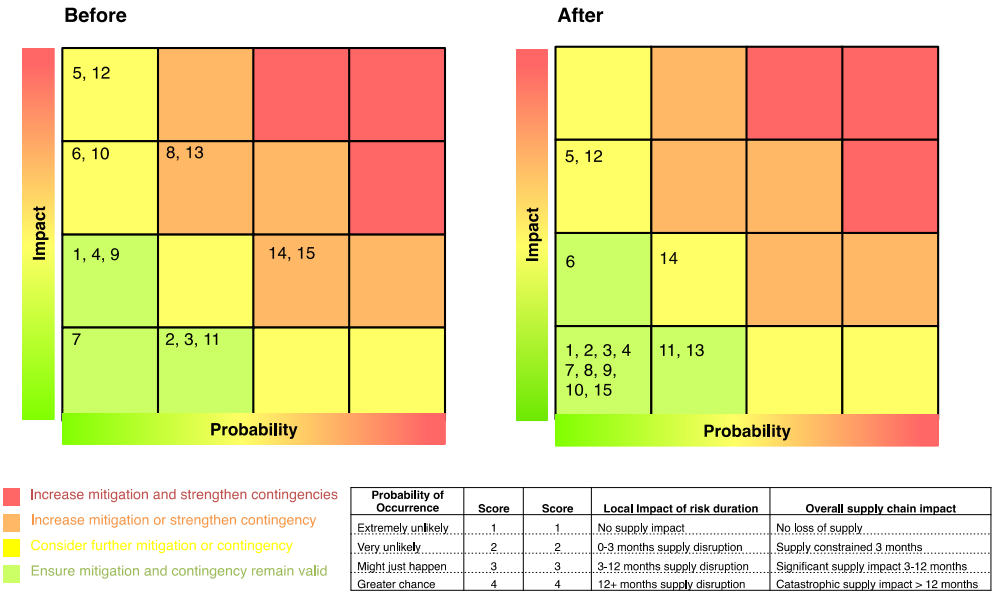
Table 22: Five by Five Matrix - Likelihood and Impact Scoring

Source: PHARMA

Risk Register
1. A description of risk.
2. A consequence if this event actually occurs.
3. A probability of its occurrence (score).
4. An impact (score)
5. Raw risk score (score).
6. Mitigation plan (how to reduce the probability of an event occurring).
7. Contingency plan (action to be taken to reduce impact should it occur).
8. Mitigated likelihood score (a score of probability after mitigation).
9. Mitigated consequence score (a score of supply chain impact after contingency).
10. Mitigated index value (new overall risk score).
11. Risk team owner.
12. Escalation.

Table 23: A Range of Content for Risk Register

Source: PHARMA



Probability of Occurrence	Score	Score	Local Impact of risk duration	Overall supply chain impact
Extremely unlikely	1	1	No supply impact	No loss of supply
Very unlikely	2	2	0-3 months supply disruption	Supply constrained 3 months
Might just happen	3	3	3-12 months supply disruption	Significant supply impact 3-12 months
Greater chance	4	4	12+ months supply disruption	Catastrophic supply impact > 12 months

Figure 14: Risk Analysis Matrix Before and After Mitigation and Contingency Plan

Source: PHARMA

Manufacturing Site Business Contingency Plan

Business continuity plans (BCPs) at PHARMA are part of a formal planning process to identify the potential impact of significant unplanned adverse events on critical business processes and assets and to formulate viable strategies and plans to minimise the impact on business continuity for the organisation following a significant business interruption.

BCP focus on developing contingency and recovery plans that minimise the impact of an event, rather than the threats and causes of the event. The BCP in Figure 15 is a balanced, ongoing, coordinated programme of strategies, plans and procedures that provide the ability to manage and ensure the ready availability of enterprise-wide critical resources in response to disaster or unplanned interruptions.

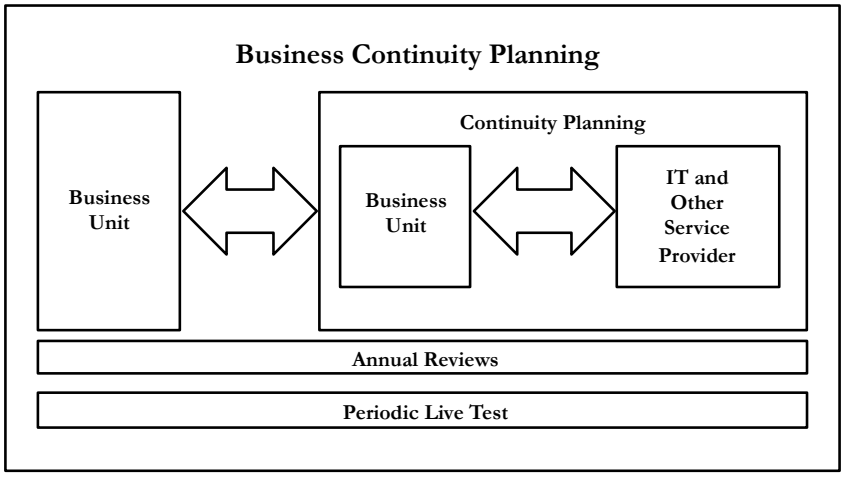


Figure 15: Business Continuity Planning Model

Source: PHARMA

Business Unit – must ensure that BCPs exist for all critical processes.

Continuity Planning – a subset of continuity planning that ensures that an adequate recovery strategy is in place to restore minimum essential service and systems in the event of a significant disruption.

SLA (1) – Service Level Agreements (SLA) or contracts should be developed and agreed between the business and the unit that confirms, in measurable terms, the recovery service that the unit will provide to ensure critical processes remain uninterrupted in the event of a disaster.

SLA (2) - must be established to ensure adequate recovery capabilities for service that are operated by IT internal or external service providers.

IT and other services providers – a service level agreement or contract developed to confirm, in measurable terms, the recovery services that will be provided to ensure critical applications and services remain uninterrupted in the event of a disaster.

Annual Reviews – continuity plans are reviewed annually to ensure they are kept up-to-date and accurate.

Periodic Live Testing and joint live testing - performed on continuity plan to ensure that the plans will work in the event of a disaster.

Logistics Pandemic Business Continuity Plan

The logistics pandemic business continuity plan is based, in part, on the WHO national preparedness plan. It defines the roles and activities of MSC and the supply chain pandemic management team, which will be formed in the event of an Influenza pandemic being declared. In addition, it states the responsibilities and describes the methods and sequence for performing the Influenza pandemic logistics process.

This process document forms a central part of the overall MSC activities as outlined in the formal MSC preparedness plan. It aims to ensure that, in the event of a pandemic, medically critical products from PHARMA will continue to be supplied, defined business critical products will continue to be supplied, the number and duration of stock-outs and the impact on sales will be minimised and manufacturing site BCPs are aligned to this process plan. In addition, its aim is to mitigate the negative effects of the pandemic and maintain business operation as efficiently as possible.

4.3 Background of the H1N1 2009 Influenza Pandemic

History of the Influenza Pandemic

It is generally agreed that three pandemics of Influenza occurred in the 20th century: in 1918, 1957 and 1968. The latter two pandemics together are thought to have caused between one million and four million deaths. They were in the era of

modern virology and as such have been the most thoroughly studied. All three have been informally identified by their presumed sites of origin as Spanish, Asian and Hong Kong Influenza, respectively. They are now known to represent three different antigenic subtypes of the Influenza A virus: H1N1, H2N2, and H3N2, respectively.

The 'Spanish flu' outbreak in 1918 is thought to have infected up to one-third of the world's population and caused 20 to 50 million deaths from 1918 to 1919. It occurred in three waves, beginning with a first spring wave in 1918 that was mild, a severe second wave quickly followed by a milder third wave in early 1919. This pandemic is estimated to have had an overall case fatality rate of approximately 2% of infected persons.

Not classified as true pandemics are three notable epidemics: (1) a 'Pseudo-pandemic' in 1947 with low death rates, (2) an epidemic in 1977 that was a pandemic in children and (3) an abortive epidemic of swine flu in 1976 that was feared to have pandemic potential. Major Influenza epidemics show no predictable periodicity and all differ from one another in impact.

Current theory suggests that the basic genetic structure that varies according to origin (e.g. strains of aviary or porcine origin) will evolve through mutation and genetic reassortment in mild forms (antigenic 'drift') or significant forms (antigenic 'shift'). The latter was presumed to typically be followed by a pandemic, because the population at large was effectively not immunised as they might have been from previous mild transmissions of similar Influenza strains.

History of the Avian Flu

Influenza A virus subtype H5N1, or simply H5N1, is a subtype of the Influenza A virus that can cause illness in humans and many other animal species. In birds this virus can cause a wide spectrum of manifestations, ranging from mild illness to rapidly fatal disease. Avian Influenza A virus strains are classified as low pathogenic (associated with mild disease) and highly pathogenic (HPAI; associated with severe illness and high mortality). A bird-adapted strain of H5N1, called HPAI A, was cause of H5N1 flu, commonly known as avian Influenza or bird flu.

Avian Influenza A (H5N1) first came to attention worldwide in 1997, following a massive outbreak in poultry flocks in Hong Kong. Another brief outbreak occurred in February 2003 in Asia, Africa, the Pacific, Europe and the Near East. Limited person-to-person transmission kept this bird flu strain from causing a pandemic, although experts continued to closely monitor bird flu cases.

Avian Influenza viruses do not usually infect humans; however, several instances of human infections and outbreaks of avian Influenza have been reported since 1997. In 2003, Influenza A (H7N7) infections occurred among persons who handled affected poultry and their families in the Netherlands during an outbreak of avian flu among poultry. More than 80 cases of H7N7 illness were reported with symptoms ranging from eye infections (conjunctivitis) to severe respiratory disease (pneumonia). One patient, a veterinarian who had visited an H7N7 flu-affected farm, subsequently died.

Although there was evidence of limited person-to-person spread of infection, sustained human-to-human transmission did not occur in the previous outbreaks of avian Influenza. It is believed that most cases of avian Influenza infection in humans resulted from contact with infected poultry or contaminated surfaces.

According to the UN Food and Agriculture Organization (FAO) Avian Influenza Disease Emergency Situation Update in 2008, H5N1 pathogenicity was continuing to gradually rise in endemic areas but the avian Influenza disease situation in farmed birds was being held in check by vaccination. Eleven outbreaks of H5N1 were reported worldwide in June 2008 in five countries (China, Egypt, Indonesia, Pakistan and Vietnam) compared with 65 outbreaks in June 2006 and 55 in June 2007. The "global HPAI situation can be said to have improved markedly in the first half of 2008 but cases of HPAI are still underestimated and underreported in many countries because of limitations in country disease surveillance systems[3]."

On December 21 2009, the WHO confirmed 447 human cases, which resulted in 263 deaths.

---

3 Food and Agriculture Organisation (2010)

Severe acute respiratory syndrome (SARS) was first reported in Asia in February 2003, causing severe respiratory illnesses in 8,098 people worldwide. Before the SARS outbreak was contained in July 2003, 774 people died. However, avian Influenza and SARS are entirely different disease entities caused by completely different viruses, although some of the symptoms are the same.

The 2009 H1N1 Influenza Pandemic

In April 2009, a novel Influenza virus strain began to spread around the world. The WHO referred to the virus as Influenza A (H1N1), whereas the CDC and other Administration officials referred to it as 2009 H1N1 flu. Public reports referred to the virus as 'swine flu', which reflected the dominant genetic makeup of the unknown disease. Throughout this report, this event will be referred to as the 'H1N1 pandemic' is a highly contagious acute respiratory disease of pigs, caused by one of several swine Influenza A viruses. Morbidity tends to be high and mortality low (1–4%). The virus is spread among pigs by aerosols, direct and indirect contact, and asymptomatic carrier pigs (e.g. animals that do not appear to be infected). Outbreaks in pigs occur year round, with an increased incidence in the autumn and winter in temperate zones. Many countries routinely vaccinate swine populations against swine Influenza.

The WHO formally investigated and explained how the disease emerged: pigs can be infected by avian (bird), human, and swine (pig) Influenza (flu) viruses. When flu viruses from different species infect pigs simultaneously, the viruses can reassort (swap genes) and new viruses that are a mix of swine, human or avian flu viruses can emerge. This type of reassortment has already happened in pigs; avian and human genes have been circulating among swine in the United States since 1998. This type of reassortment can also occur in humans. The currently circulating Influenza A (H1N1) virus is such a reassortment, composed of genes of swine, avian and human origin. This particular combination had not been seen in humans or in swine. The origin of this reassortment, and when and where it happened, is not known. This virus is now being transmitted from human to human in a sustained manner.

Swine Influenza viruses are most commonly of the H1N1 subtype, but other subtypes are also circulating in pigs (e.g., H1N2, H3N1, H3N2). Pigs can also be

infected with avian Influenza viruses and human seasonal Influenza viruses as well as swine Influenza viruses. The H3N2 swine virus was thought to have been originally introduced into pigs by humans. Pigs can be infected with more than one virus type at a time, which can allow the genes from these viruses to mix.

According to the US Centres for Disease Control and Prevention (CDC), the first large-scale outbreak was registered in Mexico in late March 2009, resulting in an effective shutdown of Mexico City. Although the illness caused was typically mild and similar to common seasonal flu, patients with underlying health issues were at risk and the global spread during June triggered a major response by governments and pharmaceutical companies.

Although many illnesses are successfully and predictably treated by modern medicines, rapidly communicable diseases can overwhelm the medical profession and exhaust the availability of an affordable remedy. Historical and recent examples are many and severe, of both highly contagious diseases such as the bubonic plague or tuberculosis as well as the broader category of infectious diseases such as HIV. This study examines the response of a major pharmaceutical in the face of the global outbreak of H1N1 Influenza virus, where the eventual outcome was unknown at the time that major investments in and strategic decisions about its supply chain had to be made.

In June 2009, H1N1 reached pandemic levels. The WHO declared a pandemic on 11 June 2009, which was the first flu pandemic in 40 years. On the day of the announcement, 74 countries and territories had reported laboratory confirmed infections. Official reports stated that there had been nearly 30,000 cases globally and 141 deaths, with figures rising daily.

As of June 22 2009, the WHO confirmed more than 50,000 human cases of H1N1 in more than 80 countries and territories, including 231 deaths (Figure 6). It is important to note that more people than officially reported may have contracted H1N1; the number of cases shown in the WHO report reflected only cases confirmed by laboratory testing and reported to the WHO by foreign health authorities. By this date, most countries had since confirmed infections from the new virus.

The virus strain does not seem to be as lethal as was H5N1 avian Influenza, which re-emerged in 2005, but it is slightly more lethal than seasonal flu. Although the virus has been characterised as a pandemic, researchers could not initially predict how virulent the virus would ultimately become. The FAO, the World Organization for Animal Health (OIE) and the WHO agreed that there was a risk of contracting the virus from consuming well-cooked pork or pork products. The WHO asserted that imposing travel restrictions would minimally affect the spread of the virus, but would be highly disruptive to the global community. Nevertheless, local authorities shutdown Mexico City for five days and imposed wide-ranging restrictions over weeks in an attempt to slow the spread of the H1N1 virus.

The globalisation of the pharmaceutical industry has had an impact beyond the core corporate aim of managing profitability; in an industry where investment costs in research are huge and few drugs reach 'blockbuster' profitability status. Other aspects such as public policy, public perception, intellectual property rights and competition can affect efficient supply chain operations for the pharmaceutical industry. After the pandemic declaration by the WHO, PHARMA experienced a sudden increase in demand for its Nicole product, one of just two commonly available treatments in the market along with a competitors product, referred to here as Abaco. PHARMA is the only company licensed to make Nicole; however, it was increasingly feared during the first stages of the swine flu pandemic that the higher end of demand estimates for Nicole might not be met.

Therefore, in this study, I look at the role of time on PHARMA's response to the 2009 Influenza pandemic and the impact it had on a range of risk management and supply chain management policies. As one of the largest global pharmaceutical development and manufacturing firms, PHARMA has a particularly important role in addressing the health challenges posed by viral pandemics. Like other pharmaceuticals, PHARMA's sourcing and manufacturing strategy is global and complex, with a broad range of commodity and high-value products including life-critical medicines. Selling in markets and to governments worldwide, PHARMA is exposed to demand-side fluctuation and influence that make forecasting and stock allocation a complex process.

Available Treatments and Vaccines for 2009 H1N1 Influenza

According to the WHO, most people who have contracted H1N1 have experienced Influenza-like symptoms, such as a sore throat, cough, runny nose, fever, malaise, headache and joint/muscle pain, and recovered without antiviral treatment. Drugs provided to H1N1 patients may reduce the symptoms and duration of illness, just as they do for seasonal Influenza. They also may contribute to preventing severe disease and death. The strain of H1N1 circulating the globe was a new virus, and only a small number of people with the infection have been treated for it with antiviral drugs.

The strain of H1N1 is treatable with two antiviral drugs, Osolia (brand name Abaco marketed by PHARMA's competitor and Xtazo (brand name Nicole) marketed by PHARMA. The WHO has maintained a global stockpile of approximately five million adult treatment courses of Abaco, which were donated by manufacturers and sponsoring governments. This stockpile was initiated after the onset of H5N1 bird flu outbreaks. The WHO had already distributed some of the treatments through its regional offices and distributed another three million treatment courses from its stockpile to developing countries in the first months of the pandemic.

At the beginning of the H1N1 outbreak, there was no available vaccine against the current strain of H1N1, although the CDC, the WHO and others were working on developing one. Scientific evidence, although incomplete, suggested that the then available seasonal Influenza vaccines would offer no protection against H1N1. The WHO and CDC prepared vaccine candidate viruses and estimated that once the strain had been modified, it would take between five and six months to mass produce a vaccine against H1N1. Once a vaccine had been developed, the WHO estimated that one to two billion vaccine doses could be produced annually. Five major pharmaceutical companies have since developed these flu vaccines. One of these companies announced that it would donate 100 million doses to the WHO for distribution to poor countries in need. PHARMA also reportedly planned to donate 50 million doses to the WHO.

Nicole Dry Powder Inhaler

Nicole inhalation powder contains the active pharmaceutical ingredient called Xtazo, which is a type of medicine called a neuraminidase inhibitor. It is used to

treat and prevent infection with the Influenza virus. Nicole is marketed by PHARMA competes with Abaco which is a product contains the API called Osolia from ISSA.

PHARMA has adapted two technologies for delivering the Nicole drug. The first technology uses a dry powder inhaler with the Nicole inhalation powder packed in blisters on a circular foil disk. From a patient perspective, the multi-dose format is convenient but more expensive to manufacture. The second technology is capsule-based, in which the drug is delivered in a single application form using a capsule to be inserted by the patient in the inhaler device.

Nicole can minimise the impact of the virus when taken by the patient within 72 hours of exposure. Nicole is an alternative treatment from Abaco; however, using an inhaler for treatment is less convenient compared with Abaco, which is taken in tablet form. Nicole is also understood to be more expensive to manufacture than Abaco.

Most countries have built stockpiles of antiviral medication consisting of approximately 80% of Abaco and 20% of Nicole. Both products have advantages and disadvantages.

According to the WHO, Abaco was working against the strains of the new H1N1 flu but some health experts expressed concerns that it might be less effective than Nicole was, since there had been widespread reports in the past year of resistance to Abaco by seasonal flu. The swine Influenza A (H1N1) viruses that had been detected in humans in the US and Mexico in 2009 were also resistant to Amantadine and Rimantadine.

Clinical tests had confirmed that 2009 H1N1 pandemic virus were sensitive to inhibitors of neuraminidase such as Abaco and Nicole. As said by CDC, Nicole was the preferred medication for all circulating subtypes of the Influenza virus at that time. As a result Nicole has typically been used to diversify and add to government stockpiles of Osolia (Abaco).

Following the outbreak, PHARMA contacted governments around the world to ascertain demand for Nicole and put in place a series of measures to raise production levels. PHARMA expected to be able to increase its annual production

capacity of Nicole to 190 million treatment courses by the end of 2009. This new capacity is three times more than PHARMA's previous maximum capacity of 60 million treatment courses.

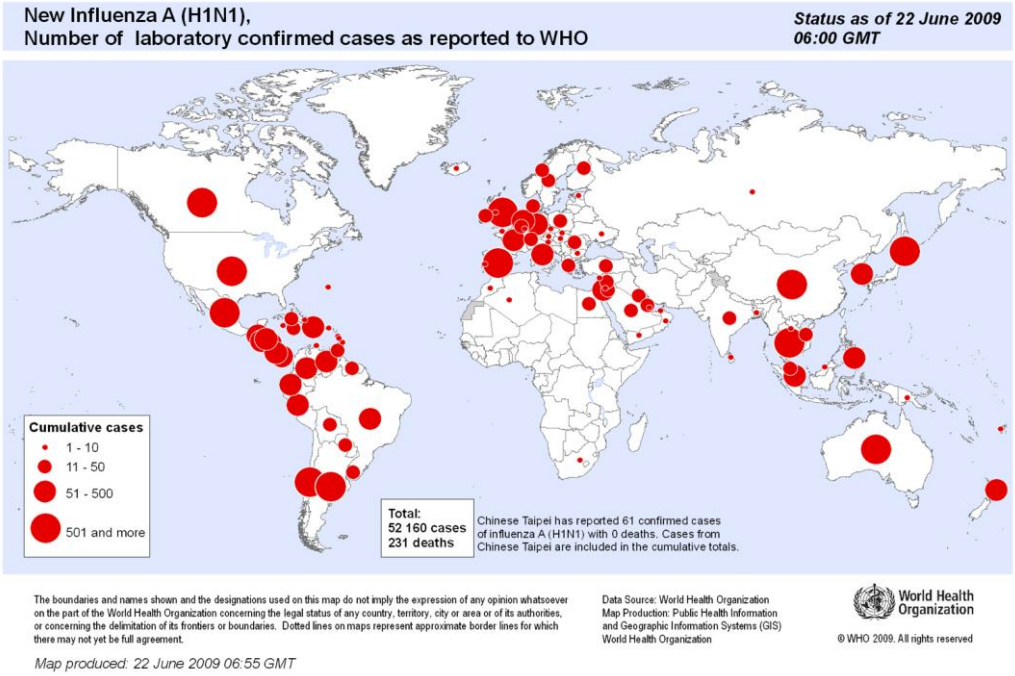


Figure 16: Number of Laboratory Confirmed Cases as of 22 June 2009

Source: World Health Organisation (2009)

4.4 Companies and Parties Involved

A range of national and international agencies are involved the response to a possible pandemic.

World Health Organisation (WHO)

The World Health Organisation is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends. The headquarters of WHO is located in Geneva, Switzerland.

WHO Pandemic Phases

The phases of pandemic alert (Figure 17) are defined and managed by the World Health Organisation. They were first developed in 1999. It is applicable globally and provides a framework to aid countries in pandemic preparedness and response planning. The use of a six-phased approach has been developed to facilitate incorporation of new recommendations into existing national plans.

To facilitate planning at national and global levels, Phases 1 to 3 correlate with preparedness, including capacity development and response planning activities; Phases 4 to 6 clearly signal the need for response and mitigation effects and have been grouped to include common action points.

In addition, the time after the first pandemic wave has been elaborated into post peak and post pandemic periods. When making a change to the global phase, WHO considers all available information to assess if the criteria for a new phase have been met.

In May 2009, there was vigorous debate about whether WHO should maintain its pandemic Influenza phase system, which reflects the spread of the virus and transmission patterns rather than the severity. Some argued that WHO should develop an alert system that is based on severity. Supporters of this idea asserted that the public might not understand that widespread death may not occur at the highest pandemic phase level. Critics of the systems, including some European leaders, warned that if WHO raised the pandemic threat level to Phase 6, panic might ensue and considerable economic and social disruptions may occur. Other health experts maintained that cases of sustained human-to-human transmission of H1N1 at that time in Japan justified raising the pandemic threat level to Phase 6.

On 11 June 2009, WHO raised the 2009 pandemic phase level from Phase 5 to Phase 6. When announcing her decision, WHO Director General Margaret Chan underscored that the shift did not reflect a change in severity. WHO also released a pandemic Influenza preparedness and response guide that was updated and replaced its 2005 guide. Among other changes, the update "retained the six-phase structure, but regrouped and redefined the phases to more accurately reflect pandemic risk and the epidemiological situation based upon observable

phenomena[4]." The update also outlined steps governments should take in planning and preparing for an epidemic (Table 24).

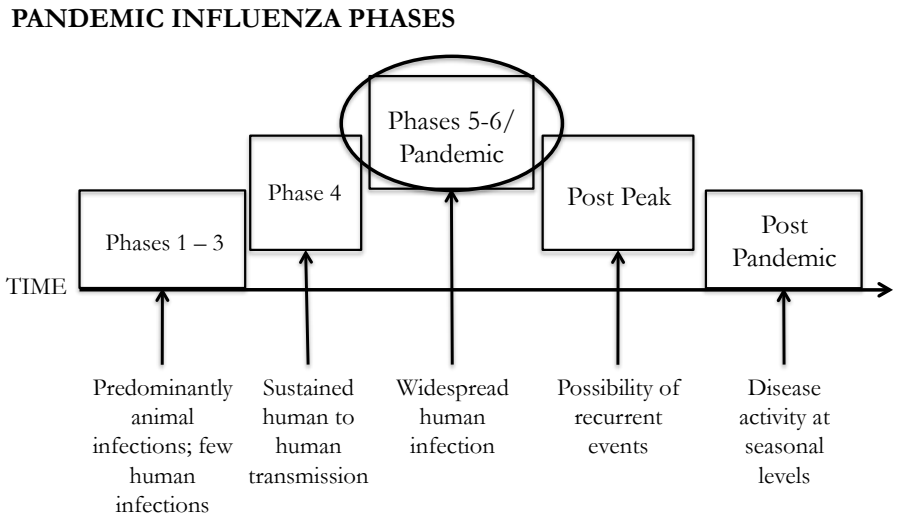


Figure 17: WHO Pandemic Influenza Phases

Source: WHO pandemic preparedness and response plan (2009)

By their nature, Influenza viruses circulate continuously among animals, especially birds. Even though such viruses might theoretically develop into pandemic viruses, by definition, in Phase one no viruses circulating among animals have been reported to cause infections in humans.

Phase two, an animal Influenza virus circulating among domesticated or wild animals is known to have caused infection in humans, and is therefore considered a potential pandemic threat.

Phase three, an animal or human-animal Influenza reassortant virus has caused sporadic cases or small clusters of disease in people, but has not resulted in human-to-human transmission sufficient to sustain community-level outbreaks. Limited human-to-human transmission may occur under some circumstances, for example, when there is close contact between an infected person and an unprotected caregiver. However, limited transmission under such restricted circumstances does

[4] Salaam-Blyther, T. (2009)

not indicate that the virus has gained the level of transmissibility among humans necessary to cause a pandemic.

Phase four is characterised by verified human-to-human transmission of an animal or human-animal Influenza reassortant virus able to cause "community-level outbreaks." The ability to cause sustained disease outbreaks in a community marks a significant upwards shift in the risk for a pandemic. Any country that suspects or has verified such an event is asked to urgently consult with WHO so that the situation can be jointly assessed and a decision made by the affected country if implementation of a rapid pandemic containment operation is warranted. Phase four indicates a significant increase in risk of a pandemic but does not necessarily mean that a pandemic is a forgone conclusion.

Phase five is characterised by human-to-human spread of the virus into at least two countries in one WHO region. While most countries will not be affected at this stage, the declaration of Phase 5 is a strong signal that a pandemic is imminent and that the time to finalise the organisation, communication, and implementation of the planned mitigation measures is short.

Phase six, the pandemic phase, is characterised by community level outbreaks in at least one other country in a different WHO region in addition to the criteria defined in Phase five. Designation of this phase indicates that a global pandemic is under way.

Phase	Estimated probability of pandemic	Description	Main Actions in Affected Countries	Main Action in Not-Yet Affected Countries
Phase 1	Uncertain	No animal Influenza virus circulating among animals has been reported to cause infection in humans.	Producing, implementing, exercising, and harmonizing national response plans with national emergency preparedness and response plans.	
Phase 2	Uncertain	An animal Influenza virus circulating among domesticated or wild animals is known to have caused infection in humans and is therefore considered a specific potential pandemic treat.	Producing, implementing, exercising, and harmonizing national response plans with national emergency preparedness and response plans.	
Phase 3	Uncertain	An animal or human-animal Influenza reassortant virus has caused sporadic causes or small clusters of disease in people, but has not resulted in human-to-human transmission sufficient to sustain community-level outbreaks.	Producing, implementing, exercising, and harmonizing national response plans with national emergency preparedness and response plans.	
Phase 4	Medium to high	Human-to-human transmission of an animal or human-animal Influenza reassortant virus able to sustain community-level outbreaks has been verified.	Rapid containment	Readiness for pandemic response
Phase 5	High to certain	The same identified virus has caused sustained community level outbreaks in two or more countries in one WHO region.	Pandemic response: Each country to implement actions as called for in their national plans.	Readiness for imminent response
Phase 6	Pandemic in progress	In addition to the criteria defined in Phase 5, the same virus has caused sustained community level outbreaks in at least one other country in another WHO region.	Pandemic response: Each country to implement actions as called for in their national plans.	Readiness for imminent response
Post-peak period		Levels of pandemic Influenza in most countries with adequate surveillance have dropped below peak levels.	Evaluation of response; response; recovery; preparation for possible second wave.	Readiness for imminent response
Possible new wave		Levels of pandemic Influenza activity in most countries with adequate surveillance rising again.	Response	Readiness for imminent response
Post-pandemic period		Levels of Influenza activity have returned to the levels seen for seasonal Influenza in most countries with adequate surveillance.	Evaluation of response; revision of plans;	Readiness for imminent response

Table 24: WHO Pandemic Influenza Phase Descriptions and Actions in Each Phase

Source: WHO pandemic Influenza preparedness and response, guidance document (2009)

During the post-peak period, pandemic disease levels in most countries with adequate surveillance will have dropped below peak observed levels. The post-peak period signifies that pandemic activity appears to be decreasing; however, it is uncertain if additional waves will occur and countries will need to be prepared for a second wave.

Previous pandemics have been characterised by waves of activity spread over months. Once the level of disease activity drops, a critical communications task of WHO will be to balance this information with the possibility of another wave. Pandemic waves can be separated by months and an immediate "at-ease" signal may be premature.

In the post-pandemic period, Influenza disease activity will have returned to levels normally seen for seasonal Influenza. It is expected that the pandemic virus will behave as a seasonal Influenza A virus. At this stage, WHO advises that surveillance be maintained and pandemic preparedness and response plans are updated accordingly. An intensive phase of recovery and evaluation may be required.

The Role of National Pandemic Preparedness Plan

The WHO has developed a range of recommendations for responding to the threat of a pandemic. The strategic actions are designed to reduce likelihood of infection, enable early warning systems, contain or delay spread at the source of the outbreak, and reduce mortality, social and economic disruption. The guidelines are revised periodically and the last update was issued in late 2008.

Many countries have adopted and tailored the recommendations for creating their national pandemic preparedness plans. These typically include measures such as the stockpiling of antivirals and pre-pandemic vaccines to be used immediately when a pandemic is declared. Governments also have implemented Advanced Purchase Agreements (APAs) with local and global pharmaceuticals for acquiring the vaccines specific to the pandemic Influenza strain once they become available. Additional stockpiles of related medicines and medical supplies have been implemented, for example for antibiotics and personal protective equipment. Actual deployment of the preparedness plans, however, and varies widely across countries,

according a recent report by the UN System Influenza Coordinator and World Bank issued in 2008[5].

Centres for Diseases Control and Prevention (CDC)

The CDC is an agency of the United States within the Department of Health and Human Services. Its focus is on health promotion, prevention and preparedness to address infectious diseases, injuries, workplace hazards, disabilities and health threats. The agency works with local, state and international governments to provide a system of health surveillance and monitoring, with personnel stationed throughout the United States and in more than 25 countries. The CDC maintains detailed health statistics and has in depth data and experience on the epidemics and pandemics that affected the US during the last 100 years.

The Food and Drug Administration (FDA)

The FDA is an agency with the Federal Department of Health and Human Services. The mission of the FDA is to protect public health by assuring the efficacy, safety and security of human and veterinary drugs, biological products, medical devices, also the food supply, cosmetics and materials with radioactive properties. The agency is the primary regulatory body controlling the manufacturing, marketing and distribution of tobacco products.

The FDA also seeks to improve public health through fostering industry innovation that can make food and medicines safer, more effective, and more affordable. It also provides science-based information the public on medicines and nutrition to improve health.

The World Organisation for Animal Health (OIE)

The OIE is an international intergovernmental organisation founded in 1924 with headquarters in Paris, France. It represents a total of 178 Member Countries and Territories and acts as the primary intergovernmental organization responsible for improving animal health.

---

[5] PHARMA (2009), Pandemic Preparedness, *Global Public Policy Issues,* March 2009.

The Food and Agriculture Organisation of the United Nation (FAO)

The FAO is a specialised agency of the United Nations that leads international efforts to combat hunger. It provides a forum for developed and developing countries to formulate and debate policy and negotiate agreements on improving agriculture, forestry and fisheries practices. Avian Influenza and other infectious diseases form a significant part of the FAO agenda.

U.S. Agencies for International Development (USAID)

The United States Agency for International Development (USAID) is the United States federal government agency primarily responsible for administering civilian foreign aid. Its history is based on the Marshall Program after World War II and the Truman Administration's Point Four program. The agency itself was created by executive order of President John F. Kennedy to implement development assistance programs in the areas authorized by the Congress in the Foreign Assistance Act of 1961. An independent federal agency, USAID receives overall foreign policy guidance from the United States Secretary of State and seeks to "extend a helping hand to those people overseas struggling to make a better life, recover from a disaster or striving to live in a free and democratic country[6]." It operates in Sub-Saharan Africa; Asia and the Near East, Latin America and the Caribbean, Europe and Eurasia.

US Federal Government First Response to H1N1 Influenza Pandemic

On 1 May 2009, the US Agency for International Development (USAID) established the Pandemic Influenza Response Management Team – composed of its Bureaus of Global Health and Democracy, Conflict and Humanitarian Assistance – to coordinate the US humanitarian response to the H1N1 outbreak.

As of 18 May 2009, the US had provided more than USD 16 Million to assist countries responding to H1N1 outbreaks. Primarily the CDC and USAID conducted global responses by US agencies to H1N1, although the US Department of Defence also provided some support to global aid. The CDC sent experts to Latin America and the Caribbean to help countries there strengthen laboratory

[6] USAID, Available from http://www.usaid.gov/about_usaid/

capacity and train health experts. The US Department of Health and Human Service sent 400,000 treatment courses to Mexico, accounting for less than 1% of the total American stockpile.

Investments made by the US and other stakeholders to prepare for a possible Influenza pandemic and to monitor the spread of other infectious diseases were applied to the most recent global response to H1N1. Although health experts have made considerable gains against the disease, questions remained. Some health experts were concerned that poorer countries would not have the capacity to sufficiently monitor and respond to H1N1. Others warned that H1N1 transmission might accelerate in winter. Questions remained about whether the disease could change or undergo reassortant, particularly in countries simultaneously contending with H5N1 bird flu cases (such as Egypt, Vietnam and Indonesia). The deadly nature of bird flu could be catastrophic when combined with a strain supporting faster transmission.

As of late June 2009, with the exception of the UK and Australia, all human deaths from H1N1 had occurred in the Americas. Approximately 87% of all deaths occurred in Mexico (49%) and the US (38%).

The Health Protection Agency (HPA)

The HPA plays a leading role in providing an integrated approach to protecting health in the United Kingdom, in particular against infectious diseases and preventing harm and reducing impact when hazards involving chemicals, poison or radiation occur.

4.5 Timeline of the Disruption

On 21 April 2009, the CDC reported that two children in California had recovered from a unique Influenza strain, which contained gene segments from swine flu viruses. The children had not been in contact with pigs. Two days later, the CDC reported five more H1N1 cases, three in California and two in Texas.

On 23 April 2009,human cases of the new swine flu Influenza A H1N1 virus were officially confirmed in Mexico and the US. Officials issued orders to close schools in Mexico City and begin a process of limiting public crowds. The CDC held its first media briefing on H1N1 swine flu.

On 24 April 2009, the WHO announced an outbreak of H1N1 virus in Mexico and the US. Mexico's health ministry announced that a new strain of Influenza was affecting the country, with just over 1,000 suspected cases. The Mexican government also announced that it was closing schools and cancelling public gatherings such as sporting events and concerts in Mexico City and surrounding states until 6 May 2009. For example, football fans were forced to watch televised games from the Aztec Stadium, which normally houses more than 105,000 spectators.

On 27 April 2009, the WHO raised its alert level to Phase 4.It announced that health officials in Canada and Spain had reported human cases with no deaths. The first two confirmed UK cases of pandemic Influenza were reported in a couple who had returned to Scotland from Mexico. In the UK, ministers met for the first time under the chairmanship of the then Secretary of State for Health.

On 29 April 2009, the WHO announced it was raising its alert level from phase 4 to 5. The first case in England - a schoolchild in Devon, was announced. The child's school was the first to be closed. Gordon Brown, the Prime Minister, announced to the House of Commons that the stockpile of antivirals would be increased from 33.5 million to 50 million (covering 80% of the population).

On 11 June 2009, the WHO Director raised the pandemic alert level from Phase 5 to the highest level 6. This triggered advanced purchase agreements for vaccines, which were in place between a number of governments and global and local pharmaceutical firms. Dr. Chan characterised the virus as 'moderately severe', although she warned the virus could become increasing virulent at anytime. Dr. Chan emphasised that the shift reflected the spread of the disease rather than a change in virulence.

As of 22 June 2009, the WHO confirmed more than 50,000 human cases of H1N1 in more than 80 countries and territories, including 231 deaths. On 15 September 2009, FDA approved H1N1 vaccines developed by major pharmaceutical companies.

On 10 August 2010, WHO declared pandemic to be over and the world had entered the "post-pandemic period".

A full timeline of the H1N1 2009 Influenza pandemic is shown in Table 25.

Date	The 2009 H1N1 Pandemic
2005	• **PHARMA Corporate Executive Team (CET) approves a global pandemic policy and plans to address threat of Influenza.**
2005-2009	• **PHARMA countries site/ functions develop individual pandemic preparedness plans addressing local needs and issues.**
2006	• **PHARMA granted license to China to manufacture and sell Xtazo (API of Nicole) in China, Indonesia, Thailand, Vietnam and all least developing countries (LDCs)**
March 2009	• **First reports of a novel flu virus in Mexico**
28 March 2009	• Earliest onset date of swine flu reaching the United States, according to the CDC.
21 April 2009	• **CDC reported that two children in California had recovered from a unique Influenza strain, which contained gene segments from swine flu viruses. The children had not contact with pigs. Two days later, CDC reported five more H1N1 cases, three in California and two in Texas.**
23 April 2009	• CDC holds its first media briefing on H1N1 swine flu. • Human cases of new swine flu Influenza A H1N1 virus were officially confirmed in Mexico and the United States. Officials issue orders to close school in Mexico City, beginning a process of limiting public crowds. Three major soccer games around Mexico City close stadium gates to all fans the weekend of 25-26 April 2009, with games broadcast on television. Stadium closures continue through 2-3 May 2009.
24 April 2009 * This study defined this point of time as 'the event' in analysis.	• **The World Health Organisation (WHO) announced an outbreak of H1N1 virus in Mexico and the USA.** • **PHARMA acknowledged swine flu cases that occurred in Mexico.** • Mexico's Health Ministry announced that a new strain of Influenza was affecting the country, with just over 1,000 suspected cases. The Mexican government also announced that it was closing schools and cancelling public gatherings such as sporting events and concerts in Mexico City and surrounding states through 6 May 2009, which was subsequently to all schools throughout the country.
25 April 2009	• **Director of WHO -Dr. Margaret Chan calls the flu problem "a public health emergency of international concern"** • **PHARMA set up 'Emergency Supply Chain Planning Nicole Ramp Up Plan Meeting' with objective to ensure the supply chain is operating at maximum capacity.**
26 April 2009	• Health authorities step up vigilance measures around the world. • **PHARMA, Value Stream Leader appointed by President of Manufacture and Supply Chain (MSC) to be a head of Manufacturing and Supply Lead in responding to 2009 H1N1 outbreak.**
27 April 2009	• **The WHO level to 4 having confirmed human-to-human transmission able to cause 'community-level outbreaks'. "**Phase 4 indicates a significant increase in risk of a pandemic but does not necessarily mean that a pandemic is a forgone conclusion," says the organization. • **PHARMA created Pandemic Management Organisation Chart** • **PHARMA increased frequency of the 'MSC Executive Team Meeting' to provide governance and guidance, now daily** • **PHARMA setup 'Crisis Management Team Meeting' to bring the various workstations together to gain overview of pandemic.** • **PHARMA increased frequency of the 'Corporate Executive Team Meeting', now daily.** • Canada reports six cases of swine flu and Spain reports one. In the United States 40 people have flu confirmed. In Mexico 26 cases are confirmed, with 7 deaths resulting. Estimates for the true number of deaths hover around 80. • First three cases are confirmed in Europe. • In UK, the first two confirmed UK cases of pandemic Influenza were reported in a couple that had returned to Scotland from Mexico. Ministers met for the first time in the UK's Civil Contingencies Committee (CCC), under the chairmanship of the then Secretary of State for Health. • At that stage the information emerging from Mexico was worrying: there had been a total of 149 deaths from 878 reported cases (of which only 18 deaths were as yet confirmed to be H1N1). The UK Foreign & Commonwealth Office (FCO) advised against all but essential travel to Mexico.
28 April 2009	• **PHARMA Pandemic Rationing Team was set up.** • **PHARMA distribute antiviral medicines to Mexico.** • The first cases in the Middle East. • Seven countries are now reporting cases of H1N1 swine flu: the United States, Mexico, Canada, New Zealand, the United Kingdom, Israel and Spain.
29 April 2009	• **The WHO raise pandemic lever alert to Phase 5, "a strong signal that a pandemic is imminent".** • First swine-flu death outside Mexico reported as a baby dies in Texas. The WHO confirmed seven more cases in Canada; bring the total number to 13 cases. • • Gordon Brown, the Prime Minister of United Kingdom announced to the House of Commons that the stockpile of antivirals would be increased from 33.5 million to 50 million (covering 80% of the UK populations). • **The first case in England was announced.** The child's school in Devon became the fist school

Date	The 2009 H1N1 Pandemic
	to be closed.
30 April 2009	• **CEO of PHARMA gave the first speech to employees about H1N1 Outbreak.** • **PHARMA start to ramp up Nicole production.** "We already restarted manufacturing this week, and it will grow every week over the next few weeks and months." • WHO adopts the term "Influenza A (H1N1)" after veterinary experts point out that the virus is not occurring among pigs. • There had been 91 confirmed cases in the USA, with one confirmed death, while in Mexico there were 730 suspected cases, 26 confirmed cases and 7 deaths. At this point the virus appeared to be mild and self-limiting outside Mexico; the outbreak seemed likely to be less severe overall than the 1918-19 pandemic, although it had the potential to be worse than the pandemics of 1958 and 1968. • In UK, ministers decided that there was no need, at that point, to advise the public against attending mass gatherings, to restrict domestic transport or to recommend mass closures of schools. Individual schools would take decisions in consultation with the Health Protection Agency (HPA) and the health protection services in devolved countries. Proposals to extend the sickness certification period to 14 days during a pandemic in order to reduce the strain on GPs were agreed in principle, but it was decided that there was no need to implement them at the current time. • The H1N1 information campaign was rolled out on television, radio and in print media, with a booklet in preparation for household delivery. The Swine Flu Information Line was put into operation in United Kingdom. • Austria, Switzerland and the Netherlands join the countries with confirmed cases. The agency also announces it would refer to the virus not as swine flu but as Influenza A (H1N1).
1 May 2009	• **The European regulators approved PHARMA antiviral facemask that the company had developed over the last two years.** • As of this morning, 331 cases of H1N1 have been reported in 11 countries. According to the worst outbreaks are still in Mexico (156 cases and nine deaths) and the United States (109 cases and one death). • **Started to conduct semi-structured face-to-face interviews with senior supply chain managers and executives.**
2 May 2009	• The virus makes its appearance in Asia. • China (Hong Kong special administrative region), Costa Rica, Denmark, France, and the Republic of Korea join the list. Total cases reported to the WHO are now at 658 in 16 countries. • Canadian authorities announce that H1N1 has been detected in a swineherd in Alberta. The pigs likely caught the virus from a Canadian who had recently visited Mexico, making this the first known case of human-to-animal transmission.
3 May 2009	• Ireland and Italy each report one case. 898 cases are now reported.
4 May 2009	• Colombia joins the club. There are now 985 cases in 20 countries. Mexico is up to 25 deaths, but officials there say the disease seems to be on the decline.
5 May 2009	• Mexico's H1N1 shutdown should begin to ease, with restaurants and cafes set to reopen. • The latest say the virus has now spread to 21 countries. Mexico has reported 590 cases and 25 deaths while the United States has reported 286 cases and one death. • However, the Texas Department of State Health Services has confirmed a second person has died in the United States. The DSHS says a woman with "chronic underlying health conditions" died earlier this week. • The following countries have reported cases but no deaths: Austria, Canada, China (Hong Kong Special Administrative Region), Costa Rica, Colombia, Denmark, El Salvador, France, Germany, Ireland, Israel, Italy, Netherlands, New Zealand, Portugal, Republic of Korea, Spain, Switzerland and the United Kingdom. • MSC Pandemic Organisation Chart was created in order to explain which product line should be covered during the outbreak of H1N1.
6 May 2009	• WHO swine flu cases in Sweden and Guatemala.
7 May 2009	• Worldwide-confirmed cases are reported to be 2,371.
8 May 2009	• Brazil reports four cases, bringing the number of affected countries to 25. Deaths now stand at 44 worldwide, with 2,500 confirmed cases. Most newly reported cases in new areas, the WHO says, come from travellers returning from affected areas. • The CDC reports that hospitalization rates in the US are coming down, to 3.5%, as testing expands to include milder cases. • The Harvard School of Public Health releases a poll in which 83% of Americans polled say they are satisfied with the waypublic health officials have managed the outbreak. Still, 48% of parents with children in school think they or a family member will come down with H1N1 in the next year.
11 May 2009	• The WHO has swine flu deaths in Canada and Costa Rica, bringing the total number of countries where fatalities have occurred to four. • Mexico has reported 48 deaths and the United States three. Worldwide, 30 countries have officially reported 4694 cases. • A modelling study in Science suggests that the virus spreads at a rate comparable to that of previous Influenza pandemics.
12 May 2009	• The CDC that it is seeing some severe complications in cases of H1N1 in pregnant women, including one death in the US.
13 May 2009	• As of this morning, 33 countries have reported 5,728 cases of H1N1 to the WHO.
18 May 2009	• The day it that 8,829 H1N1 cases have been reported in 40 countries, the WHO has cautioned

Date	The 2009 H1N1 Pandemic
	against complacency. • "This virus may have given us a grace period, but we do not know how long this grace period will last, "WHO director general "No once can say whether this is just the calm before the storm." • However, the pandemic alert level is still at five today, one level below a full pandemic.
20 May 2009	• WHO says that H1N1 has officially contaminated 10,243 in 41 countries and killed 80 people worldwide.
22 May 2009	• Australia raises its alert level to 'Contain', even as the Mexican government relaxes its restrictions in Mexico City.
27 May 2009	• A New England Journal of Medical article, in response to suggestions that the WHO evaluate its criteria for moving to Phase 6 and declaring a pandemic, that "the global extent of a pandemic should be described objectively and should be just one factor in decisions about how to respond."
31 May 2009	• **PHARMA received approval of Nicole Capsule Inhaler**
1 June 2009	• **The FDA has approved PHARMA antiviral facemask for use in the United States.** • June opens with 17,410 cases reported in 62 countries, including newbie's like the Bahamas and Estonia. The death toll in Mexico stands at 97. • In the US there are or have been cases in all 50 states, including 17 deaths, according to the CDC.MedImmune, a biotechnology firm in Gaithersburg, Maryland, wins a USD 90 million contract from the federal government to begin developing a live attenuated vaccine for H1N1.
2 June 2009	• **The WHO says it is closer to moving its pandemic alert status to Phase 6, which would denote official global pandemic status.**
3 June 2009	• H1N1 has reached Africa. The WHO has a case in Egypt. Cases in Australia stand at 501, the largest number outside of the Americas. • A report Euro surveillance estimates a reproduction number for the virus – the average number of secondary cases generated by a single primary case – of 2.3 in Japan, higher than estimates from elsewhere. • The CDC's Morbidity and Mortality Weekly Report suggests that the outbreak in Mexico may have peaked in the late April.
8 June 2009	• The WHO adds a death in the Dominican Republic to its list, bringing the number of countries that have reported deaths to six.
9 June 2009	• The WHO reports that Inuit communities in Canada may be particularly hard-hit. It continues to face questions as to why a full-blown pandemic has not been declared.
11 June 2009	• Pandemic is declared! WHO Director – General Margaret Chan raised the pandemic alert level from Phrase 5 to Phase 6, which is the highest level. The world is a full-blown Influenza pandemic for the first time in 41 years. This triggered the advance-purchase agreements for vaccine. Dr. Chan characterised the virus as 'moderately severe', though she warned the virus could become increasing virulent at anytime. Dr. Chan emphasised that the shift reflected the spread of the disease but not signal a change in virulence.
14 June 2009	• The first swine flu death in Europe has been reported. A woman in Scotland who died with H1N1 had "underlying health conditions", according to the Scottish government. This is the first death outside the American continent.
19 June 2009	• South Africa confirms its first case of swine flu - officially marking the disease's spread into sub-Saharan Africa.
22 June 2009	• Chinese state news source Xinhua reports tests have begun on the first H1N1 vaccine developed in the country.
24 June 2009	• Argentinian authorities report that a pig at a pig farm in Buenos Aires province has tested positive for the novel H1N1 strain, making it only the second known swine infection outside of Canada.
29 June 2009	• Denmark reports the first case of resistance to Abaco, considered to be the most effective treatment for the flu by the WHO. The virus continues to spread throughout the world with 11,000 new cases in three days.
2 July 2009	• Japan's health ministry reports that it too has detected a case of Abaco resistant H1N1. • The UK moves its swine flu response from 'containment' to 'treatment'. 'Our national focus should be on treating the increasing numbers affected by swine flu," says health minister Andy Burnham.
8 July 2009	• WHO says the three incidences of drug resistant H1N1 to date are "sporadic cases" of resistance. "At this time, there is no evidence to indicate the development of widespread antiviral resistance among pandemic H1N1 viruses."
16 July 2009	• WHO changes reporting requirements for H1N1 and abandons issuing global tables with numbers of confirmed cases for all countries. • It notes that the increasing number of cases "is making it extremely difficult, if not impossible, for countries to try and confirm them through laboratory testing".
17 July 2009	• The WHO says that the swine flu pandemic is moving around the globe at an "unprecedented" speed.
22 July 2009	• **PHARMA distributed antiviral medicines to all UK employees.** • **PHARMA confirmed that it had contracts in place to supply 195 million doses of its pandemic (H1N1) 2009 adjuvanted Influenza vaccine and had a variety of agreements in place with the US Government to supply pandemic products worth USD 250 million.** Since that date, nine government contracts have been signed for a further 96 million doses of the vaccine. This now brings the total number of doses ordered for PHARMA's adjuvanted vaccine to 291 million. • Two Australian companies say they have started human trials of their swine flu vaccines.
28 July 2009	• The death of a 22-year-old university student in South Africa marks the first death in sub-Saharan

Date	The 2009 H1N1 Pandemic
	Africa. Confirmation of H1N1 as the cause comes 3 August.
29 July 2009	• Researchers from the US Centers for Disease Control and Prevention warn that pregnant women "might be at increased risk for complications from pandemic H1N1"
31 July 2009	• **PHARMA had executive after action review meeting**
3 August 2009	• India confirms first death from H1N1, the victim being a 14-year old girl in the city of Pune.
14 August 2009	• **PHARMA commenced the clinical development programme for its adjuvanted pandemic vaccines.**
21 August 2009	• Healthy victims of swine flu should not routinely be given antiviral drugs, the World Health Organization. • The total UK death is 60.
10 September 2009	• Two papers published in the *New England Journal of Medicine* show two new vaccines against H1N1 are likely to be effective after just one dose. • "The obvious advantage of a one-dose schedule is that, in the current time of vaccine scarcity, it doubles the number of people who may be vaccinated with a fixed amount of vaccine," writes Kathleen Neuzil, of PATH, in an accompanying editorial. "On the basis of these data, it would be appropriate to begin vaccination with the use of one dose of the usual antigen content."
15 September2009	• FDA approves four H1N1 vaccines, from major pharmaceutical companies.
25 September 2009	• **European Committee for Medicinal Production for Human Use (CHMP) has issued a positive opinion and recommends approval of PHARMA's candidate pandemic adjuvanted vaccine.**
30 September 2009	• Australia begins mass H1N1 vaccinations.
1 October 2009	• **The four health ministers in the United Kingdom heard that the PHARMA vaccine had been licensed for those over six months and for pregnant women. Ministers agreed to double existing ECMO capacity in line with broader policy on critical care capacity.**
8 October 2009	• The JCVI reconfirmed its previous advice of 7 August concerning the priority groups for vaccination. Once all those in the priority groups had been offered vaccination, it should be offered to the healthy population. The JCVI advised that a single dose of (the PHARMA H1N1 adjuvant vaccine) should generally be sufficient for those aged 10 and above, although two doses would be required for the immunocompromised and those below 10 years would require two half-doses of vaccine. While PHARMA's rivals vaccines required two doses for treatment in all groups.
18 October 2009	• This week Mongolia, Rwanda, and Sao Tome and Principe issue first reports of H1N1 and Iceland, Sudan, and Trinidad and Tobago reported their first deaths.
21 October 2009	• In UK, vaccination program begins: front-line healthcare workers and their patients who fall into at-risk categories.
25 October 2009	• This week: vaccinations get underway in many European countries.
29 October 2009	• The total UK deaths are 137.
30 October 2009	• Strategic Advisory Group of Experts (SAGE) on Immunization issues vaccination advice to the WHO, including use of a single dose of vaccine in adults and adolescents and use of any licensed vaccine for pregnant women. • 27 October 2009: Russian media reports the country's first H1N1 deaths. • **PHARMA distributed the first vaccine to their employees; PHARMA biological and MSC staffs only.**
1 November 20 09	• WHO reports that more than 199 countries and overseas territories have laboratory confirmed cases of H1N1, with over 6,000-recorded deaths.
10 November 2009	• **US FDA approved PHARMA's pandemic H1N1 adjuvanted vaccine.** • **PHARMA announced to donate 50 million doses of its adjuvanted pandemic H1N1 Influenza to WHO for distributing to developing countries.**
19 November 2009	• China says it has dispatched monitoring teams to 12 regions after a high profile doctor suggested some cases of H1N1 might be being deliberately not reported. • After around 65 million people have been vaccinated, the WHO says H1N1 vaccines appear to have an "excellent safety profile". None of the deaths investigated in those vaccinated have found a direct link to vaccination.
23 November 2009	• **PHARMA H1N1 vaccines have been distributed to countries globally for use in government-initiated vaccine programmed.**
8 December 09	• A review in the BMJ warns that there is insufficient evidence for or against using neuraminidase inhibitors (Nicole and Abaco) for preventing Influenza complications. An accompanying editorial says, "The review and a linked investigation undertaken jointly by the BMJ and Channel 4 News cast doubt not only on the effectiveness and safety of Osolia (API of Abaco) but on the system by which drugs are evaluated, regulated, and promoted."
27 December2009	• The WHO says over than 208 countries, territories and communities have reported H1N1 cases, including "at least" 12,220 deaths.
2 January 2010	• China's ministry of health confirms there have been 659 deaths from H1N1 in the country as of 2 January. A spokesman warns of "the danger of an explosion of outbreaks in some places".
14 January 2010	• **The four health ministers agreed to suspend deliveries of the PHARMA H1N1 adjuvanted vaccine from 16 January and to enter into negotiations with the supplier over terminating the contract.** A variety of options were considered for managing the pandemic flu vaccine stockpile, including donating or selling vaccines to pharmacies, private companies or other countries.
26 January 2010	• The WHO defends itself against allegations it overhyped the dangers of H1N1 under pressure from vaccine manufacturers at a hearing of the Council of Europe's health committee.

Date	The 2009 H1N1 Pandemic
	• "Let me state clearly for the record. The Influenza pandemic policies and responses recommended and taken by WHO were not improperly influenced by the pharmaceutical industry," says Keiji Fukuda.
18 March 2010	• 342 deaths in England related to H1N1 had been recorded 69 in Scotland, 28 in Wales and 18 in Northern Ireland, giving a UK total of 457.
1 April 2010	• Antiviral medicines were no longer available from national stockpile, and antiviral collection points in England were closed. The Swine Flu Information Line also closed, and treatment of people with flu-like symptom returned to business as usual, with people advised to contact their GP.
10 August2010	• **The WHO declared pandemic is over. The world has now entered the "post-pandemic period".**
11 April 2011	• **PHARMA welcomes key agreement coordinated by the WHO on a framework to support global preparedness for a future Influenza pandemic.**

Table 25: Timeline of the 2009 H1N1 Pandemic

Source: Adapted from PHARMA report

UK and the H1N1 Influenza pandemic

The virus reached the UK in April 2009.The first cases were confirmed on 27 April 2009 in passengers returning from Mexico. As mentioned above, the government began closing schools after the first case of person-to-person transmission within the UK was announced on 1 May 2009. The first death attributed to H1N1 in the UK occurred in Scotland (reported on 14 June 2009).

The UK had been preparing for Influenza pandemic for some time. The possibility of the emergence of an avian virus such as H5N1 was of particular concern and provided a reason for the UK government to stockpile antiviral medicine.

The arrangements of the UK's current central government crisis management had been in place since 2002 and had been tested in various crises and exercises. The pre-pandemic planning, set out in Pandemic Flu: A National Framework for Responding to an Influenza Pandemic, ensured that many decisions had already been made in principle prior to the pandemic and that key personnel had the opportunity to work together. The Department of Health and the Cabinet Office jointly published this plan in November 2007 and it formed the basis for the 2009 pandemic response.

On 29 April 2009, the Prime Minister announced to the House of Commons that the stockpile of antivirals would be increased from 33.5 million to 50 million (covering 80% of the population).

After a slow start, the virus spread rapidly in the UK during July 2009, with new cases peaking at 110,000 in the last week of that month, according to the Health Protection Agency's modelling estimate, but declining sharply in the first week of

August 2009. Cases fell progressively down to 3,000 in the first week of September 2009, and then began to rise again. The decline in cases during the summer had been predicted, but a large surge was expected in the autumn to coincide with the normal flu season. New cases rose to 84,000 for October, well below the summer's peak and then declined during November.

Chapter 4
Findings: PHARMA Response during the H1N1 Influenza Pandemic

This chapter examines the response of a major pharmaceutical in the face of the global outbreak of H1N1 Influenza virus, where the eventual outcome was unknown and major investments and strategic decisions about its supply chain had to be made. The challenges faced by PHARMA are discussed including financial and product pricing issues. PHARMA's response is outlined, structured along the dimension of the 3D time-based framework.

The initial coding and categorization is of the PHARMA data is then presented, from open, axial and selective coding stages of analysis. The process of constant comparison was employed to confirm preliminary categories. The goal was first to compare selected data to each other to gauge similarity and dissimilarity, and to then compare additionally to potential categories, assessing whether the data was consistent or inconsistent with the initial coding structure consisting of approximately 110 codes.

Theoretical saturation of the core categories and related concepts was done through new interviews and questions to the original participants. Through a process of theoretical sorting, memos from the data were related and integrated to the emerging structure. Theoretical codes, and patterns relating the codes and the factors of the company response in dealing with disruption, are described.

Finally, the four preliminary core categories and 18 subcategories of response time are described, which will be validated with the BP disruptions as is described in the subsequent chapters.

Table 26 below illustrates application of Grounded Theory methodology in this study

Phase		Description	This study	Output
Phase 1 Research design	**Step 1**	Preparation	Preliminary literature review: Time-Based Management and Response - Time Based Risk Management Framework (Sodhi & Tang, 2009).	General research problem – What factors underlie companies' time response to supply chain disruption?
	Step 2	Case selection	Selected PHARMA for a study of their response to H1N1 Pandemic. Chose two disruptions from BP to validate the finding from PHARMA.	1. PHARMA 2. BP Deepwater Horizon 3. BP Texas City
Phase 2 Data collection and data ordering	**Step 3**	Develop rigorous data collection protocol	Data gathering from: semi-structured telephone and face-to-face interviews, direct observation, participant-observation (meeting and conference calls), archival records and documentation from internal (report, presentation) and external sources (news, press).	Interview guides and inventory of available data sources.
	Step 4	Entering the field	Data gathering through company visit. Interviews with senior supply chain managers and executives.	Transcripts and data.
	Step 5	Data ordering	Arraying events and information chronologically to facilitate easier data analysis.	Collated data.
Phase 3 Data analysis	**Step 6**	Analysis data *Open coding* *Axial coding* *Selective coding* *Memoing*	Developed concepts from PHARMA data through coding. Preliminary core categories were established. Relationship between categories and subcategories were developed. Core categories were integrated to build theoretical framework. Write-up of ideas about codes and their relationships; this is an on going process from data analysis through completion of the study.	Approximately 110 codes, 18 subcategories and preliminary 4 core categories were established. Memos.

Phase		Description	This study	Output
Phase 3 Data analysis	**Step 7**	Theoretical Sampling	Determine where to find additional data to develop the emergent theory. Re-interview original participants and complete additional interviews until no new properties or aspects could be identified.	Defined scope and saturation of categories.
	Step 8	Constant comparison	Compare new to previous interviews and compare events to other sources of information for similarities and differences.	
	Step 9	Theoretical Saturation	Saturation is reach when further data gathering and analysis from PHARMA added little to the conceptualisation.	Saturated core categories 1. Preparation 2. Partnership 3. Organisation 4. Reserve
	Step 10	Theoretical sorting memos Theoretical coding	Memos, which have been written since data analysis phase, were sorted theoretically and four propositions are derived from the findings.	Four propositions and Emergent Theory
Phase 4 Literature comparison and write up	**Step 11**	Integrating the literature	Compare emergent theory with extant literature (comparisons with conflicting or similar frameworks)	
	Step 12	Validation of theory	Validation the emergent theory using two disruptions from BP: Deepwater Horizon Oil Spill and BP Texas Refinery Explosion. Iteration back to step 2 for data collection and data analysis to check theoretical fit, relevance, workability and modifiability.	Confirmed core categories – Factors underlying response time.
	Step 13	Write up of theory	Writing research report.	This document.

Table 26: Application of Grounded Theory Methodology in This Study

5.1 The Disruption

Prior to the 2009 Influenza outbreak, the World Health Organization evaluated the growing probability that a major flu pandemic could be approaching. The previous pandemic occurred in 1968. WHO Director Margaret Chan assessed that Influenza pandemic to be a unique type of event[7]. It is "impossible to anticipate when the next pandemic might occur or how severe its consequences might be…on average, three pandemics per century have been documented since the 16thcentrury, occurring at intervals of 10-50 years[8]." The World Bank estimated that a new flu pandemic could kill more than 70 million worldwide with worst-case fatalities up to 260 million (Osterholm, 2005)[9]. For every death, many more would suffer from mild or severe symptoms. The direct and indirect effect on the population could trigger a major recession of the global economy costing more than USD 3 Trillion. Lower global domestic productivity would drop by 4.8 percent, a result of lower tourism, transportation and retail sales as well lower productivity and employee absenteeism[10]. In this context, PHARMA's response played a crucial role in reducing the impact of a possible pandemic.

Pandemics are by nature unpredictable but also unavoidable. Transmission rates and virulence of the Influenza strains vary greatly, from the widespread seasonal flu to the historical Spanish flu in 1918 that killed over 50 million people. Hence declaration of a pandemic put PHARMA in a challenging situation: not only was its production of medically and business critical drugs potentially at risk, but the world would be watching closely how such a market-leading (and profitable) corporation met the exploding demands for antiviral medicines.

Based on PHARMA Corporate Executive Team workshop in 2009, Influenza pandemic was thought to be one of the most significant risks facing PHARMA (Table 2). On its five-by-five risk matrix, PHARMA scored the likelihood of a pandemic as '2' two – 'unlikely to happen' (every 5-10 years) and impact of it as '5' five – catastrophic. PHARMA uses a conservative approach, selecting a higher

---

[7] Margaret Chan, DG WHO address to the Pacific Health Summit, Seattle, Washington, 13 June 2007
[8] In-Pharma (2006)
[9] Osterholm, M.T. (2005)
[10] Burins et al, (2008)

matrix input where the best estimate falls into a range overlapping two possibilities. Multiplying the two inputs on the PHARMA risk scale gave a total score of ten, which put the recommended response at level three – increase mitigation or strengthen the contingency plans.

The manufacturing and supply BCP leader concurred: the company is not able to reduce the likelihood of a pandemic and must focus on reducing the impact of the event through its contingency plans.

> *"So the mitigation plan can't reduce the frequency of the event ... But by designing the supply chain, we can reduce the impact. And we can probably reduce that impact from a catastrophic event to a moderate event. The contingency plan introduces how we set our supply chains up to be flexible, how we had business continuity plans for every other site, .how we issue antivirals to staff. These were all our contingency plans to reduce that effect from catastrophic. And the whole pandemic crisis management was a way of controlling that event."*
>
> *Manufacturing and Supply BCP Lead*

An Influenza pandemic could trigger risks across of PHARMA internally as well as externally. Mitigating one risk can end up exacerbating another risk in some business area (Chopra and Sodhi, 2004):

> *"The pandemic triggered all those risks. Risk that R&D will not deliver a commercially successful product - this involved our new product in capsule inhaler device, weakness of intellectual property protection in certain countries which was challenge in the emerging market, sales and market regulations, regulatory controls, risk of interruption of product supply and global political and economics conditions."*
>
> *Manufacturing and Supply BCP Lead*

Given the evolving situation, the first challenge was to understand what factors drove WHO to declare a pandemic so quickly, or more importantly, what that meant in actual opportunity, risk and required decision making for swift response. Swine-flu impact on world health was catastrophic in the worst-case scenarios; at the same time, early scientific review hinted at a milder form of Influenza. Potential evolution of the strain during the next flu season, as well as possible resistance to PHARMAs antiviral treatments, meant vigilance was required and supply chain response had to be managed under considerable uncertainty.

PHARMA had immediate supply challenges as the company had recently stopped API production and was reducing secondary packaging as the rate of commercial orders was dropping in the first quarter 2009. Demand rose dramatically after April

27th as governments reviewed their preparedness plans and placed forecasted abnormal demand on the two suppliers of H1N1 antivirals.

> *"With sudden increased demand from many countries, there was clearly not enough product available. Annual demand typically means 60 million treatment doses, and PHARMA had only three million devices on hand since we have stopped production. Within a day, the government asked for an immediate additional 32 million additional doses, which we would normally take six months of production."*
>
> *Manufacturing Strategy Manager*

Allocation of limited stock was as much a political process as commercial – governments and press can create reputation risk irrespective of the ethical commitments PHARMA fulfils.

Expansion of capacity required evaluation of a broad portfolio of techniques: expanding too soon created investment risk, with millions of Pounds of cost taken on to prepare for rapid ramp-up in production. Expanding too late meant missing commercial opportunity but also put lives – tens of thousands of lives – at risk. Expanding production too broadly using internal capacity created production risk on other critical drugs; external expansion through licensing could create downstream intellectual property and marketing challenges in growth markets.

Underlying these challenging supply circumstances, there are pressures on compliance and quality standards. PHARMA has a well-established quality management system, high compliance standards and culture. These standards are fundamental to the PHARMA culture and maintained throughout the supply chain expansion.

Apart from production sites, PHARMA faced challenges in terms of assuring continuity of the internal organization and external suppliers. Protection of employees – medically and in terms of ability to adapt to changing requirements and be able to continue to work – was critical. Clarity of communication and decision-making was also important, as PHARMA has to respond to this situation quickly.

As well as restarting and expanding Nicole supply capability, PHARMA had to look at other business critical products, e.g. large revenue generating products. PHARMA must consider its business objectives, along with supporting global humanitarian response. PHARMA also needed to closely look at assuring production and distribution of 32 medically critical products. These were defined as

products that are critical to patient survival that are made uniquely by PHARMA: it could be fatal if the product was not available and PHARMA must assure that sufficient stock is locally available.

For example, Hematol is a business critical product: it generates significant revenue to PHARMA.

> *"Not only do we need to restart, maximise and expand Nicole production and develop and manufacture the Vaccine but this must be achieved not at the expense of other business critical and medically critical products to protect the lives of millions of patients who rely on these products and protect the ongoing financial security of the company."*
>
> *Manufacturing and Supply BCP Lead*

PHARMA culture is risk averse, having built capacity, triple sourcing and resilience into its Nicole Supply Chain as part of supply chain risk mitigation. The company also sees itself as excellent in responding to crisis situations in the view of the Manufacturing and Supply BCP:

> *"As well as our approach to risk management we thrive on reacting to crisis situations. This is where our values of empowerment and collaboration come to the fore and the whole organisation aligns itself to support the challenge."*
>
> *Manufacturing and Supply BCP*

Financial Challenge

PHARMA invested substantially in R&D in preparing for Influenza pandemic and in this 2009 pandemic, PHARMA publically committed itself to support the governments and international authorities.

These risks and challenges in facing the H1N1 Influenza presented PHARMA with a unique opportunity; today PHARMA sees itself better positioned to react far more quickly in the likely, but unpredictable, even of the next pandemic.

Financial risk in the pharmaceutical industry is significant in terms of both the long-term investment required and the possible failure to capture revenue or market share from events such as the Influenza pandemic.

"The company has spent USD 2.5 Billion over the last seven years preparing for this situation. PHARMA has been planning for a pandemic for three-and-a-half years and has spent more than GBP 1 Billion to ensure its factories could crank up production at short notice."

CEO of PHARMA

This investment in the Nicole supply chain and R&D must be matched by an appropriate return, which in turn can have an impact on prioritisation and pricing. PHARMA sales are publicly reported with and without pandemic products. In the first six months, PHARMA's global revenue grew by only 1% without this category; however, it was boosted 6% (GBP 14.4 Billion) in the April–June quarter between 2009 and 2010. The majority of this sales increase in Q1 was because of Nicole and the H1N1 vaccine.

PHARMA is a commercial organisation, however, it must also respect perceived ethical constraints; as a global pharmaceutical company, public trust is essential and production decisions are based on factors in addition to profitability. Investment policy in Influenza-related medicines can affect large populations as well as small numbers of patients needing critical, immediate care, such as in intravenous formulations: " We committed significant money and resources into developing an intravenous (IV) dose form, but we'll only sell 5000 doses. We'll save the lives of 5000 people and we won't make any money on it. But if you were desperately in hospital ….So this will save people from dying."

According to a BMJ article in 2010 (340L 2385), the CEO of PHARMA denied accusations that the company profiteered during the swine flu crisis. Last year, PHARMA made a pre-tax profit of more than GBP 8.5 Billion.

Pricing Challenge

PHARMA manufactures a portfolio of antiviral medicines and related medical supplies. As such, its pricing policy extends across the portfolio. Pricing policy on preventative vaccines developed after the start of the outbreak attracted particular attention. In an interview on the BBC's World *Have Your Say* programme on 26 April 2010, the CEO denied that the company had "charged the whole world" for a vaccine that may not have been necessary.

"PHARMA charged a very reasonable price for the swine flu vaccination, the same price we charge for regular seasonal flu. We did not charge a special crisis price."

Manufacture Strategy Managers

Nevertheless, the revenue opportunity presented by the pandemic response was significant. According to the *Guardian* newspaper on 10 January 2010, the swine flu boosted PHARMA's revenues by GBP 1 Billion. CEO stated that the "company has worked hard to come up with a vaccine and that it would be foolish to deny that events like these aren't good for business."

CEO of PHARMA said that the company had been there when it was needed by governments around the world to help them cover their risks of swine flu and the products that PHARMA had supplied will help with future crises.

"More importantly, the medicines and vaccinations that we have manufactured and sold are able to be held in stockpiles. For example, the Nicole flu treatment has a shelf life of seven years so governments now have that in stock for future use, and even our vaccine has a technology which will allow at least a piece of that vaccine to be used against other potential flu strains in the future."

CEO of PHARMA

Among others, PHARMA used two mechanisms to manage both commitments to customers and supply chain capacity, namely price and stock allocation. Early in the response to the crisis, when Nicole orders exceeded stock by a factor of 20, a mechanism for prioritisation was developed for stock allocation. Nicole pricing policy also has political visibility: accordingly, richer countries were charged higher prices than were poorer countries. Reports of individual consumer pricing showed the same differential mechanism existed within certain markets.

5.2 Overview of PHARMA Response

In dealing with H1N1 pandemic, PHARMA faced the interdependence of a wide range of issues: production, supply chain constraints, commercial objectives, licensing, external supplier, product design but also politics and speculation on the spread and severity of the pandemic itself. Underlying these issues is the need for speed in response – all aspects were changing quickly and were unpredictable; PHARMA had to respond quickly to changing conditions to contain the risk, to serve an urgent and unmet patient need and to capture the revenue opportunity.

Following Sodhi & Tang (2009), I consider the respond in terms of

- D1 – Detection of the event
- D2 – Design of a solution, and
- D3 – Deployment of the solution in response.

D1 - Detection of the Event

In the late March 2009, Mexico began to register cases of a stronger than normal Influenza virus in Mexico City. On 21 April 2009, the Centers for Disease Control and Prevention (CDC) also reported that two cases of febrile respiratory illness in children in southern California had been caused by infection with genetically similar swine Influenza A (H1N1) virus. The viruses contained a unique combination of gene segments that had not been reported previously among swine or human Influenza viruses in the United States or elsewhere.

The outbreak became visible to PHARMA on 24 April 2009 after being reported on various newswires and the WHO officially announced the outbreak of H1N1 virus in Mexico and the USA.

PHARMA was able detect the event and had their first steps in place in a short time after the event occurred. Two elements which helped PHARMA detect the event early were first, having a good monitoring system and second, by regularly conducting preparedness and stress testing.

D2 – Design of a Solution

PHARMA took immediately action to respond to the declaration of the outbreak by the WHO. Numbers of step has been implemented to organise its internal and external responses to the outbreak and eventual pandemic. At the outset, the flu outbreak was seen to have a potentially dramatic impact on the ability of PHARMA to manufacture critical medicines as well as strong reason to ramp up the production and distribution of antivirals.

The first initial steps that PHARMA design to respond to the event are: increase the frequency of senior executive governance meetings, assess the existing pandemic preparedness plan, establish an integrated response team and create a new

organization chart to reflect emergency roles and responsibilities. This enabled PHARMA to then quickly move toward design and assessment of appropriate supply chain response in antivirals and related medicines.

The next step in PHARMA's response addressed the challenges of rapid supply chain for the antivirals and related medical supplies that help treat the symptoms of an existing infection. This is the focus of the PHARMA case study in this paper. Once the H1N1 strain was identified and isolated, PHARMA was able to adapt its Influenza-related portfolio of preventative vaccines and vaccine production technology. Research by government, industry and academic continues to pursue development of vaccines that can fit a broader range of Influenza strains and can be put more rapidly into production.

At the first indication of a new Influenza strain, PHARMA executives quickly took action to prepare for a possible pandemic. Such events were seen as rare but quite possible, even probable over time. The potential impact was entirely uncertain in both the speed with which it spread and its mortality. Preparedness plans, which the company had in place, were based upon WHO guidance about the spread and mortality of the pandemic. Events proved to be very different from this original guidance. The first reported cases were severe and the upper estimates of scientific community and popular press on mortality called for urgent action. Press reports predicted tens of thousands of deaths in the UK alone during the summer of 2009.

Given the uncertainty, PHARMA prepared its organization to better make and execute informed decisions, adding scientific know-how and other disciplines to a purpose-built Pandemic response team. The activation of previously prepared pandemic response plans required an update of communications as well as role and responsibilities, given the organizational and staffing changes from recent fine-tuning of regular supply chain operations. Daily monitoring by PHARMA executives and supply chain managers allowed decision making to closely track the evolving pandemic storyline. Frequent communication with employees and internal sites across the globe as well as government agencies and the press allowed PHARMA to maintain the confidence of its workforce and the public that were both hungry for information on what was an essentially unpredictable situation.

With governance for crisis response in place, PHARMA could begin to address the sudden flood of requests for antivirals from governments around the world. Key medicines were in limited production and stockpiles of antivirals were a fraction of what was requested. A proportional response was developed to best allocate existing stock and new production, reflecting the urgency based on growing case information and input from health and other governmental organizations. A fair, tiered pricing structure was developed as well to reflect the ability of a country to afford the necessary medicines. PHARMA was, in the words of one supply chain executive, 'not a charity', but 'would never say 'no' where lives were at stake'.

PHARMA produces a wide portfolio of critical medicines and other drugs; employee health and labour availability was at risk and could affect not only the pandemic response but overall supply chain performance. Plans were made for absentee rates that could exceed 50%. Accordingly, PHARMA took steps to assure management was focussed in country and that employees had access to antivirals as soon as was deemed necessary.

PHARMA had to consider a broad range of existing and new techniques for meeting the sudden demand, and preparing for a much higher requirement should a second pandemic wave hit in the Northern Hemisphere autumn flu season.

Primary capacity was shifted and expanded in a balanced manner from other large-volume, critical drugs across multiple production sites to reduce the secondary risks from the dramatic spike in antiviral production. Moving to round-the-clock production was possible with external, temporary staff taking on less-skilled steps and carefully allocating internal skills. With additional key supplies and materials put in place, PHARMA could move to dramatically higher monthly production in just 12 weeks from the sudden declaration of the pandemic.

> *"After the outbreak in April, we are beginning to receive orders from governments again, and we will start engaging with those governments on what the supply and delivery schedules can look like for Nicole…A tremendous amount of work is being done on Nicole in terms of ramping up our short-term production capability, and the MSC has worked ceaselessly in the last week on this issue."*
>
> *Demand Operation Manager*

Additional options were explored to accelerate ramp up and maximise production including postponement of country-specific product packaging configuration,

essentially a 'vanilla pack' that was easier to produce and ship globally. By shifting production between sites, moving to round-the-clock shifts, and various other supply chain improvements, production of Nicole could be increased from a maximum annual capacity of 60 million doses to 90 million. Government approval of a new, simpler dose delivery format – already designed and ready for manufacture – was accelerated by having pandemic contingency plans in place in agreement with key health authorities. Voluntary licensing for manufacturing in China allowed PHARMA to expand the global supply capability with a single dose delivery device to meet a predicted increase in demand from emerging market countries where there was a potentially huge patient base. With the new delivery format, PHARMA could attain a 300% increase for a total capacity of 190 million doses. PHARMA was able to quickly bring additional pandemic healthcare supplies such as an antiviral mask to limit the spread of the infection and meet the increased demand of other medicines triggered by Influenza cases.

PHARMA was able to assure rapid response at all stages of a pandemic, able to deploy antivirals and 'pre-pandemic' vaccines that can be deployed early before a fully matched, new vaccine becomes available. The new Influenza strain was shown to have some resistance to competitors' drugs, increasing the opportunity to PHARMA and reinforcing its potentially critical role in the pandemic if the strain evolved further resistance. Its response had to reflect changing insight and evolving government policy in major markets:

> *"Pandemics by their nature are unpredictable and we recognise that governments' needs are changing. We are committed to finding solutions for governments changing their immunisation programmes and to fulfilling recent new orders."*
>
> *CEO of PHARMA*

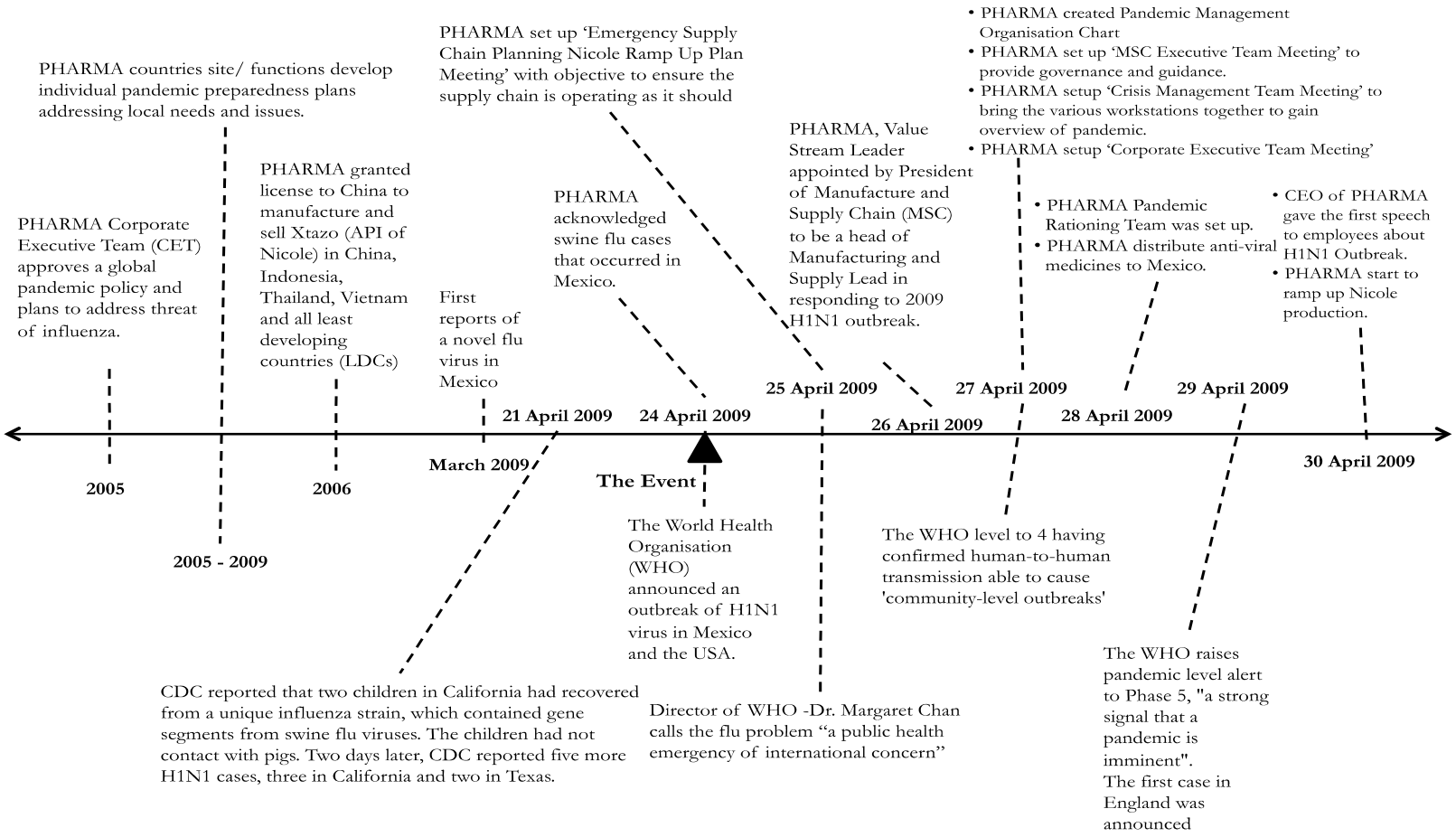
Ultimately the mortality was lower and while the Influenza strain sadly claimed the lives of more than 45,000 worldwide – and continued to be responsible for deaths each week, PHARMA was able to rapidly meet the overall demand for antivirals and later for flu vaccines. What was, in fact, a real crisis facing its supply chain, was at the same time a unique opportunity to tailor and expanding existing strategies and decision making structures in the likely but unpredictable event of future pandemics. It was finally "Good for PHARMA", contributing to its profit and reputation as a leading global manufacturer.

D3 – Deployment of the Solution

PHARMA had a number of production solutions in place but not yet activated. After the event occurred, PHARMA was able to update, tailor and quickly implement pre-existing plans, shortening design lead-time and assuring faster deployment. In the following discussion, the preparation is reviewed relative to its impact on deployment lead-time.

The timeline of the pandemic response is shown in Figure 18. In this study, the date 24 April 2009 is defined as 'the disruption event' for purpose of analysis. (See also the detailed of the event in Table 25 in Chapter 4.)

Timeline of PHARMA Response to the H1N1 2009 Pandemic



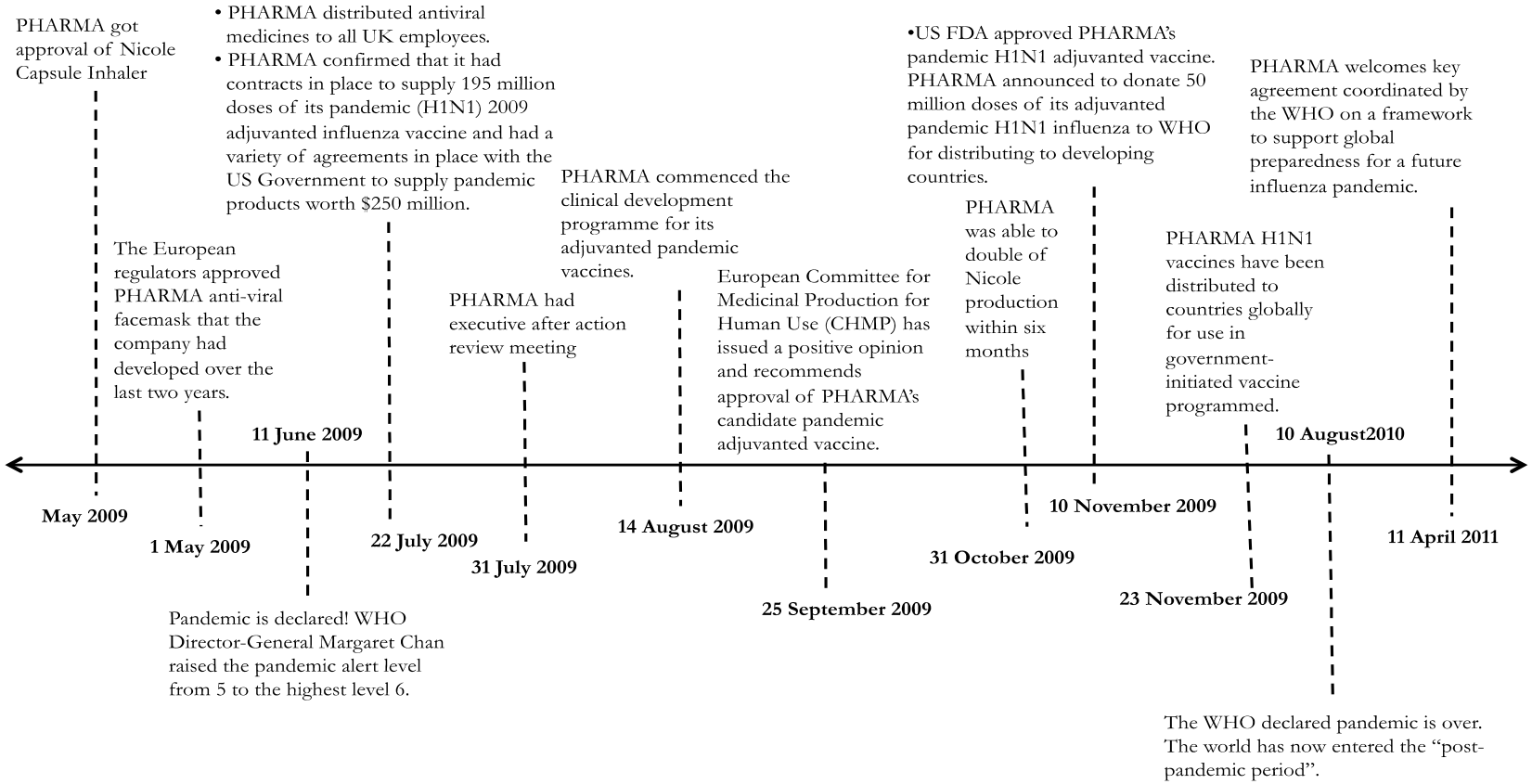


Figure 18: Timeline of PHARMA Response to the 2009 H1N1 Pandemic

5.3 Coding and Categorisation of PHARMA Data

This section reports on the analysis of the data collected from interviews, internal documents, direct observation and media in PHARMA case using the Grounded Theory method. It illustrates on how PHARMA solved the challenges mentioned in section 4.6 in detail by leveraging contingency plans and enhancing the company's performance by its response. Analysis was performed a systematic and iterative approach with constant comparison of data, as described in Methodology (Chapter 3).

In addition to the process of coding, interviews were recorded and summarised. Those interviews, which could be taped, were transcribed verbatim. For interviews in which the recording device was not allowed, interview notes and memos were written from memory. In conjunction with a constant comparative method of data analysis in keeping with Grounded Theory method, the process of constant comparative analysis was continually rechecked and memos were written throughout the research to assist with theory development.

Dissimilar data was not discarded as it was significant in the analysis and was used where similar and dissimilar data appeared as separate codes within categories. Later in the study this data was also used to identify properties of categories and links between sub-categories and core categories.

During analysis of the second and subsequent interviews, the data was constantly compared with the prior interviews to highlight the similarities and difference response to the events and areas of interest. Similar data is grouped together to form codes. Codes were grouped into analytic concept or categories according to Charmaz (2006). Though the analytic questions, based on the time-based response framework, provided some initial ideas for categories, these ideas were not imposed on the data. The categorisation of codes required careful consideration and proved to be conceptually complex. Ideas were interconnected with people's statement and documents, frequently, had multiple meaning that could be categorised in a range of ways.

Using the 3-D Framework by Sodhi & Tang (2009): D1- detection of the pandemic by PHARMA, D2 – design and evaluation of possible supply chain and D3 – solution deployment across the organisation, helped to locate and determine the relevance and importance of the study, provided direction for theory development and connected the study to disciplinary practice. Of course, the real-world response does not fall into simple linear progression – solution design, for example, typically encompass development of a portfolio of possible initiatives, which overlap in deployment.

The following section is a discussion of codes I created from PHARMA data (Figure 19). The analysis looks at the steps the company, took as well recommendations made after the event, where significant lack of capability or action is believed to have hindered the company in its response. Approximately 110 codes were identified and revised in the PHARMA setting. Codes were identified as the words, concepts and phrases with similar intent. The codes are enumerated below along with selected underlying source data. At this point, some codes overlap in some aspects, as certain concepts can be coded in multiple ways. Eighteen subcategories were developed as follow:

1. Warning	2. Stress test
3. Modeling	4. Planning
5. Training	6. External communication
7. Relationship with competitors	8. Relationship with governments and agencies
9. Relationship with business partners	10. Teamwork
11. Internal communication	12. Roles and responsibilities
13. Learning	14. Employee capacity
15. Production capacity	16. Supplier capacity
17. Product design	18. Solution design

Figure 19A-D shows an overview of codes, sub-categories and potential four core categories following completion of the analysis of PHARMA data. Subcategories of the core categories represent tailored approaches taken by the firm, that is, the are the action patterns that express the implementation of activities to address a specific risk management strategy. For example, sub categories of '*reserve*' are: *assure management and employee capacity*, *increase production capacity*, *develop product or solution extensions*, *acquire additional suppliers*, *increase flexibility*, and *increase inventory*. Axial coding indicates a relationship between the sub-categories, for example in time sequence, prioritization, and interdependency.

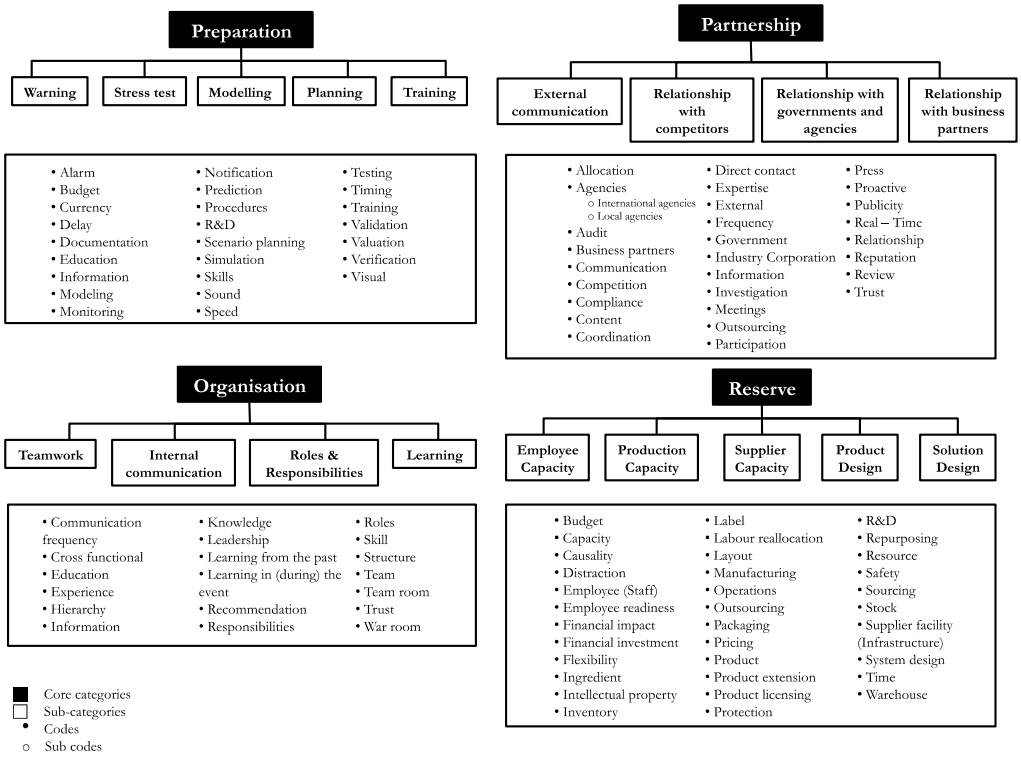


Figure 19: An Overview of the Codes, Sub-Categories and Potential Core Categories

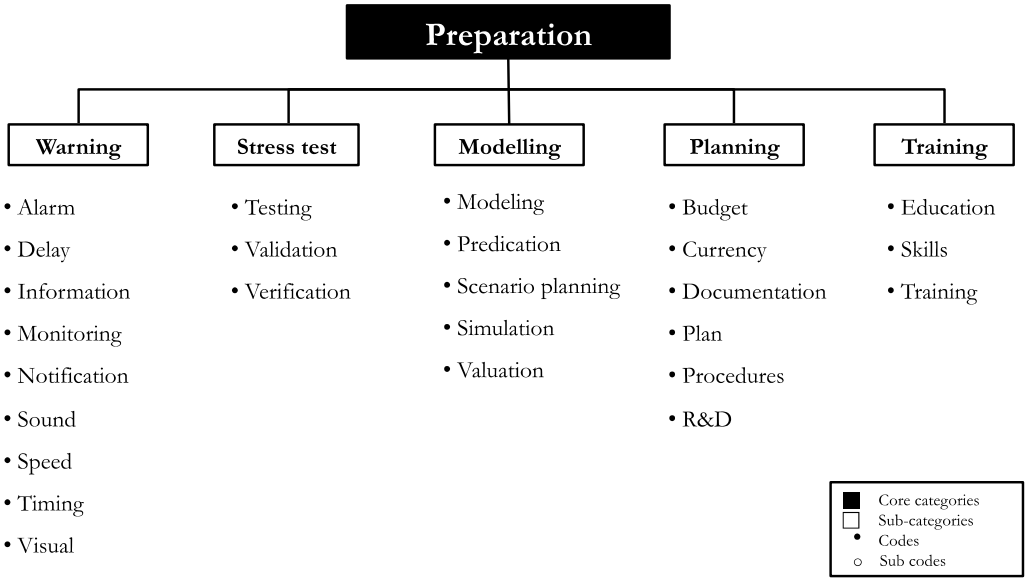


Figure 19A: A Structure of the Category "PREPARATION" and Its Sub-Categories and Codes

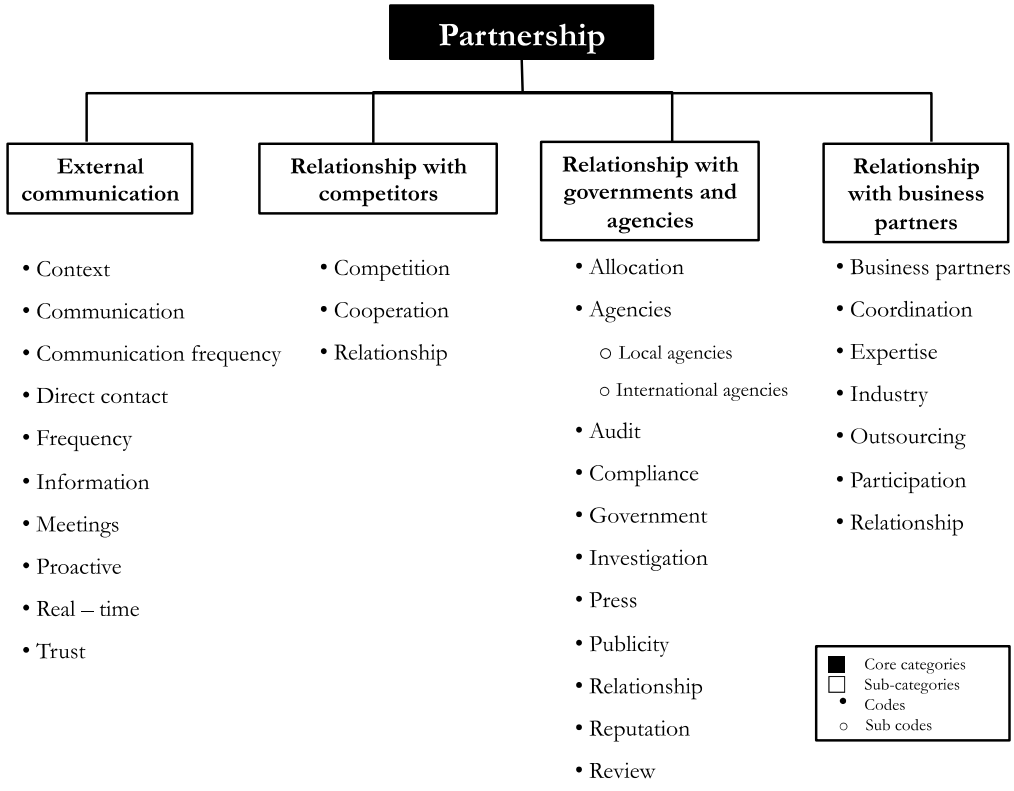


Figure 19B: A Structure of the Category "PARTNERSHIP" and Its Sub-Categories and Codes

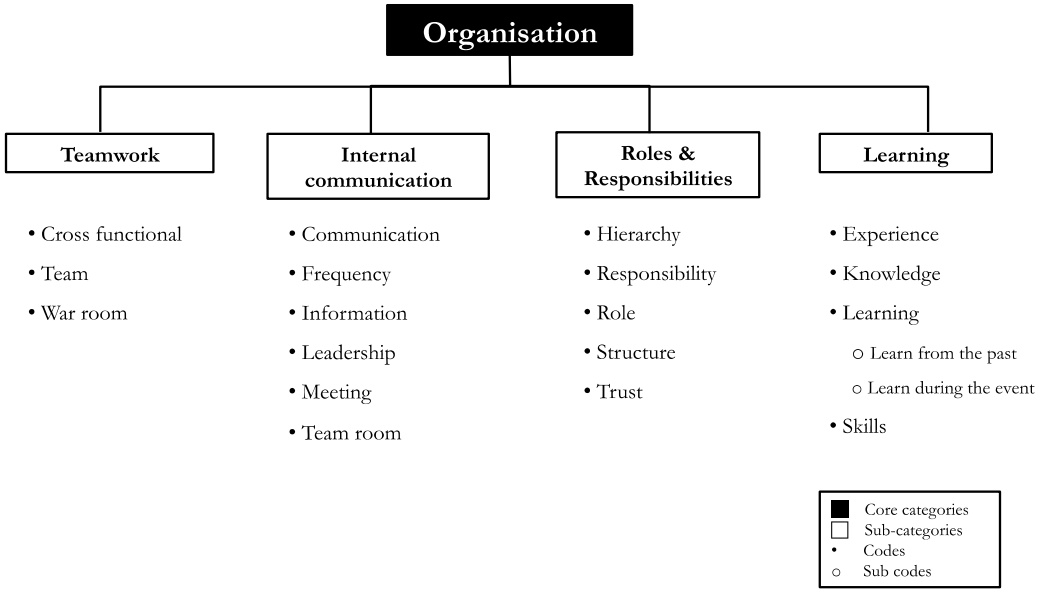


Figure 19C: A Structure of the Category "ORGANISATION" and Its Sub-Categories and Codes

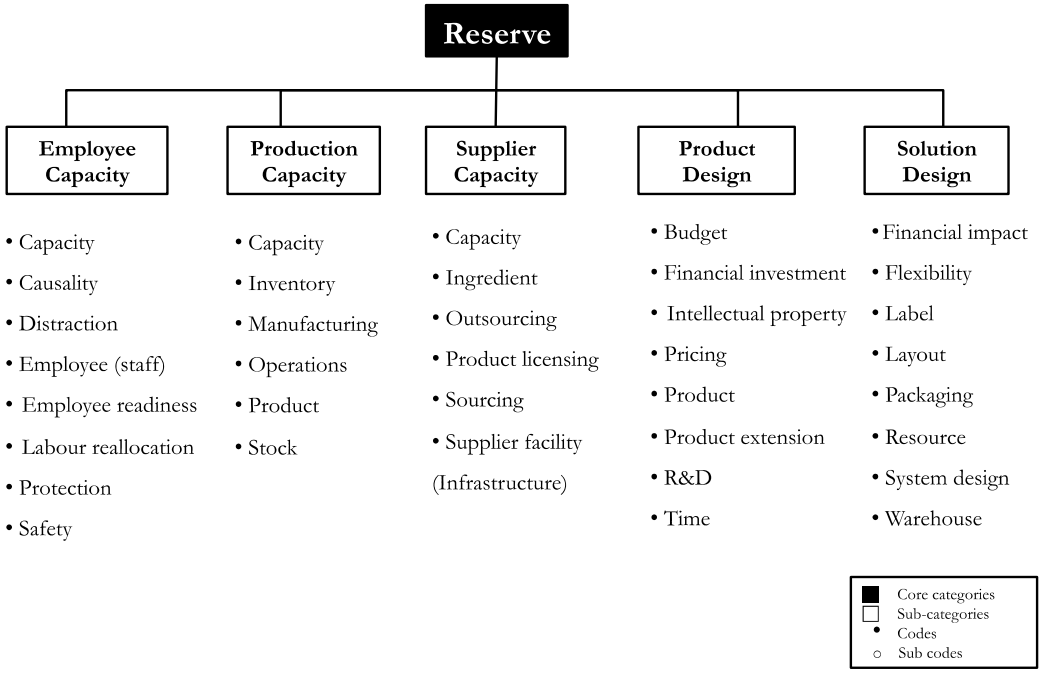


Figure 19D: A Structure of the Category "RESERVE" and Its Sub-Categories and Codes

Warning - Develop advanced warning system

Example: Assign staff to monitor the information and process flow

Codes: Information, Monitoring, Notification, Speed and Timing

PHARMA monitors production of its key suppliers as well as its own inventory at the manufacturing sites. The company has dedicated staffs that monitor the information flow (demand forecasts, production schedule, inventory level, quality) and process flow constantly; thus, when the Influenza outbreak occurred, management was able to get a clear overview immediately and design solutions accordingly. The monitoring system helps PHARMA reduce detection time D1 and reduce design lead-time D2.

Prior to the start of the event, PHARMA had put in place and tested several aspects of its response to a pandemic. Potential issues due to rationing of stock were identified and policies were put in place. Testing was performed on the procedures; however, the dependencies made this an apparently complex process.

> *"We have written procedures on how we would ration in the event of a pandemic. We potentially have to run rationing across many products not just Nicole as potentially our global production capability across 72 sites and all our products could have been compromised if staff were absent through contracting the disease. The timescales, impact and scenarios were very complicated and it proved impossible to test all scenarios. A selection of probable scenarios were chosen and tested."*
>
> *Manufacturing and Supply BCP*

What was not anticipated, however, was the speed with which measures would have to be implemented. Virulence and transmission rates of viruses such as H1N1 tend to follow certain patterns and timings. In this case, the unknown impact of the virus led the WHO to escalate the issue in a very short period: "The WHO guidance was saying it was going to take four to six weeks (to move from Phase 4 to 5); in fact it went in 24 hours."

The speed of this response by the WHO put PHARMA in unchartered territory, in particular initiating a global response when the initial outbreak was still confined to Mexico: "Phase 5, in our old flu pandemic procedures, meant we would issue antivirals to all staff in all locations across the world. We would put in measures to limit social risks, we would stop travel, we would activate all these plans to move stock from all these sites, from Singapore to our secondary sites, and then to move stocks from our sites into the market to try to push material down the supply chain.

And of course, we don't really need to do this, because we only have an outbreak in Mexico."

Stress Test - Conduct stress testing

Example: Pandemic stress testing annually (July)

Codes: Testing, Validation and Verification

According to the PHARMA pandemic preparedness plan, the company also creates and rehearses different scenarios for pandemic events once each year around July. As, the H1N1 pandemic broke out before the scheduled test in 2009, the previous 'pandemic stress test' was run nearly one year before events unfolded.

Modelling - Develop scenario plan and modelling capacity

Example: Modelling the second wave of pandemic to estimate demand of antiviral medicines.

Codes: Modelling, Prediction, Scenario planning, Simulation and Valuation

PHARMA had developed a planning scenario in order to estimate the demand of medicines and how to ramp up production in order to handle the second wave of Influenza cases, which as predicted to occur during October 2009 at the onset of the winter flu season in the northern hemisphere.

Planning - Leverage site pandemic preparedness plan

Example: Assessment and update site pandemic preparedness plan

Codes: Documentation, Plan and Procedures

PHARMA has a site Pandemic Preparedness Plan to protect the health and safety of site personnel, protect site assets and preserve its ability to provide essential medicines to the market in case a pandemic occurs. MSC develops a common site Pandemic Preparedness Plan that is for adapted for each site. These plans include the Business Continuity Plan, Plant Manager Emergency Response Plan and Site Crisis Management Plan.

The Pandemic Preparedness Plan is arranged in sections corresponding to the WHO pandemic alert system. It describes in detail the tasks to be performed at each site. At each stage of the incident, this plan is used by site directors and the Crisis Management Team (CMT) to establish, review and execute procedures to manage the impact of flu pandemic on the workforce. It also describes actions, triggers and communications within and between the sites, the regional CMT and PHARMA Corporate functions in the WHO Phases 3, Phase 4, Phase 5 and Phase 6 of a pandemic. The pandemic preparedness plan has been prepared in line with PHARMA's global principles.

Although PHARMA had these existing plans in place, some documents were found to be out-of date, having been written between 2006 and 2008. Key persons identified in the plans were no longer responsible for the tasks addressed therein, due in part to changes that are typical for large organizations. . The generic preparedness plan, which was to be deployed in the event of a major event, was last updated in 2008. Thus, PHARMA's first solution design task was to update and refine the pandemic preparedness plan:

> *"We activated all our business continuity plans and our pandemic preparedness plan for the entire organisation across the world. There was a gap between the documented procedures and what staff members were actually doing. The preparedness documents were from 2006; Sites used them as a basis for their initial response at the end of April . An instruction was sent to all site directors to update their plans based on a best practice example within 2 weeks of the outbreak."*
>
> *Director of Supply Chain Planning*

The new pandemic preparedness plan was issued to the manufacturing sites across the world. The roles and responsibilities in the plan were tightened up, listing the contact details by job role and title instead of name to assure clear ownership of responsibility irrespective of staff changes.

Having a base line Pandemic Preparedness Plan in place accelerated PHARMA's response to the event in design and deployment process.

Training - Implement training

Example: Assure skill availability for managing risk by training

Codes: Education, Skills and Training

PHARMA assure skill availability for managing risk by implementing training of management staff and sufficient skill for replacement to maintain understanding how to manage risk in case there is an absence of experienced staff.

> *"For key roles in the CMT and key positions in the supply chains, BCP and Pandemic preparedness plans now require deputies to be identified and trained in case in any future event key staff contract the disease and are absent from work."*
>
> *Manufacturing and Supply BCP Lead*

External communication – Establish frequent communications

Example: Create frequent communication with governments, agencies and business partners.

Codes: Communication, Communication frequency, Direct contact, Information, Real-time, Reputation and Trust

PHARMA increase frequency of press and public communication when there was the outbreak. This is in order to keep the public inform what they are doing and show that company has aware of the issue and need to response to the public need to save people life as soon as possible. In addition, this is to get real-time information so that the company can response to the event better.

> *"Information flow is crucial. We need real-time information with all parties that involved in this pandemic is really important to respond better."*
>
> *Manufacturing Strategy Manager*

Example: Increase frequency of press and public communication

Codes Communication, Communication frequency, Compliance, Press, Publicity, Relationship and Review

Public perception is also important in the highly visible response to a possible pandemic. Governments drive the sale of the majority of Influenza medicine directly through tenders or indirectly through medical advisory bodies such as the CDC and participate in the funding of research.

The pharmaceutical industry plays a crucial role in the health and well being of the global population; pharmaceutical firms typically attract the direct scrutiny of the press. For PHARMA, the press and public communication are seen to have an important role and the company could not delay its response, as it would give the company negative image.

> *"Our mission statement is built around improving the quality of human life. Given the importance of our brand in the market, we operate and communicate with press to maintain our strong reputation."*
>
> *Manufacturing Strategy Manager*

Relationship – Establish relationship with governments, agencies and supply chain partners.

Example: Coordinate with governments, agencies and business partners

Codes: Agencies (local and international), Cooperation, Compliance, Expertise, Government, Industry, Press, Publicity, Relationship and Review

In the event of pandemic, establishing relationship with partners such as governments and international agencies is critical:

> *"No one organisation or country, or group, can meet the pandemic challenge alone. All partners – multilateral organisations such as UN, developed countries, developing countries, public-private partnerships and industry – must work together to put in place a robust and effective global response."*
>
> *Global Public Policy Issue PHARMA's Position (2009)*

To respond to the Influenza outbreak efficiently, PHARMA closely monitored the situation and proactively contacted relevant organisations and health authorities around the world – including the WHO, the CDC and the Department of Health and Human Service in the US and the European Centre for Disease Prevention and Control – to gain a better understanding of the support and response needed. Frequent communications and direct line of communication with its partners benefits PHARMA in terms improving forecasting accuracy:

> *"We are talking to them about a range of issues, trying to understand exactly what this new virus is, exactly how the WHO and CDC believe this may develop so we can response to their need more quickly and efficiently."*
>
> *CEO of PHARMA*

In term of its relationship with governments, PHARMA had been working to supply antivirals for use in a pandemic situation since the global spread of avian Influenza (H5N1) in 2003.PHARMAwas committed to supporting governments worldwide. This commitment included addressing the needs of developing countries and their concerns about timely and affordable access to medical interventions.

According to PHARMA's annual report 2008, sales Nicole fell 80% reflecting fewer government orders for pre-pandemic stockpiling. PHARMA stopped receiving orders for Nicole three months before the start of the pandemic. No production was planned for 2009.

> *"With no additional orders from governments, PHARMA had stopped Nicole production some three months before the start of the pandemic. No production was planned for 2009. At that time, PHARMA's commercial position was that no additional production would be planned without firm orders from governments."*
>
> *Manufacturing Strategy Manager*

Once PHARMA acknowledged the outbreak, the company has contacted governments around the world to ascertain demand for Nicole, including those countries most affected by the virus, such as Mexico and the United States. Proactive contact with government helps PHARMA in managing the limited existing stocks of Nicole and anticipating demand of Nicole to determine appropriate solutions to raise Nicole production levels.

> *"PHARMA established contact with local governments via the country managers to confirm the timing and estimate of required capacity and priority. Pandemics by their nature are unpredictable and we recognise that governments' needs change. We are committed to finding solutions for governments changing their immunisation programmes and to fulfilling recent new orders."*
>
> *CEO of PHARMA*

Example: Proactive contact with governments to anticipate orders and allocate stock proportional to need

Codes: Allocation, coordination, government, proactive, stock

When the outbreak occurred, PHARMA faced an immediate challenge in allocation of existing stock. At that time PHARMA has only 6 million treatment packs available. The company prioritised orders to governments and was working with them closely to determine the best mechanisms for distribution of this antiviral

treatment through either public or commercial routes as well as to allocate stock proportional to the need of the governments.

Political pressure was a factor in the initial response. For example, a PHARMA senior vice president demanded 200,000 packs of Nicole for country 'C' – ISSA (PHARMA's competitor) had apparently promised to deliver an equivalent number of doses of Abaco. The government insisted they needed the full amount immediately. However, country 'C' was not considered by PHARMA to be a priority destination for several reasons. First, it did not have an Influenza outbreak. Second, they had not placed a firm order for which they would have to take delivery; in other words, if PHARMA produced a Nicole package, they would have to commit to payment. Four hours after the demand was made, country 'C' cancelled its order.

By the end of April, it was clear that the impact of the H1N1 outbreak affect the organisation across a range of areas, including organisation and communication, finance and product development.

Regarding to stock allocation in coordination with government, it became urgent for PHARMA to understand the commercial priority in terms of who would be allocated product, and country managers were asked to talk to their governments to understand the potential demand. By the second week of the outbreak, PHARMA created a map of outbreak areas and determined the priority of locations to be supplied with Nicole.

PHARMA needed absolute clarity from the commercial team on who was to be supplied based on the medical need. Therefore, the rationing team had to develop clear guidelines. The rationing process was refined during the pandemic response to meet ethical and corporate objectives. As stated by director of supply chain planning, a hierarchy of priorities was defined as follow:

> *First: countries with a confirmed outbreak, which had deaths and had placed a firm order such as Mexico. Second: confirmed outbreak, no deaths, but countries that wanted to place a firm order such as Paraguay. Third: confirmed outbreak, no deaths, but hadn't placed firm orders. Fourth: no outbreak, no deaths, but firm orders. And fifth: no outbreak, no deaths, and no firm order.*
>
> *Director of Supply Chain Planning*

For example, after the WHO rapidly increased the level of alert, without a definitive assessment of the pathology of H1N1, PHARMA evaluated and initiated a 'proportional response' that sought to more appropriately balance perceived with actual risks. By developing a system of fair, proportional response, PHARMA could accelerate delivery of medicines to populations with the most urgent need. The approach was developed as one of the first solutions to meet rapidly increasing demand, and serves as a template for general response during a pandemic.

Example: Establish relationship with experts in the industry

Codes: Expertise, Industry and Relationship

PHARMA also coordinated with experts by bringing scientists and doctors onto the team to advise on the WHO guidelines for pandemic alert levels and interpret the various other sources of information. This was seen as a turning point for MSC in its initial handling of a potential crisis for PHARMA.

Teamwork – Create integrated response team

Example: Create frequent communication with site directors

Codes: Communication, Cross functional, Frequency, Leadership and Meeting

Once PHARMA acknowledge the event, three responses were set up with the MSC executive and the central executive teams the following days. The first was to run an emergency supply chain planning meeting for Nicole. This meeting was previously run monthly but a meeting was held immediately to provide an accurate assessment of our stockpiles of API, raw materials and intermediates and finished goods, ongoing production and commercial commitments. The second response is MSC executive meeting, which aims to provide governance and guidance in the supply chain. The frequency of this meeting was increased from monthly to weekly then to daily as the situation became clearer. The third response was to establish a crisis management team comprised of key operational staff across the PHARMA business with the aim to provide overall governance and guidance focus on three areas: (1) finding solutions to meet the order for 32 million doses of Nicole; (2) putting into action initiatives across the supply chain to protect the business; and (3) determining how the company could move from its existing capacity of Nicole to a production dose capacity a factor of three times per annum greater in the event of

pandemic. This much higher estimate was considered possible during the second wave of Influenza cases, which could come during October 2009 at the onset of the winter flu season in the northern hemisphere.

PHARMA created a frequency communication with site directors. During the first three months of the event, these meetings were held on a daily basis. There was clear delegation and empowerment of the Crisis Management team allowing faster and more responsive decision making during the design phase to ramp up and expand production.

In addition to the responses in the MSC the whole of the PHARMA business responded including daily meetings of the CET attended by the CEO of PHARMA Communication to all employees in every country was a key objective from the CET in order to communicate the response and changes in a very dynamic and evolving situation.

> *"I am absolutely committed to ensuring that we communicate with the organisation as we develop the response. This may mean that you get a daily update from the CET on the decision and direction we are taking. It may also mean that we have to change the direction that we set on one day very soon afterwards because this is a fast moving situation and I ask for your understanding in that situation if it occurs."*
>
> *CEO of PHARMA*

Example: Establish integrated response team called 'Crisis Management Team'

Codes: Team

In order to reduce design and deploy time, PHARMA also created integrated response team called MSC Crisis Management Team (CMT). The President of the MSC appointed the value stream leader as manufacturing and supply pandemic lead to bring together the disciplines across supply chain needed to identify possible solutions to respond to the event. PHARMA's existing pandemic procedures were reviewed immediately after the event. They found the existing response plans were a good basis, but needed to be expanded to cover all products, not just antivirals.

Example: Crate pandemic management organisation chart

Codes: Cross-functional, hierarchy and structure

Apart from create CMT, based on the identified gaps PHARMA also created a new Manufacture and Supply Chain (MSC) pandemic management organisation chart

(Figure 20) this organisation chart was used as a core organisation setup during the response to help MSC executives communicate and understand which product lines could be affected. The pandemic organisation chart provides clarity of roles and responsibilities through out the distributed supply chain organization.

As part of this CMT, a sub team was set up to address the potential impact of the Influenza on multiple supply chains, initially thought to be unrelated. Continuity of the supply of critical medicines was vital to patients as well as to PHARMA's corporate mission.

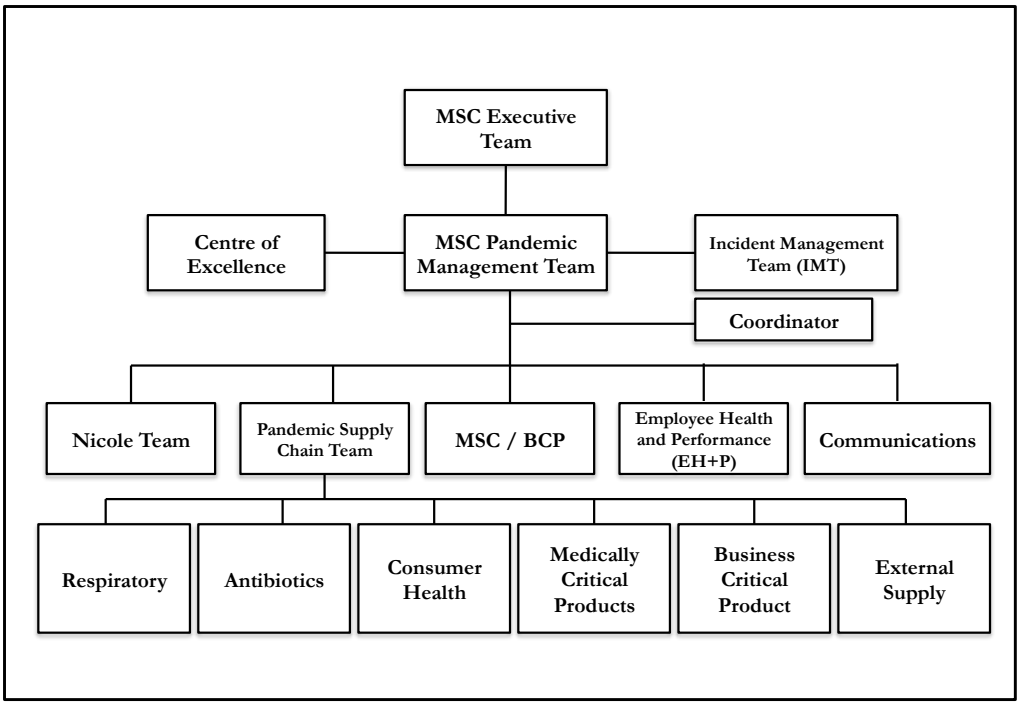


Figure 20: Manufacturing and Supply Chain (MSC) Pandemic Management Organisation Chart

Source: PHARMA

Moreover, a pandemic creates additional demand for a broad range of medical and health-related products. Asthma patients, for example, are more susceptible to Influenza infection. PHARMA had to consider additional areas such as respiratory, antibiotics (demand for antibiotics was also predicted to increase because of weakness in the body caused by the Influenza virus can trigger secondary bacterial infections), consumer health (antiviral facemask), business-critical products and external supply in which demand would increase in the face of a pandemic.

The newly created sub team reported to MSC pandemic management team who reported, in turn, on a daily basis to the MSC executive team during the outbreak.

Example: Established online team room for document sharing and set up a war room at headquarter

Codes: Communication, Team room and War room

PHARMA established a control room for the purpose of agreeing strategy and directing global operations during the pandemic to develop and execute a crisis response plan. The room was conveniently located at its global headquarters where members of the crisis management team and MSC pandemic management team had easily access. To aid in the process, valuable visual information such as budget and timetables, demand forecasts, production plans and project information are available as charts in the control room.

PHARMA also created an online electronic database for information such as risk management plans, strategic plan, BCP, etc. With uninterrupted access, this helped managers worldwide to get the documents faster for implementation and deployment. The focus of the document sharing was on project management in deployment, and had proven useful during the solution design phase as well.

Internal communication – Shorten lines of communication within the organisation

Example: Modify organisation hierarchy to shorten lines of communication

Communication, Frequency, Hierarchy and Structure

Communications emerged as a key issue in the response to the pandemic. In the words of one executive:

> *"There was an initial problem with lines of communication. An immediate lesson was that greater communication was required to give the sites better guidance, and therefore a communication team was established."*
>
> *Manufacturing Strategy Manager*

Another executive added:

> *"Normal lines of Communication were used initially during the response but these proved inadequate and not responsive enough. Amended communication channels were put in place aligned to the role responsibilities during the response phases.*
>
> *Manufacturing and Supply BCP Lead*

Consistency of communication was vital. Under normal conditions, PHARMA had both formal and informal channels of communication that existed side-by-side. Additional management teams were put in place without – in retrospect – having been aligned to handle appropriately the scope and route of communications. Inconsistent communication resulted in considerable 'noise'.

One executive explained,

> *"When PHARMA gets in a situation like this, PHARMA changed the formal network. They put in bodies that would communicate on the pandemic, bypassing some of the normal communication channels. So, that created a lot of noise, because we are expecting those channels to communicate, but we're getting those channels communicating. So if you run a site, instead of getting information from one channel, you have four."*
>
> *Director of Supply Chain Planning*

Figure 21 shows communication lines during the response of H1N1 outbreak. It illustrated that the sites were getting different messages from a number of different sources; Employee Health Management (HRM) executives, the Incident Management Team (about many topics, including personnel issues, the distribution of antivirals and the stages and levels of the pandemic and reactions.), the Senior Vice President (SVP) (about the pandemic response e.g. moving stock) and from the Crisis Management Team (CMT).

This structure prevented PHARMA from being able to communicate effectively; accordingly, restructuring the communications channel was a key design objective. PHAMA shorten the line of communication by proposed that the CMT would be responsible for communicating all issues during the pandemic (Figure 22).

Ownership and authority were also under pressure. For example, management staff outside the MSC and not based in the United Kingdom, who believed they held risk management responsibility, had remained peripheral to the activities of the response, yet later pushed to be part of the executive review process.

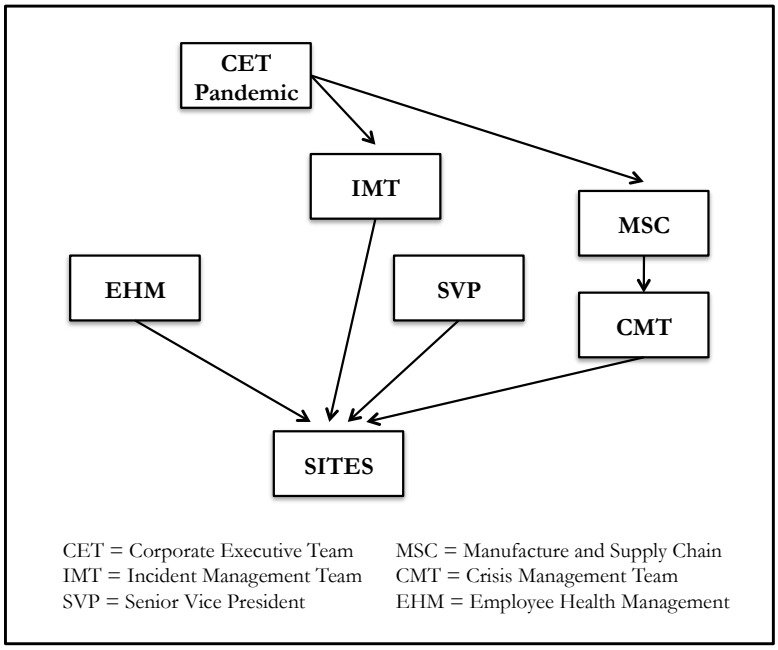


Figure 21: Communication Lines during the Initial Response of H1N1 Outbreak

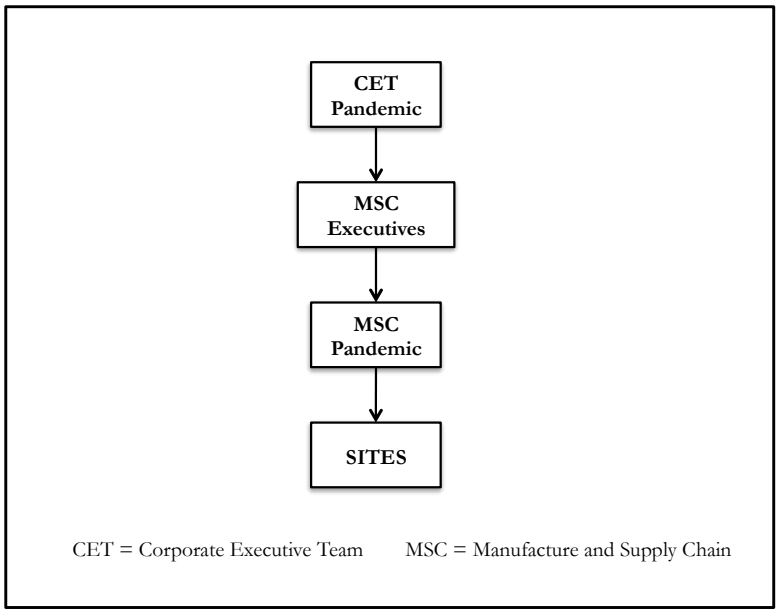


Figure 22: Revised Communication Lines During the H1N1 Outbreak

Roles and Responsibilities – Clarity of roles and responsibilities

Example: Revised and updated roles and responsibilities as formally documented in RACI diagram.

Codes: Hierarchy, Responsibility, Role and Structure

To clarify individual/departmental roles and responsibilities, PHARMA revised and updated their logistics pandemic BCP, site pandemic preparedness plan and 'RACI' diagram.

RACI diagram captures four roles, specifically for Responsible (those participants, management or employees, internal or external, who are to do actually assigned tasks), Accountable (those ultimately will be held accountable for the completion of the tasks), Consult (whose input or opinions should be sought) and Inform (those that should be kept up-to-date on progress and status of the work).

RACI is a technique for identifying functional areas, key activities, and decision points where confusion may exist. This approach enables PHARMA management team to actively participate in the process of systematically describing, decisions that have to be made, activities that must be implemented, and to clarify the responsibilities in relation to those activities and decisions. By formally identifying accountabilities, the pandemic management team south to improve communications across MSC.

Learning - Establish learning from past events and during the events

Example: Learning from past epidemics

Codes: Experience, Knowledge, Learning from the past, Learning during the event and Skills

Prior to the H1N1 Pandemic, events such as the H5N1 Avian Flu provided insight into the evolution and transmission of Influenza strains. However, this affected primarily animals (birds in this case), with relatively few incidents of human fatality.

"We have learnt from previous outbreaks, although bird flu was less severe than this and confined for the most part to aviary death. But since then we have been focussing on developing our antiviral medicines…the thing with bird flu, and it was less severe, in that it was killing birds. In some areas there were problems, where there was very close proximity between people and birds such as in China. But the transmission from birds to humans isn't so easy. Swine flu is different. Transmission from pigs to humans has happened and of course transmission from humans to humans.

Site Logistics Head

With additional experience from the H1N1 response, it could respond significantly faster: what used to take weeks now takes just days to deploy.

"We have learned a lot, we are in a much better state of response now in case that ever happened again. We understand our vulnerability and we can respond faster . . .I have the feeling we responded better than most companies. We certainly responded increasing our supply chain capacity very well. No one would produce that portfolio. We didn't have that product six months ago, we didn't have a vaccine, we didn't have Nicole capsule inhaler, we didn't have an IV product. That development has been unprecedented.

Director of Supply Chain Planning

Production capacity – Increase capacity

Example: Ramp up production to increase capacity of Nicole

Codes: Capacity, Inventory, Product and Stock

In the event of a major pandemic, PHARMA would invest heavily in increasing supply chain capacity to help governments and other customer organisations. Significant investments would need to be made internally for antiviral drugs such as Nicole but also for an H1N1 vaccine and potentially external suppliers who could help PHARMA meet demand.

Before discussing how PHARMA increase antiviral capacity to meet up demand during pandemic, I would like two explain a structure of two important supply chains: Nicole and Hematol. Table 27 below shows PHARMA manufacturing sites and locations.

Manufacturing Site	Location
Site A	United Kingdom
Site B	United Kingdom (Scotland)
Site C	France
Site D	United States
Site E	Australia
Site F	Singapore

Table 27: PHARMA Manufacturing Sites and Locations

- **Hematol Supply Chain**

Hematol is one of PHARMA's biggest revenue-generating products. It contains two active ingredients, Fancrose and Salmora. Two primary sites manufacture the APIs for Fancrose and Salmora. The APIs are micronised at PHARMA in France (Site C) and the United Kingdom (Site A) and secondary dry powder inhaler product is manufactured and packed at sites in United Kingdom (Site A), United States (Site D) and France (Site C).

- **Nicole Supply Chain**

Nicole is a medicine for the treatment of Influenza and for reducing the chance of getting flu in community and household settings. It belongs to a group of medicines called neuraminidase inhibitors. These medications attack the Influenza virus and prevent it from spreading through the body. Nicole treats the cause of Influenza at its source, rather than simply masking the symptoms. Nicole is delivered via inhalation using a dry powder inhaler, a PHARMA proprietary device for delivering medicines.

The API of Nicole is called Xtazo. There are three suppliers of raw material intermediates to primary site in United Kingdom (Site B): a PHARMA internal supplier in United Kingdom along with the third-party supplier sites in Italy and Belgium.

Figure 23 illustrates the Nicole supply chain. The primary manufacturing site is responsible for the production of the API contained within the medications. This normally involves either chemical synthesis and separation stages to build up the complex molecules involved, or fermentation and product recovery and purification in the case of biochemical process. In the Nicole supply chain, this process happens at PHARMA's manufacturing site in the United Kingdom (Site B).

The secondary manufacturing site is responsible for taking the API produced at the primary site and micronising and adding 'excipient' (pharmacologically inert) material along with further processing, quality control and packaging to produce the finished dry powder inhaler products.

For Nicole secondary production, the API is micronised at secondary site in France (Site C). The product is then blended, filled, assembled and packed at secondary sites in France (Site C), Australia (Site E) and United States (Site D).

PHARMA stated in its corporate commitment to make flu pandemic medicines affordable and broadly available and further mentions its production capacity as a key part of its corporate responsibility. The company championed ethical values and doing the right things for society. Presenting the critical role of its supply chain vital, the CEO stated that:

> *"We need stay focused on the main job, which is to ensure that important PHARMA medicines continue to be developed, manufactured and distributed to patients who need them. They will need them more than ever in the event of further healthcare crisis."*
>
> *CEO of PHARMA*

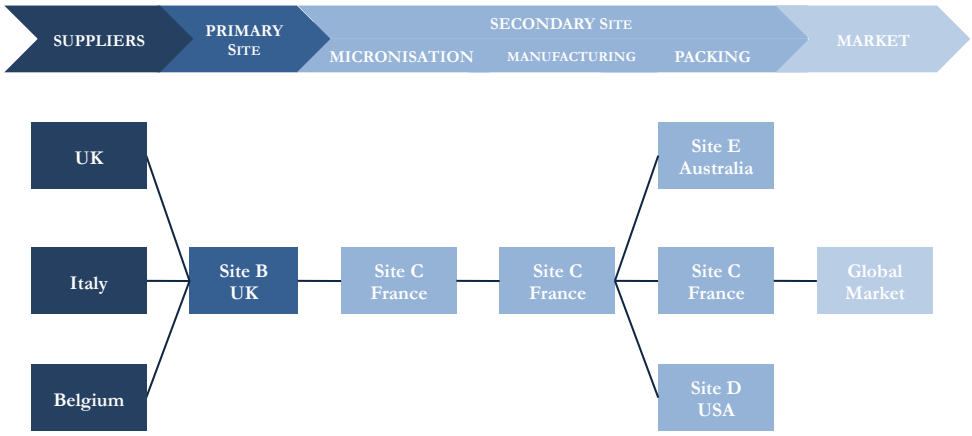


Figure 23: Nicole Supply Chain

Starting from effectively halted production, PHARMA expected to achieve its target of producing Nicole at the much higher rate of output within 12 to 14 weeks after the outbreak.

> *"That will take a few weeks. But be rest assured, we are already manufacturing Nicole this week, and it will grow every week over the next few weeks and months."*
>
> *CEO of PHARMA*

The challenge to the MSC team was to design a solution to go from zero production to maximum production and then expand production by a further 50% in as short a time as possible. The main question that was raised was summarised by one interviewee:

> *"How quickly we could move from other duties back onto Nicole, how we then had to start the filling operation, then there is an assembly operation, then a packing operation…time was our constraint and we knew that we had to design a solution as soon as possible."*
>
> *Site Production Head*

Example: Leverage production load balancing by reducing load of production on some sites while increase production of Nicole site

Codes: Capacity, Inventory, Labour reallocation, Product and Stock

PHARMA correctly predicted an increase in demand for medication to treat respiratory ailments such as Hematol. The PHARMA Project manager explained: "People who have asthma are likely to be more easily affected by the Influenza virus. A viral chest infection can trigger an asthma attack. These people are more vulnerable and hence more likely to take asthma medicine, driving up the demand for Hematol."

There were two main reasons why PHARMA was concerned about the impact on demand for this product. First, Hematol is a medically critical product, which means its availability can mean life or death for some or all of its users. An impact on the supply of this product could result in the loss of company reputation and/or customer loyalty. Second, Hematol is one the company's main products, which generates GBP 4Billion per year. Any reduction in the production could have a significant financial impact.

When the pandemic was declared, employees working on Hematol manufacturing at Site D (United States) were needed for Nicole production. Production output of Hematol was scaled back at site D and global demand was sustained by taking up the capacity shortfall at Site B, which did not make Nicole. This load balancing flexibility was designed in when the supply chains for Nicole and Hematol were configured. Site B was asked to produce five million disks of Hematol a month, which was considerably more than they had ever produced. Six months before the

pandemic; Site B had moved from 24 hour /7 days-per-week shifts to 24/5 shifts, and now they were going back to 24/7.

To increase the capacity of the Nicole dry powder inhaler device, PHARMA had to reallocate the capacity of Hematol production in each manufacturing site. Decisions were made for each site to:

- Maximise Hematol production at Site B (United Kingdom).
- Maximise Nicole production at Site E (Australia)
- Maximise Hematol and Nicole production at Site D (United States).

Maximise Hematol and Nicole production at Site C (France). Although Nicole and Hematol do not share the same supply chain, they share some common resources as mentioned earlier. Therefore they were able to divert resources (e.g. labour resources), which is one of PHARMA's risk mitigation strategies. Figure 24 shows how PHARMA used production load balancing to both maximize production of Nicole and assure multi-site production of both Nicole and Hematol.

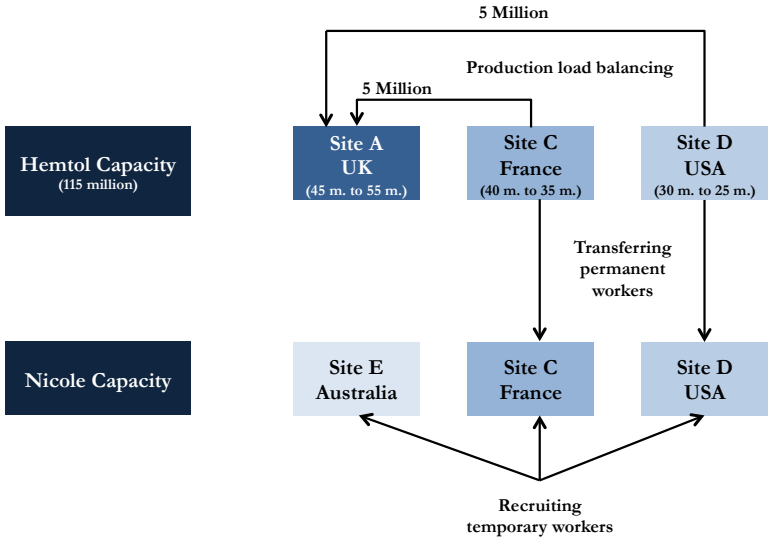


Figure 24: Production Load Balancing Strategy

Production capacity – Financial investment and R&D

Example: Multi-billion dollar investments in R&D, manufacturing capacity, and also short-term tactics to increase production capacity.

Codes: Budget, Capacity, Financial investment, Product, Product extension and R&D

PHARMA has been conducting R&D of vaccines since 1997 to enable governments to protect their populations in the event of an outbreak. More than GBP 2 Billion has been invested in developing technologies to respond to an Influenza pandemic by increasing capacity at its vaccine and antiviral manufacturing sites. Supply chain investment during the past three-and-a-half years to 2009 was more than GBP 1 Billion and aimed to improve production response at short notice. "We don't know how big this deal is going to be, but no one can say we aren't ready," claimed CEO of PHARMA at the outbreak of the H1N1 flu.

Significant tactical investments for Nicole production were made during the initial response without any assurance of a return, "The sums of money we were investing were huge; we made a decision to put over GBP 100 Million to expand capacity, not knowing if we would recover our costs." Investments in R&D as well as manufacturing were considerable, measuring in the billions of dollars (1988,1989), with an estimated 60% of the total manufacturing costs for the Influenza vaccine fixed (HHS, 1998).

Employee capacity – Assure employee capacity

Example: Recruiting contingency workers to cover peak period and move to 24/7 shifts for greater production in existing site (Nicole)

Codes: Capacity, Employee, Employee readiness and Labour reallocation

PHARMA also putting extra shifts on, recruited temporary external staff, also transfer of experienced production labour who previously made Hematol in Site C and Site D, and maximizing Hematol production in Site A.

> *"Although Site A does not produce Nicole at all, but All staff responded urgently knowing that by making more Hematol they were helping maximise Nicole as well."*
>
> *Site Production Head*

"This is a part of our supply chain integrity, in that we have multiple plants to do this, multiple plants to do that. But obviously, we don't have people just waiting around manufacture if we don't have demand. So as we went lost orders for Nicole a year ago, we released our staffs, we mothballed those facilities -we wouldn't keep that cost . . . now the demand is peak, so we have to get the lines running, we would have to re-recruit temporary worker to build the capacity, but at the same time we have to have experienced workers who know the production operation well."

Manufacturing and Supply BCP Lead

Supply chains that can share resources, such as experienced and temporary external labour and facilities helped PHARMA rapidly ramp up capacity of Nicole quicker but also sustained the production of Hematol. To solve this, PHARMA using production load-balancing strategy to cascade production, reducing impact on the Hematol supply chain.

"It allows you to deploy quicker for Nicole but also impacts production of Hematol because they share the same common resources such as warehouse and labour. That's why they need load balancing to cascade the impact from one to other."

Manufacturing and Supply BCP Lead

Employee capacity – Assure management capacity

Example: Distribute H1N1 antiviral medicine to employee and lockdown managers in country and restrict travel

Codes: Capacity, Employee readiness, Protection and Safety

After PHARMA acknowledged the outbreak, the CEO of PHARMA instructed all country managers to physically stay in their countries so that they could better focus on local business unit issues and assure their supply and distribution chains would run effectively. All non-essential travel to Mexico was halted. The CEO guidance to employee was 'to remain calm and carry on' with their work to make sure patients would continue to have access to critical medicines.

The protection of PHARMA employees was an important objective in the initial stages of the response. In the face of the infection, employee health was protected by distributing the company's own H1N1 antiviral medicine to employees according to Employee Health and Preparedness Plan. The key objective of this plan is to collate information required by the centre to assure the antiviral storage, allocation and delivery of pre-pandemic and pandemic vaccines for employees.

Product design – Develop product extension

Example: Having easier-to-manufacture Nicole capsule inhaler product design in place and ready to produce

Codes: Capacity, Product, Product extension and R&D

PHARMA achieved new capacity by increasing production levels of Nicole dry powder inhaler from 60 million treatment courses to 90 million and building new capacity to produce 100 million treatment courses a year of Nicole capsule inhaler.

Another stream of increasing the capacity of Nicole was through alternative dose forms for antivirals. A few years prior to the swine flu pandemic, PHARMA developed a capsule inhaler device. This delivery format was slightly more difficult to use from a patient perspective. The patient has to load the device with every capsule, and then breathe in the medicine for dose delivery:

> *"The advantage of the Nicole capsule inhaler form is that PHARMA manufacturing has capsule capability at six of the PHARMA sites. So, the project team was formed to develop this product and to look at how we will carry out emergency registration with regulatory governmental authority and then spend the money for industrial analysis to validate so that we can have 100 million Nicole capsule inhaler capacity in place in about five months time; as it is predicted that the second wave will come in around October 2009."*
>
> *Manufacturing Strategy Manager*

By having new dose delivery mechanism, such as the Nicole capsule inhal)er, developed before the outbreak helped PHARMA save design lead time and ramp up production much faster. Figure 25 shows capacity of Nicole production in percentage.

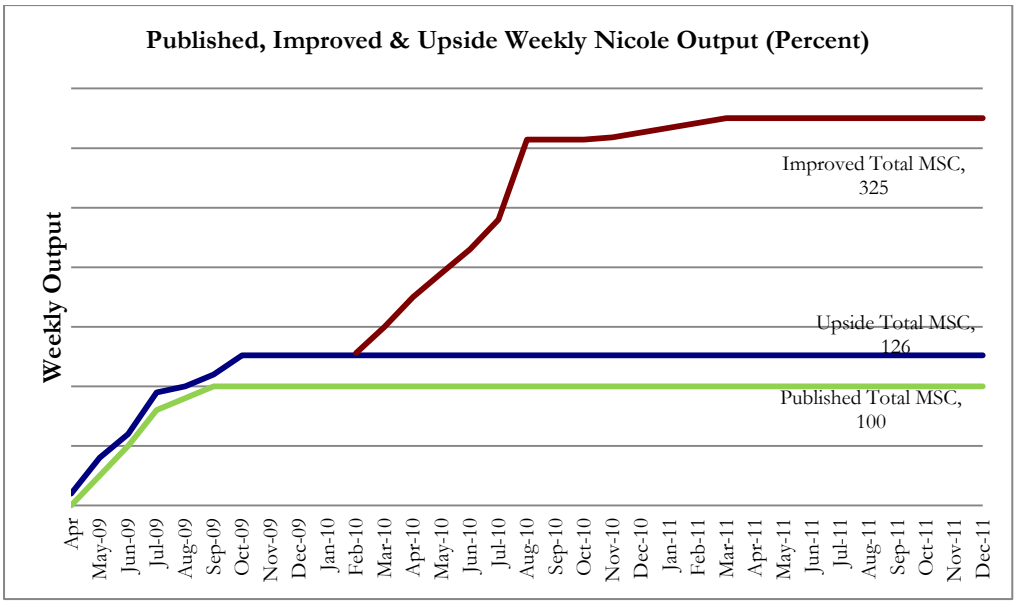


Figure 25: Published, Improved & Upside Weekly Nicole Output

Example: Accelerate approval process for new product such as Nicole capsule inhaler and antiviral masks

Codes: Capacity, Product, Product extension, R&D and Time

Nicole capsule inhaler format had been approved to manufacture but not for sale in the market yet. PHARMA had submitted the Nicole capsule inhaler device to the regulatory authorities several years ago, and the company had gotten certain approvals. At the time, PHARMA decided to discontinue the regulatory submissions due to the lack of demand in the market and patient preference for the more convenient, multi-dose delivery format (the dry powder inhaler).

To meet rapidly growing production targets, the capsule-based format required regulatory approval. PHARMA accelerated deploy lead-time through fast-track approval of the product via the Swedish regulator on behalf of European regulatory bodies. This product was granted temporary approval for sale only in pandemic situations. This helped PHARMA respond quickly, especially important in anticipation of major second i

Influenza wave in the Northern Hemisphere, which could begin in October - December 2009.

Normally the fast track scheme can take approximately six months. Some products take two to three years to review, for example, due to extensive and complex clinical trial data. As this product had proven clinical results and the same active ingredients as the previously approved Nicole dry powder inhaler; the regulatory authorities also understood the urgency:

> *"In the pandemic, we had to go back, dig out all the regulatory information on the Nicole capsule and resubmit our application. We then had to fast-track it through the regulatory bodies . . . normally, at the regulatory authorities, their fast track scheme is six months but they understood the urgency of this and the world is in a potential pandemic. They were reviewing and approving this quicker. Also we try to point out that this is the same product with Nicole dry powder inhaler, just in a new single dose device. The regulatory authorities understood the situation and accelerated their response without compromising their standards. So all we had to do is show that we could administer it therapeutically..."*
>
> *Manufacturing and Supply BCP Lead*

The availability of existing product definition greatly shortens the deploy lead-time for new solutions. PHARMA hoped to profit from its existing disposable respirator, a specially fitted type of facemask, which has an antiviral coating. The company was able to accelerate government approval for a related antiviral facemask adapted for the H1N1 virus

> *" ... The antiviral facemask has been approved for use in Europe and certain international markets and last month was approved for occupational use in the United States by the FDA…"*
>
> *CEO of PHARMA*

Supplier capacity – Acquire additional suppliers

Example: Granting a production licence to a Chinese manufacture

Codes: Capacity, Product, Product licensing and Intellectual property

Another way to increase capacity of Nicole was through licensing production. PHARMA committed to engage in voluntary license discussions with other companies willing to manufacture and supply a Nicole product for use in developing countries. Other companies would not be able to make Nicole in dry powder inhaler format because the delivery device is relatively complicated, but they could more readily adopt the capsule inhaler format.

Two years ago, PHARMA had given a voluntary license to a Chinese company to manufacture flu drug. The company in China has the right to manufacture and sell Xtazo in China, Indonesia, Thailand, Vietnam and all least developed countries (LDCs).

> *"PHARMA is doing everything we can to prepare for a global Influenza pandemic including expanding production of Nicole and developing a pandemic vaccine . . . this agreement with Chinese company is intended to expand available suppliers of Xtazo in areas of the word that may be on the front line of a possible Influenza pandemic."*
>
> *President of the company's pharmaceutical operations*

Three main reasons that Nicole capsule inhaler is a 'good fit' for granting license are: easy to manufacture, leverage the existing drug approval documentation made several years earlier, and it was suitable for licensing to third-party from an intellectual property perspective.

Having a pre-existing licensing arrangement with Chinese manufacture shortened the search and implementation for external. It was seen as a good solution to responding for handling increase demand since China given the high volume needed for such a large population.

> *"There are a number of companies that we would give voluntary license to make this product. However, they would not be able to make dry powder inhaler because that is a complicated device that needs sophisticated manufacturing and technical expertise . . . Instead they could make Nicole capsule because that uses a relatively simple technology available to pharmaceutical manufacturers globally. And that meant we could grant Nicole capsule inhaler license into countries such as China."*
>
> *Manufacturing and Supply BCP Lead*

PHARMA also needed to control the quality of external suppliers to match that of its internal manufacturing capacity so that all applicable quality, safety and efficacy standards are maintained.

> *"PHARMA also investigated the company who had been doing development work on this product and within those companies at the end of the day we want to investigate giving a license to them so they can produce these products to satisfy demand volume… Governments can issue compulsory licences to other companies but these licences would require significant technical assistance in order to manufacture the product and scale up within the demanding timelines of the pandemic. In addition key raw materials for manufacturing and packaging of Nicole are in short supply due to the PHARMA expansion and the suppliers are constrained due to the unprecedented demand."*
>
> *Manufacturing and Supply BCP Lead*

Supplier capacity – Increase raw material and inventory

Example: Increase raw material by securing all available active pharmaceutical ingredients (API) from the suppliers

Codes: Capacity, Inventory, Outsourcing, Sourcing and Stock

PHARMA identified a series of additional projects to increase capacity. First, PHARMA had to increase the capacity of suppliers; second, it had to increase the capacity of its secondary factories and then the production capacity of the APIs.

This meant buying more materials, which implied an immediate (and risky) initial financial outlay. PHARMA purchased raw materials and components to produce a significant volume over the period of several months.

> *"We are also beginning to increase our bulk raw material manufacturing plans for Nicole to assure we have enough raw bulk material in the future."*
>
> *Manufacturing Strategy Manager*

Example: Increase strategic stock of micronised ingredients

Codes: Capacity, Ingredient, and Stock

For shared equipment with finite capacity, such as the microniser, PHARMA's supply risk mitigation strategy is to build strategic stock and hold high levels of micronised material. With micronized material in warehouse, PHARMA can start manufacturing the product quicker, albeit at a potentially higher work-in-process relative to competitors.

> *"We had built a lot of strategic capacity in micronising. We hold high levels of micronised materials in our supply chain as part of the manufacturing strategy for common products."*
>
> *Manufacturing and Supply BCP Lead*

Solution design – Increase flexibility

Example: Implement generic packaging (vanilla pack) instead of market specific packaging and using multi-language labelling

Codes: Flexibility, Label and Packaging

Additional options were explored including postponement or delaying the last stage of country-specific product packaging configuration, 'vanilla pack' or 'generic pack'

A straightforward simplification of the packaging of Nicole would help speed-up production, using a supply chain method referred to as 'postponement'. In this approach, customer- or market-specific configuration is delayed, to better pool supply chain capacity in production and distribution.

There two types of packaging. A 'market specific' pack is uniquely labelled with in languages specific to country an order and containing country-specific regulatory information. Approval of packaging – even details on graphics, logos and text, forms a key part of the regulatory review. The other called 'generic pack' or 'vanilla pack' is typically labelled in multiple languages such as English, French and Spanish. In the event of pandemic, local language and regulatory information on the medicine could be limited to a locally produced insert.

> *"Having vanilla pack wouldn't increase our capacity, but it would allow us to chop and change to make as much as possible and ship as much as possible. Initially there was some resistance from countries wanting their own pack but once the global benefits of flexibility were understood and regulators approved the generic pack the market specific requests decreased"*
>
> *Manufacturing Strategy Manager*

In the urgency to receive product, governments initially accepted the 'vanilla pack' but later insisted on country-specific packaging, reflecting the sensitivities of public consumers and need to confidence during the widely publicized pandemic.

> *"For example, PHARMA had product that was packaged for Japan and Japan then cancelled the order; at the same time one of the outbreaks was in another country. This country wanted the product within two weeks; PHARMA said we could supply the product to you but only in Japanese packaging (market specific label). The country accepted the Japanese order only for four weeks later to reverse their decision and request a market specific pack.".*
>
> *Manufacturing Strategy Manager*

The same approach was used for the Nicole capsule inhaler; PHARMA used multi-language labelling instead of country-specific labels in order to maximise production during the pandemic outbreak.

Example: Sharing common resources

Codes: Flexibility, Manufacturing, Resources and Warehouse

The Nicole and Hematol supply chains are unique. These are two different supply chains – they are co-dependent on certain resources such as the microniser machine; others machine such as filling and packaging equipment is separate. However, they do share he same machine, labour, resources, quality assurance and warehouse etc. Resource sharing enhances supply chain flexibility in adapting for redesign (new) supply chain design during pandemic and be able to deploy manufacture production faster.

5.4 Response Time and Preliminary Core Categories

After an initial period of confusion in the aftermath of the sudden pandemic declaration, the actions initiated across a broad range of areas were ultimately effective in PHARMA's response. Communication and decision-making – aided by daily and weekly review meetings – meant a number of tasks could be quickly delegated to the sites and country management.

> *"No formal targets exist for response time, but there is a general expectation that all Corporate Incident management teams, CMT and BCP teams would be established and operating within 24 hours after the WHO communicated the event."*
>
> *Manufacturing and Supply BCP Lead*

The rapid spread of the virus suggested that the protection of employees was critical in many locations; the distribution of antivirals to staff was prepared in advance of the eventual rollout.

The expected seasonal evolution of the pandemic set the urgency and timing of various options to respond. In the Northern Hemisphere, flu infection rates peak typically in January, with the earliest onset in October; such a possible second wave was feared to be far worse, as in it was in previous pandemics, than what actually occurred.

PHARMA responded rapidly to the outbreak, successfully leveraging plans and investments in antivirals accumulated during the previous decade. Out-of-date documents, changes in staffing and somewhat chaotic communication were quickly rectified and brought under the control of a single pandemic response team:

"Flexibility, visibility of supply chain and a clear plan are essential to the smooth running of a response to an emergency."

Site Production Head

Decreasing the cycle time in decision-making assisted PHARMA in adjusting its solution strategy as product demand evolved:

"PHARMA prides itself on it's ability to respond in a crisis and "changing the clock speed" is a phrase common in these circumstances This means monthly business processes are then run weekly, weekly processes run daily and daily activities run hourly and staff are dedicated to the response and their day jobs suspended or delegated in order to shorten this response time."

Manufacturing and Supply BCP Lead

Immediate demands for medicines from a limited stock were addressed through a rationing system and this helped provide a proportionate response to changing requirements. The rapid increase in the production of antivirals and related products was possible through new formulation and packaging, with the eventual formulation and accelerated production of a set of targeted vaccines.

Target production capacity was achieved for specific products, e.g. Nicole powder formulation, the Nicole capsule inhaler formulation and importantly for the H1N1 vaccine, over a period of several months with full capacity reached by the end of 2009.

"Time plays a key role to ensure more product is made and distributed and more patients are treated. In the pandemic response, Nicole production was restarted and output doubled within 6 months, new dose forms where developed, approved by regulators, supply chains and suppliers extended, a vaccine was available in an unprecedented timescale in 6 months."

Manufacturing and Supply BCP Lead

These solutions were each effectively incremental changes to existing mechanisms, feasible and sufficient as none of the worst-case scenarios materialised (e.g. closure of multiple active ingredient production facilities or long-term closure of regional transport). A formal review of the steps taken at the end of the first wave, e.g. July 2009, was supplemented by monthly tracking of further corrective and preventative actions to assure a greater level of preparedness going forward.

By August 2010, the WHO observed that new cases of swine flu followed a more typical seasonal flu pattern and with declining numbers of new cases and declared the pandemic to be over. In 2011, people were still catching the H1N1 swine flu in

the UK, although it was at the lowest level since the virus first appeared it is current form. The WHO estimates that there have been at least 16,813 deaths from swine flu around the world – 457 in the UK. Since the outbreak in Mexico, estimates varied widely and initial worst-case scenarios envisioned significant health and economic impacts on large populations globally.

PHARMA's fast response is also seen to have improved its competitive position:

> *"We have learned a lot, we are in a much better state of response now in case that ever happened again. We understand our vulnerability and we can respond faster . . .I have the feeling we responded better than most companies. To increase capacity by 50% then up to 300%, develop and approve new dose forms, develop a vaccine took the efforts of thousands of people in this organisation."*
>
> *Manufacturing and Supply BCP Lead*

Table 28 shows examples of actions that PHARMA took in responding to the H1N1 pandemic and affected of those actions on detection time (D1), design lead-time (D2) and deploy lead-time (D3).

Tailored approaches	Examples of PHARMA Response to H1N1 Pandemic	D1	D2	D3
Develop advanced warning system	• Assigned staff to monitor the information and process flow.	◆		
Conduct stress testing	• Pandemic stress testing each year (July).	◆	◆	
Develop scenario plan and modelling capability	• Modelling the second wave of pandemic to estimate demand of medicines.		◆	
Leverage preparedness plan	• Assessment and update site pandemic preparedness plan.		◆	◆
Implement training	• Assure skill availability for managing risk.			◆
Establish frequent communications with supply chain partners	• Coordination with international agencies e.g. CDC and WHO. • Proactive contact with governments to anticipate orders and allocate stock proportional to need. • Increase frequency of press and public communications. • Establish direct line of communication with external suppliers.	◆	◆ ◆ ◆	◆ ◆ ◆ ◆
Create integrated response team	• Create pandemic management organisation chart. • Established integrated response team called "Crisis Management Team". • Create frequent communication with site directors. • Set up a War room at headquarters. • Established online team room for document sharing.		◆ ◆	◆ ◆ ◆ ◆ ◆

Tailored approaches	Examples of PHARMA Response to H1N1 Pandemic	D1	D2	D3
Shorten lines of communications within the organisation	• Modify organisation hierarchy to shorten lines of communication.		◆	◆
Clarify roles and responsibilities	• Revised logistics pandemic BCP and site pandemic preparedness plan. • Revised and updated roles and responsibilities as formally documented in RACI diagram.		◆ ◆	
Establish learning from past events and during the events	• Learning from past epidemics (e.g. H5N1 Avian Flu).		◆	
Assure management and employee capacity	• Distribute H1N1 antiviral medicines to employees. • Lockdown managers in-country and restrict travel to at-risk areas (Mexico). • Recruiting contingency workers to cover peak period and move to 24/7 shifts for greater production capacity in existing sites (Nicole).			◆ ◆ ◆
Increase capacity	• Reallocate labour resources to increase capacity of Nicole. • Leverage production load balancing by reducing load of production on some sites while increase production on main sites.			◆ ◆
Develop product or solution extensions	• Having easier-to-manufacture Nicole capsule inhaler product design in place and ready to produce. • Accelerate approval process for new products e.g. Nicole capsule inhaler and antiviral masks.		◆	◆
Acquire additional suppliers	• Granting a production licence to a Chinese manufacturer.		◆	
Increase flexibility	• Using generic pack (vanilla pack) instead of market specific packaging. • Shift shared Hematol manufacturing capacity to Nicole. Shared same machine, labour, resources, warehouse, quality insurance etc.		◆ ◆	◆ ◆
Increase inventory	• Increase raw material by securing all available active pharmaceutical ingredients (API) from the suppliers. • Increase strategic stock of micronised ingredients.			◆ ◆

Table 28: A Summary of the Findings from PHARMA in Relation to Response Time

The search for a core category or categories begins from the outset with data collection. Codes and then categories emerge and are compared. The objective of the research using Grounded Theory is to generate theory "that accounts for the patterns of behaviour which is relevant and problematic for those involved' (Glaser, 1978. P.93). In order to achieve this goal, the researcher must discover the core

categories and delimit the investigation around it. This categorization is the crucial point for the theory; sub categories relate to it, and it accounts for most of the variation in pattern and behaviour. The core category or categories 'have the prime function of integration the theory and rendering the theory dense and saturated as the relationships increase' (Glaser, 1978, p.93).

According to Glaser (1978, p.95-97) research is looking for core category(ies) that explains the main concern or problem for the participants. He identifies the main criteria for core category selection as follows, where core category(ies) should:

- Central to as many other categories as possible, accounting for the majority of observed behaviours.
- Found throughout the data as a recurring concept, becoming more central to related categories through evolution of the research.
- Require more data than others to become saturated; that is, encompasses a broader range of data relative to other (sub) categories. Saturation "occurs when the data yields no new information for a category." (Glaser, 1978, p.95-97)
- Should have visible and meaningful links to other categories.
- Have validity and relevance to observed behaviours throughout the study. Alternate core category(ies) should be sought if only a limited duration of the study can be interpreted using the potential core category(ies) should be flexible and broad enough to encompass the emerging relationships between categories as they develop.
- The core category should also be a part of the problem itself. Therefore the core category should, in part, explain itself and its own variations.
- Should be a central part of the area under study, explaining its own role and encompassing variations on the concepts it represents.

In this study, the core pattern was managing supply chain risk by reducing response time, in which the firm undertook a series of activities to address risk in meeting supply chain demands in the event of low probability and high impact disruption.

This chapter provided a detailed description of how open coding was used to constantly compare and analyse data from the PHAMA case. It explored the codes,

subcategories and preliminary categories that emerged from the interview data and other sources. The codes explained how PHARMA leverages time in responding to the pandemic. As a result of analysis of the data, four preliminary categories were identified. These four distinct but interrelated core categories in responding to disruption are:

1. Preparation
2. Partnership
3. Organisation
4. Reserve

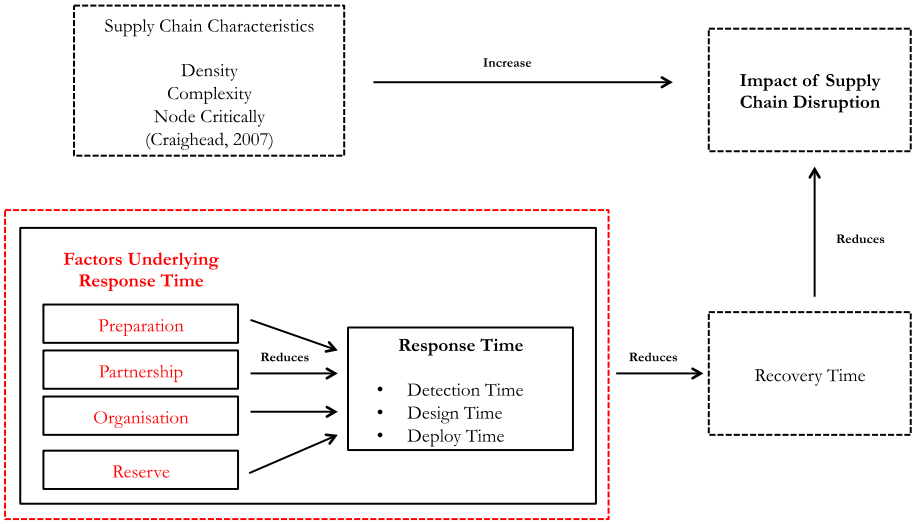


Figure 26: Finding thus Far from PHARMA Case

At this stage, it is too early in the analysis to confirm these categories. Further sampling and continued constant comparison of additional data is required to achieve theoretical saturation of this construct. The findings so far provide a preliminary answer to identification and initial characterization of the factors as was set out above (Figure 26).

Further coding from additional cases reveal more detailed characteristics of the identified subcategories after the PHARMA case. Additional subcategories are discovered in the incremental data, for example, in the BP Deepwater Horizon event. Cooperation with competitors, for example, was shown as a critical approach, which was not evident in the strategy taken by PHARMA.

Chapter 6
Validation with Disruption at BP Deepwater Horizon

The following chapter expands on the preliminary categories that were outlined in Chapter 5. This will be achieved by analysis of additional qualitative data collected through secondary sources of two additional cases. Through constant comparison with data from BP Deepwater Horizon and BP Texas City events, this process will assist in validating if the four categories are core to understanding the time-based response framework. Theoretical sampling and further coding will enable the properties of the preliminary categories and subcategories as well as the links between them to be identified, as presented in Chapter 8 - Findings.

The BP events came under intense public scrutiny for a number of reasons, most obviously due to the dramatic impact of the explosions that killed scores of workers. The immediate and long-term environmental damage drew government criticism; in turn politicians themselves were under fire for their lack of responsiveness and ultimately held responsible for creating the underlying conditions in industry which could allow such events to occur. Litigation followed, as can be expected for a major disruption involving firms along a global supply chain operating in the United States. This put a large amount of testimony into the public record. Delivered under oath, this verbatim material provides a rich source of data. The events, background and consequences were extensively documented through various government and industry investigations, along with the reports from BP itself.

It is not the aim to repeat this material nor to assess culpability, though a clear focus in the available material seeks to assign blame. Through Ground Theory methodology, the handling of these events serve to strengthen and detail the concepts emerging from PHARMA, where additional concepts extend the core categories and additional codes provider greater depth and applicability. A short summary on the background of the Deepwater Horizon disaster is provided below.

6.1 Company Overview

BP is a major international oil and gas company headquartered in London, United Kingdom. The company was founded in 1909 as the Anglo-Persian Oil Company, later Anglo-Iranian Oil Company, and was predominantly focussed on exploration and production in various countries in the Middle East. The AIOC became the British Petroleum Company in 1954, and expanded worldwide with investments in Alaska and the North Sea.

Extensive nationalization of assets in Iran and Libya and elsewhere during the 1970s forced the company to seek new sources of energy, often through cooperation with competitors like Shell and acquisitions of Amoco and Arco in the United States in 1988.

In 2001, the company was renamed BP plc. to reflect its total energy strategy ('Beyond Petroleum') and global operations, remaining headquartered in London. Today BP plc. is one of the world's largest energy companies, with extensive downstream distribution to retail customers and businesses across the globe. The BP Upstream division holds more than 500 lease blocks in the Gulf of Mexico and is the largest producer of oil and gas in the Gulf of Mexico.

6.2 Background of BP Deepwater Horizon Oil Spill

On the morning of Tuesday, April 20, working in calm waters in the Gulf of Mexico, engineers were confident of finally completing a challenging, much delayed exploration well in the Mississippi Canyon, Block 252. The area was dubbed Macondo, after the ill-fated town in Gabriel García Márquez book "One Hundred Years of Solitude". BP plc planned on drilling the first well in 100 days[11].

Though a leader in exploration, BP had little experience in the specific rock formation under Block 252 but was optimistic about finding significant hydrocarbon reserves at the Macondo Prospect. Looking to save time and expense for eventual production, offshore engineers at BP designed the exploration well to make it 'production ready'.

[11] OSC - Oil Spill Commission (2011c)

The crew was working to securing the bottom of the well with specially formulated cement which would allow the massive *Deepwater Horizon* exploration rig to 'temporarily abandon' the location. Normal exploitation could be continued at a later date with a cheaper rig, and allowing *Deepwater Horizon* to being work at new locations in the Gulf.

At 5:45 AM on the 20th of April, a cementing engineer from Halliburton Company, subcontracting to BP, sent e-mail from the rig to his colleagues in Houston a few hundred miles away. Despite some initial concerns, the work looked done: "We have completed the job and it went well.[12]"

Deep water drilling – more than 1000 feet below the sea level in current (2011) terms – is a complex endeavour, operating at the edge of engineering experience with extreme pressures, high temperatures and in remote waters. Maintaining the delicate hydrostatic balance of oil and gas pressure below with a column of heavy drilling 'mud' requires geology, experience, engineering and coordination. Conditions at sea level in the Gulf can change dramatically during the hurricane season; in fact, the Macondo well was started by an earlier Transocean drilling ship, *Marianas*, that had to be towed back for repairs after Hurricane Ida some five months earlier. The *Deepwater Horizon* had already suffered a stuck drill pipe at Macondo at more than 12,000 foot depth on March 8 when the fragile stone formation collapsed, forcing a design revision and drilling around the abandoned lower segment of the original bore hole[13]. By mid-April, the well was already six weeks late, with original projections of USD 96 million expected to overrun by USD 58 million[14].

Deepwater Horizon was one of the most sophisticated drill ships in the Gulf of Mexico, built in at a cost of USD 350 Million and operated by the largest offshore drilling fleet company, Transocean. The rig was on a long-term lease to BP with daily services fees of some USD 1 Million[15]. The safety record of *Deepwater Horizon* was generally good, with no major health and safety incidents in seven years. Two senior BP executives - company men drilling parlance - and two Transocean senior

---

[12] OSC - Oil Spill Commission (2011a)
[13] BP. 2010c. *Deepwater horizon accident investigation report*
[14] OSC - Oil Spill Commission (2011a)
[15] OSC - Oil Spill Commission (2011c)

managers – arrived on the rig that morning in April 20, 2010 for a one-day 'management visibility tour' and would congratulate the team on seven years of drilling with no major incidents[16].

Preparing the well for temporary abandonment, the drill team was testing the integrity of the 15,000 feet deep well, coordinating with specialist firms such as Halliburton and visiting BP engineers. The design of the well, formulations of concrete and mud, and techniques for securing it were specific to the geologic 'formation' and intense, specific conditions found during drilling. The engineers had to resolving differences of opinion in the approach, and were reviewing conflicting results from the various 'negative pressure' and 'positive pressure' tests.

At 21.30 PM that night, a massive geyser of sea water and drilling mud erupted and began to rain down on the rig and onto nearby support ship, covering the deck in the thick mucous-like synthetic drilling compound. Moments later, a hiss of highly compressed gas was audible. Loss of well control or 'blow-out' is one of the primary risks in drilling on sea or land, and extremely fast response is needed to avoid disaster. The drill pusher and mudrakers working on the drilling floor scrambled to take action.

At 21.41 PM, the rig shook with the first of several massive explosions. 11 crew members were killed in the blast. Most of the able and injured crew could escape by lifeboat – or jumping directly seventy feet into the oily and burning Gulf waters below. Some 27 hours later, the rig sank to the sea floor 5000 feet under the surface.

Over the next 92 days, BP would attempt a range of techniques to stop the flow of oil into the Gulf – originally thought to be minimal then 5000 barrels per day, ultimately known to be 10 times greater. The resulting oil spill reached hundreds of miles of coastline and covered vast surface and subsurface area. BP and its subcontractors faced billion-dollar litigation, on top of the USD 11.8 Billion that BP has already paid out by the end of 2010.

---

[16] OSC - Oil Spill Commission (2011a)

This was the beginning of the most expensive and damaging oil spills in American waters to date with more than 4.9 million barrels discharged into the Gulf waters. The public and industry scrutiny on this catastrophe was unparalleled, with impact beyond the critical energy supply chain that powers the American and international economy. In this case we look at the context and likely causes of the event, with a focus on how BP and its partners sought to accelerate their response to the crisis.

The United States was estimated to consume more than 18 million barrels of oil per day during 2011. The energy supply chain is critical to the national and global economy. To secure current and future hydrocarbon supplies, private industry has moved to new frontiers, drilling offshore to extreme depths and employing new techniques to extract energy sources from the ground. The wells in the Macondo Prospect are among the deepest, starting at 5000 feet below sea level and going some 13,400 feet into Miocene geologic layer that traps extensive oil reserves in the waves of salt and clay below much of the Gulf of Mexico.

The network of companies serving the Gulf of Mexico is complex, with many contracting parties for specialized services in marine geophysical surveying, offshore engineering and construction, transportation, diving and mobile drilling[17]. Due the exceptionally high cost of exploration and development, leading firms often shared costs of drilling, production and transportation [18]. According to a National Petroleum Council study, "This 'buy versus build' strategy resulted in a significant reduction in the number of skilled people within operating companies who understood development and deployment[19]".

Time pressure in this industry is considerable: "Project profitability depended on how soon production could be brought online. Drilling vessels were contracted on day-rates, increasing time pressures. Production processes were highly interdependent: delay on one place could cause delays elsewhere.[20]"

[17] OSC - Oil Spill Commission (2011a)
[18] OSC - Oil Spill Commission (2011a)
[19] OSC - Oil Spill Commission (2011a)
[20] OSC - Oil Spill Commission (2011a)

In 1985, an Office of Technology Assessment study of the Arctic and Deepwater oil drilling identified "a need for new approaches to preventing work-related injuries and fatalities in coping with new hazards in the hostile Arctic and Deepwater frontiers." It also presciently warned of the glaring deficiencies in safety oversight offshore, observing, "there is no regulatory requirement for the submission of integrated safety plans which address technical, managerial and other aspects of offshore safety operations[21]".

The offshore drilling business is expensive and dangerous. Since 2001, the Gulf of Mexico workforce – 35,000 people, working on 90 big drilling rigs and 3500 production platforms – had suffered 1,550 injuries, 60 deaths, and 948 fires and explosions[22]. Nevertheless, oil production in the Gulf is a vital part of the economy and considered generally safe for the environment; as stated by President Obama on 2 April 2010 on a speech in North Carolina, three weeks before the disaster, "Oil rigs today generally don't cause spills[23]".

Macondo Prospect, Mississippi Canyon Block 252

The Gulf of Mexico accounts for 90% of offshore drilling in the U.S. by volume and contributes approximately one third of all U.S. oil production. BP acquired the lease for Block 252 in 2008, and was approved by MMS to drill the first of two wells on May 29, 2009[24].

The well was started ('spudded') by *Marianas* on 6 October 2009. After reaching a well bore depth of 9,090 feet, the rig was badly damaged by Hurricane Ida and had work had to be re-started by Deepwater Horizon in February 2010[25].

During drilling, the team faced seven 'lost returns' events, in which the pressure from drilling fluid fractures the surrounding formation and the fluid flows into the rock. While this is not unusual, the events were frequent and at varying depths, prompting BP engineers in Houston to halt the drilling at 18,630 feet –

---

[21] OSC - Oil Spill Commission (2011a)
[22] OSC - Oil Spill Commission (2011a)
[23] The Whitehouse (2010)
[24] OSC - Oil Spill Commission (2011c)
[25] OSC - Oil Spill Commission (2011c)

approximately 1,400 feet short of the original target. Because of the fragile state of the well, additional tests and precautions are required.

> *"John Guide explained after the incident that losing returns 'was the No. 1 risk.' He and the other BP engineers worried that if their cementing procedure placed too much pressure on the geologic formation below, it might trigger another lost-returns event similar to the one on April 9."*

BP had to choose a well abandonment procedure that would balance the risk of 'lost returns' due to the fragile formation with possibility of losing well control.

To prepare a well for cementing, a mechanism known as the 'float valve' is introduced at the bottom segment ('the reamer shoe'). This has a pressure-sensitive mechanical device which changes from a two-way valve – allowing flow down and up through the pipe – to a one-way system. This conversion helps prevent mud from contaminating the cement.

The drill team had difficulty converting the valve (reversing its direction), and in multiple attempts, increased pump pressure on the ninth attempt to 3,142 psi – four times the design specification. There was the possibility that conversion did not occur due to obstruction of the very bottom of the well, the tip of the reamer shoe. To test that the obstruction, perhaps cuttings or debris, was pushed out, and the float collar converted, the crew would have needed to run at least 6 barrels of mud per minute and observe the comparable return; they did not run this test. Another possibility was that the high pressure forced the ball through the float tube, leaving it in place and leaving a bi-directional path through the float collar. If so, this could cause contamination of the cement.

The process for temporary abandonment typically requires setting of a cement plug some distance down into the well and a lock-down sleeve at the seafloor, allowing the BOP and riser to be removed. After several iterations through the well design, BP engineering planned to put the concrete plug at 3000 feet below the mudline.

1. Run the drill pipe into the well to 8,376 feet, 3300 feet below the mudline.
2. Displace the mud in the well with 3300 feet of seawater, pushing the mud into the riser above the BOP.

3. Perform a negative pressure test; to assure the concrete plug at the bottom could hold the hydrocarbon under pressure without substantial downward pressure from drilling mud
4. Displace the mud in the riser with seawater.
5. Set a cement plug at 8,376 feet.
6. Set a lockdown sleeve.

This phase would leave only the cement at the bottom reamer shoe to stop hydrocarbon flow up into well; the BOP could act as backup only if someone on the rig activated it early enough should the cement fail. This could require significant reaction speed from the operating crew, at the same time they were working with the complex mud displacement process from the riser.

This procedure allowed BP to set lock-down sleeve last, but required the upper cement barrier to be significantly deeper than was typical. Preferring to set cement in seawater, this left 8,376 feet of mud displace with much lighter seawater before any secondary barrier was in place. The procedure was developed at the last minute without performing any risk analysis. BP had changed the procedure a number of times in the two weeks prior to these final steps.

The plan on the 12 April did not include a negative pressure test, and had the cement plug set at 6,000 feet below sea level. On 14 April, BP sent a revised plan to MMS for approval, which included a negative pressure test, but required setting the cement plug in drilling mud before seawater displacement. On 15 April, BP changed the plan again, deciding to perform the negative pressure test before setting the cement plug. On April 16, BP sent the plan to MMS, which was approved in less than 90 minutes[26].

The plan changed one more time, on the day of the blowout. BP sent the Macondo team on the rig a revised plan, different to the one approved by MMS. In this final plan, the negative pressure test would be combined with displacement of mud in the riser with seawater[27].

---

[26] OSC - Oil Spill Commission (2011c)
[27] OSC - Oil Spill Commission (2011c)

Explosion and Oil Spill

Along with 11 deaths that occurred within minutes of the blast, 54 workers on the *Deepwater Horizon* were injured – some critically. Powerless after the first explosion, which destroyed its engine rooms, the burning rig drifted 1600 meters, listing heavily, before sinking to the seafloor 27 hours after the initial explosion.

By then an estimated 1500 meters of the riser connecting the rig to the wellhead lay crumpled on the sea floor. An oil slick from the initial destruction of the rig was visible for kilometres, but first impressions from the surface led the Coast guard and BP to assume that the well had been sealed during the emergency: "No oil leaking into the Gulf."

This would soon prove not be the case: "Coast Guard officials on Saturday estimated that as much as 1,000 barrels of oil is escaping each day from the well head on the ocean floor."

On April 28th, Coast Guard Adm. Mary E. Landry quoted a scientist from the National Oceanic and Atmospheric Administration who had concluded that oil is leaking at the rate of 5,000 barrels a day, not 1,000 as had been estimated. "It appears to have been calculated using a method that is specifically not recommended for major oil spills."

On April 30th, the WSJ reported that "Ian MacDonald, professor of oceanography at Florida State University who specializes in tracking ocean oil seeps from satellite imagery" had concluded the "oil spill could be leaking at a rate of 25,000 barrels a day, five times the government's current estimate".

On May 4th, Doug Suttles, an executive with BP Plc on Wednesday said the well could gush at 60,000 barrels per day if all the equipment on the sea floor restricting the current flow were removed during certain repair procedures.

> *"If the existing Blow-Out Preventer (BOP) and all the equipment were removed, it could get up to that rate."*
>
> *Oil Spill Commission, 2010b: Congestions al testimony*

By May 14th, the amount of oil spilling into the Gulf of Mexico may be at least 10 times the size of official estimates, according to an exclusive analysis conducted for NPR.

BP has said repeatedly "that there is no reliable way to measure the oil spill in the Gulf of Mexico by looking at the oil gushing out of the pipe."

Steven Wereley, an associate professor of mechanical engineering at Purdue University, analysed videotape of the seafloor gusher using a technique called particle image velocimetry. A computer program tracks particles and calculates how fast they are moving. Wereley put the BP video of the gusher into his computer. He made a few simple calculations and came up with an astonishing value for the rate of the oil spill: 70,000 barrels a day — much higher than the official estimate of 5,000 barrels a day.

On 14th May, BP spokeswoman Rebecca Bernhard said the company is standing by the 5,000-barrel figure. "We look at the fact that it's coming out of the riser (pipe) in several ways. We look at it from satellite imagery, over flight observations and on-the-water observations."

Carol Browner, director of the White House Office of Energy and Climate Change Policy noted that BP had a "vested financial interest" in downplaying the size of the leak, speaking to CBS news on "Face the Nation" that BP " . . . will ultimately pay a fine based on those rates . . ."

Representative Ed Markey of Massachusetts, head of the House Energy and Environment subcommittee, agreed that the company "had a stake in low-balling the number right from the very beginning."

Noting that BP has consistently provided information that proved to be wrong, Markey said he had "no confidence whatsoever in BP."

"The public needs to know the answers to very basic questions: How much oil is leaking into the Gulf and how much oil can be expected to end up on our shores and our ocean environment?" Markey said in a letter to BP. "I am concerned that an underestimation of the flow may be impeding the ability to solve the leak and handle management of the disaster."

Retrospective estimates of the oil leak from the first day of the disaster stand at approximately 62,000 barrels, slowing to 54,000 barrels per day by the time the well was finally capped. This figure is an order of magnitude higher than the original estimates, for a total spill of some 4.9 million barrels, making it by far the worst open sea oil spill in US waters.

6.3 Companies and Parties Involved

Transocean

Transocean is one of the leading offshore drilling companies. It owned some of the most capable drilling rigs in the industry, setting records for offshore drilling depth.

According to BP's Patrick O'Bryan, the *Deepwater Horizon* was "the best performing rig that we had in our fleet and in the Gulf of Mexico and I believe it was one of the top performing rigs in all the BP floater fleets from the standpoint of safety and drilling performance[28]". While there were several thousand hours of outstanding maintenance issues to be scheduled[29], the rig was seen as a workhorse capable of handling some of the most complex operations.

Halliburton

Halliburton is one of the world's largest oil field services providers and owns several other oil field services companies, including Baroid and Sperry Drilling. Halliburton designed and pumped the cement for all of the casing strings in the Macondo well.

The Minerals Management Service (MMS)

The Minerals Management Service (renamed on 18 June 2010 to the Bureau of Ocean Energy Management, Regulation and Enforcement, or Bureau of Ocean Energy (BOE))

[28] OSC - Oil Spill Commission (2011a)
[29] OSC - Oil Spill Commission (2011a)

The Department of the Interior's (DOI), Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE), is the federal agency responsible for overseeing the safe and environmentally responsible development of energy and mineral resources on the Outer Continental Shelf.

The Bureau is led by a Director appointed by the DOI Secretary. The Director is supported by senior executives who manage national programs, policy, and budget in Washington, DC (headquarters) and three regional directors responsible for management and program implementation.

The BOEMRE's Offshore Energy & Minerals Management (OEMM) offices contend with all aspects of offshore federal leasing and renewable energy projects. The OEMM's work includes the preparation and administration of regular offshore oil and gas lease sales. Additionally, BOEMRE is responsible for conducting supporting research and documentation leading up to each lease sale.

The OCS is a significant source of oil and gas for the Nation's energy supply. The approximately 43 million leased OCS acres generally accounts for about 15 percent of America's domestic natural gas production and about 27 percent of America's domestic oil production. The BOEMRE's oversight and regulatory framework ensure production and drilling are done in an environmentally responsible manner, and done safely.

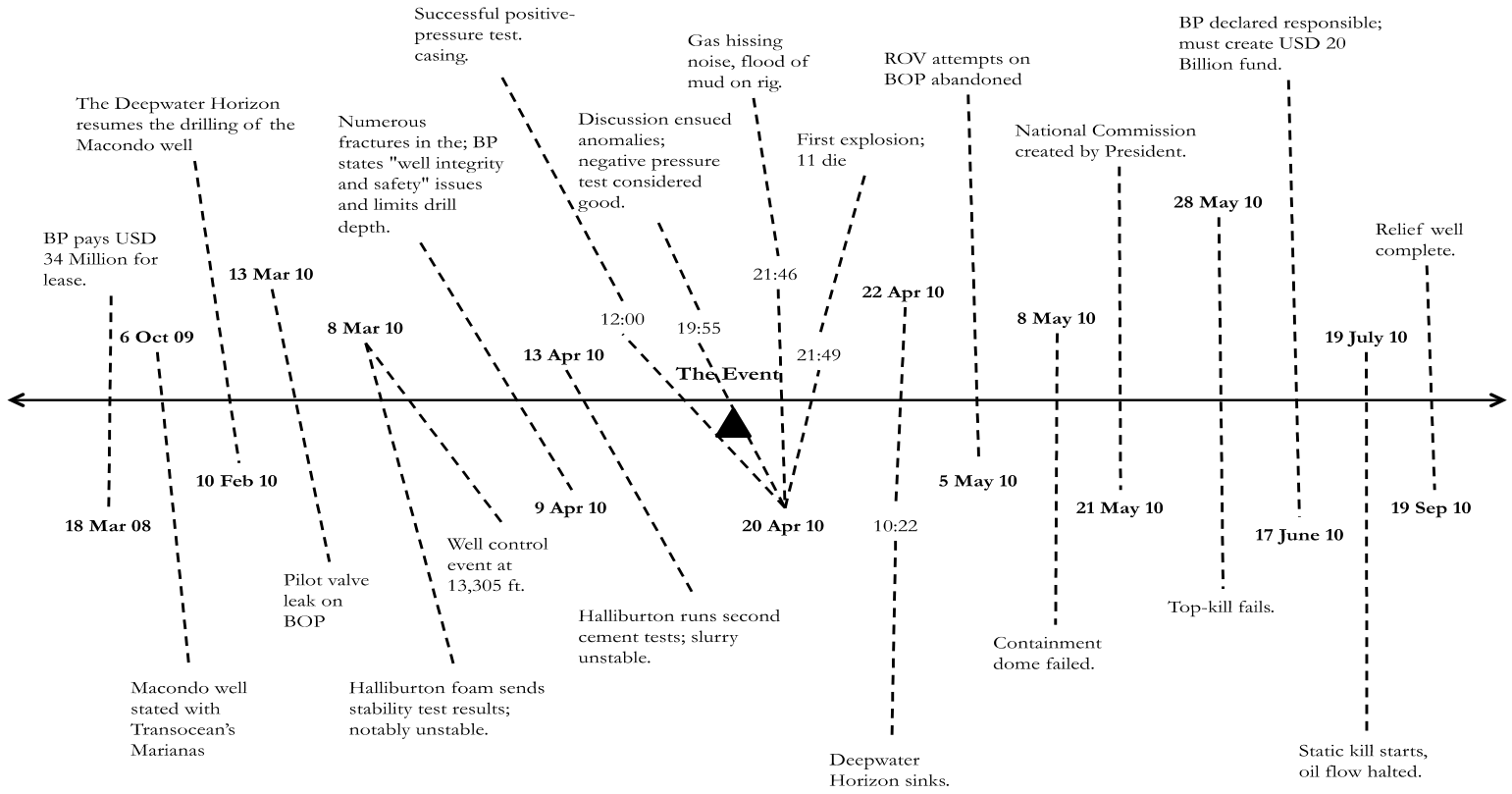
In addition to BP, Transocean and Halliburton, a number of other subcontractors to BP and individuals were "parties of interest", and participated in further investigation and eventual litigation. These companies included: Cameron (equipment manufacturer of the BOP), M I Swaco (subcontractor to Halliburton), Anadarko Petroleum, MOEX USA Corp.

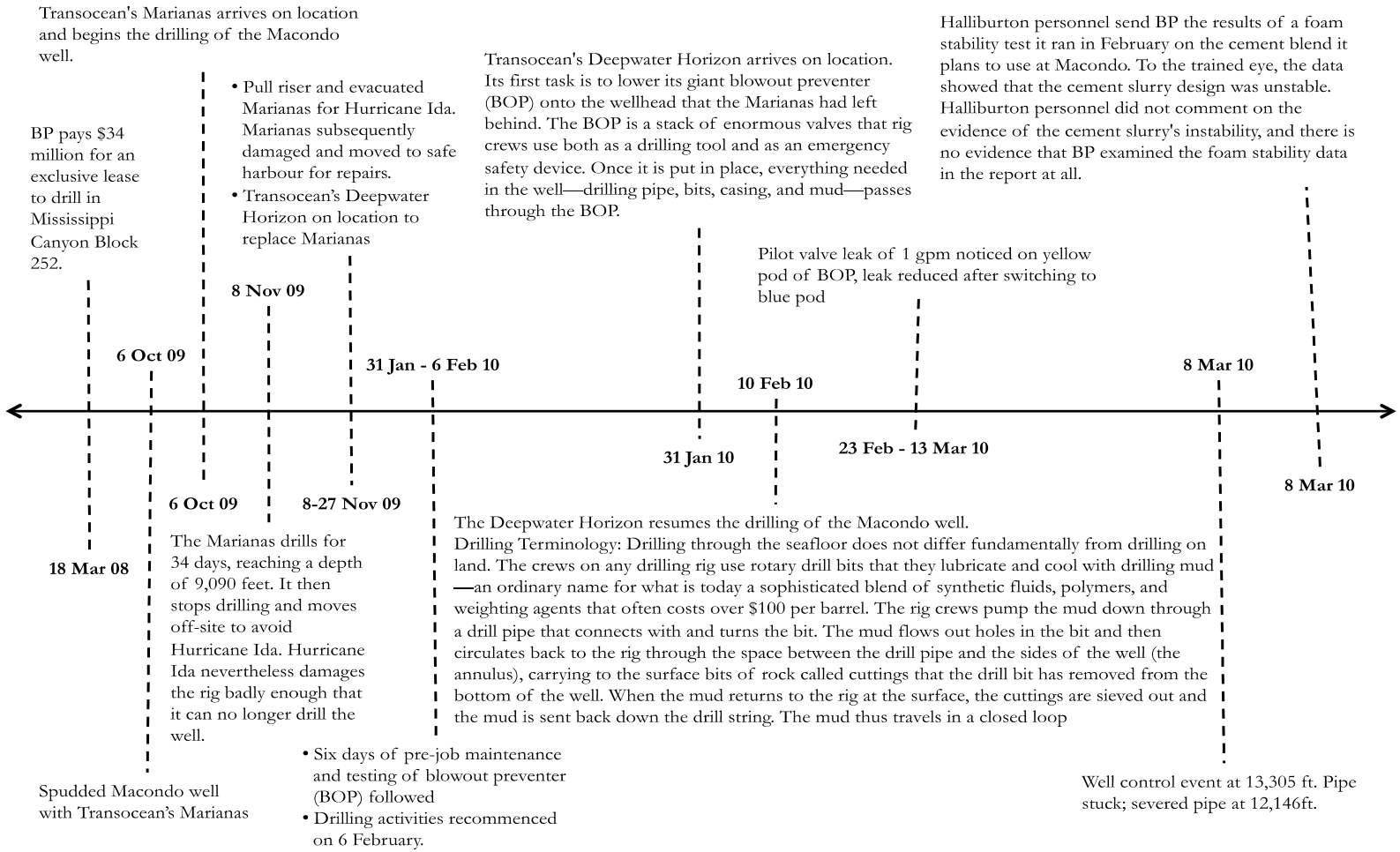
6.4 Timeline of the Disruption

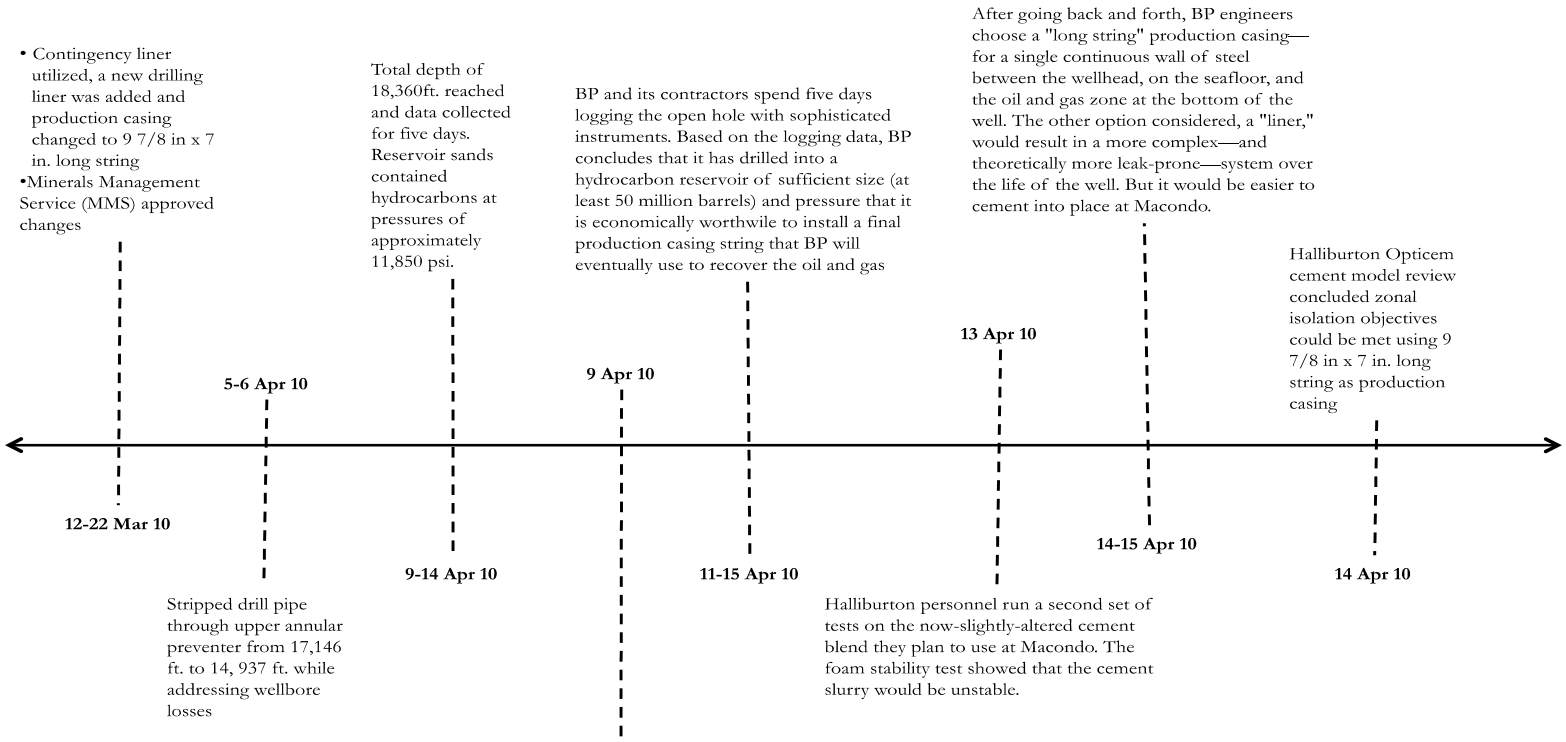
The timeline of the pandemic response is shown in

Figure 27. In this study, the date 20 April 2009 at 19:55 is defined as 'the event' for purposes of analysis because at this point in time the lost of well control became inevitable. (See also the detailed of timeline according to BP Deepwater Horizon Accident Investigation Report in Appendix 3.)

Timeline of BP Response to Deepwater Horizon Oil Spill




Transocean's Marianas arrives on location and begins the drilling of the Macondo well.
BP pays $34 million for an exclusive lease to drill in Mississippi Canyon Block 252.
• Pull riser and evacuated Marianas for Hurricane Ida. Marianas subsequently damaged and moved to safe harbour for repairs.
• Transocean's Deepwater Horizon on location to replace Marianas
Transocean's Deepwater Horizon arrives on location. Its first task is to lower its giant blowout preventer (BOP) onto the wellhead that the Marianas had left behind. The BOP is a stack of enormous valves that rig crews use both as a drilling tool and as an emergency safety device. Once it is put in place, everything needed in the well—drilling pipe, bits, casing, and mud—passes through the BOP.
Halliburton personnel send BP the results of a foam stability test it ran in February on the cement blend it plans to use at Macondo. To the trained eye, the data showed that the cement slurry design was unstable. Halliburton personnel did not comment on the evidence of the cement slurry's instability, and there is no evidence that BP examined the foam stability data in the report at all.
Pilot valve leak of 1 gpm noticed on yellow pod of BOP, leak reduced after switching to blue pod
8 Nov 09
6 Oct 09
31 Jan - 6 Feb 10
10 Feb 10
8 Mar 10
18 Mar 08
6 Oct 09
8-27 Nov 09
31 Jan 10
23 Feb - 13 Mar 10
8 Mar 10
The Marianas drills for 34 days, reaching a depth of 9,090 feet. It then stops drilling and moves off-site to avoid Hurricane Ida. Hurricane Ida nevertheless damages the rig badly enough that it can no longer drill the well.
The Deepwater Horizon resumes the drilling of the Macondo well.
Drilling Terminology: Drilling through the seafloor does not differ fundamentally from drilling on land. The crews on any drilling rig use rotary drill bits that they lubricate and cool with drilling mud —an ordinary name for what is today a sophisticated blend of synthetic fluids, polymers, and weighting agents that often costs over $100 per barrel. The rig crews pump the mud down through a drill pipe that connects with and turns the bit. The mud flows out holes in the bit and then circulates back to the rig through the space between the drill pipe and the sides of the well (the annulus), carrying to the surface bits of rock called cuttings that the drill bit has removed from the bottom of the well. When the mud returns to the rig at the surface, the cuttings are sieved out and the mud is sent back down the drill string. The mud thus travels in a closed loop
Spudded Macondo well with Transocean's Marianas
• Six days of pre-job maintenance and testing of blowout preventer (BOP) followed
• Drilling activities recommenced on 6 February.
Well control event at 13,305 ft. Pipe stuck; severed pipe at 12,146ft.



After numerous instances indicating fractures in the formation over the past few weeks, BP elects to call total depth at 18,360 feet, short of the 20,200 feet initially planned. BP informs its lease partners Anadarko and MOEX that "well integrity and safety" issues require the rig to stop drilling further. Drilling Terminology: The weight of the column of mud in a well exerts pressure that counterbalances the pressure in the hydrocarbon formation. If the mud weight is too low, fluids such as oil and gas can enter the well, causing what is known as a "kick." But if the mud weight is too high, it can fracture the surrounding rock, potentially leading to "lost returns"—leakage of the mud into the formation. The rig crew therefore monitors and adjusts the weight (density) of the drilling mud as the well is being drilled—one of many sensitive, technical tasks requiring special equipment and the interpretation of data from difficult drilling environments.

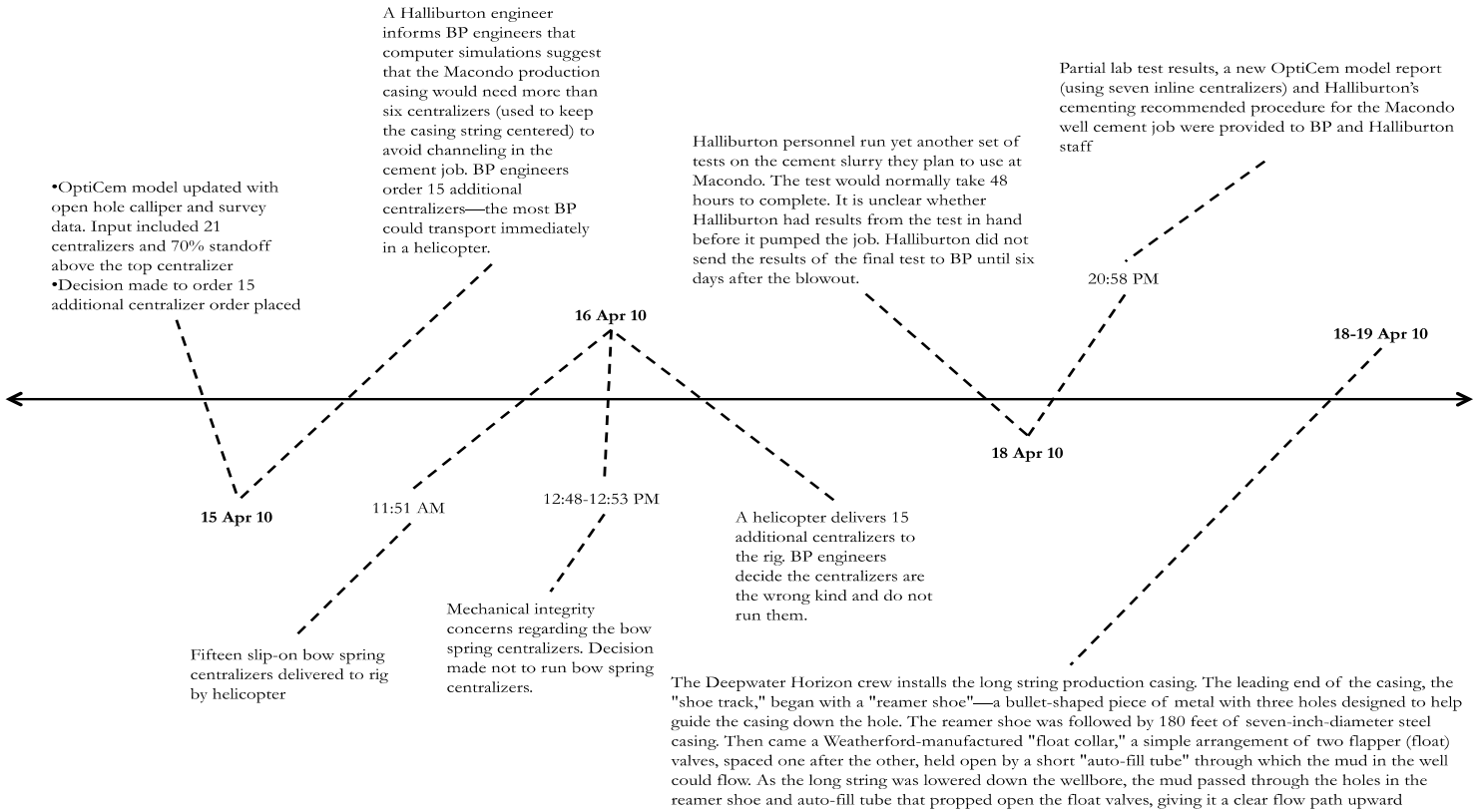


Figure 27: Timeline of BP Response to Deepwater Horizon Oil Spill

6.5 Handling of Disruption by BP

BP committed itself to sharing the lessons learned within the energy industry and the wider community. It created an internal investigation team, led by BP's head of safety and operations, immediately after the explosion inviting the expertise of more than 50 technical and other specialists.

The findings below are based publically available reports and testimony under oath from the internal investigation from BP and the various agencies:

- The Deepwater Horizon Joint Investigation, a combined effort of the US Coast Guard Marine Board of Inquiry and the US Department of Interior, Bureau of Offshore Energy Management Regulation and Enforcement.
- The National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, also known as the Presidential Commission. This commission was created by President Obama on 22 May 2010 as an independent, non-partisan entity to thorough investigate and assess the causes, responsibilities, immediate and long-term response.
- The National Academy of Engineering.
- The US Chemical Safety Board.
- The US Congress.
- The US Department of Justice.
- The US Securities and Exchange Commission.
- The US Coast Guard.

6.5.1 Assessment of Causes

From a geological perspective, each well is unique. The structure of the rock formation, depth and pressure of the layers containing hydrocarbons, compositions of those reserves and of course the drilling location make each drilling operation a unique process. Well blow-outs, in which the drilling or production platform loses control over well pressure, present a major risk and while difficult to predict, are typically preceded by early warning signs. The most obvious objective of the team is to understand the conditions, engineer accordingly and closely monitor conditions.

Once the event occurs, pressure can rise explosively as the gas and oil travel upward. Fast response is critical to 'shut-in' the well or diverts the hydrocarbons away from any ignition sources, equipment and workers. Seconds and minutes count: the tremendous volume of gas can quickly engulf a large area; the explosion that ripped through the *Deepwater Horizon* killed the drill team instantly but also destroyed equipment that was could have helped re-seal the well. Designing the safety mechanisms for surviving such a blast is a major challenge.

Once the rig was essentially abandoned and lost, the race against time began to permanently 'kill' the well. Oil was leaking at an unknown rate – five kilometers down – from multiple locations. Getting consistent information was difficult at those depths, information that the public and government demanded. The public and government lost confidence in BP's ability to handle the crisis as estimates on the rate of oil spill increased. Threat of extensive government sanctions against BP created shareholder concern as well. BP Upstream and its partners struggled to adapt known mechanisms for well-control to the harsh deepwater conditions. The only permanent, but not entirely reliable solution, would be drilling a relief well – in fact, two well, should one fail. Shorter-term engineering efforts were attempted and failed. Worst-case scenarios were reviewed in the Unified Command's various technical teams; public and academic input – solicited by BP – went to extreme measures, even use of nuclear explosion to seal the well.

As the oil spread was carried by currents, it threatened the coast areas and marine life. Oil recovery and spill control mechanisms were put in place – though little new technical advancement had been made since recovery efforts 20 years earlier. Political pressure on coastal protection triggered investment – and hence financial compensation due from BP – on measure that proved ineffective.

Legal and criminal investigation was immediately initiated; placing restrictions on the way information could be retrieved and published. BP faces on-going litigation, which could dramatically increase its exposure. The impact of the event will be felt by BP and the environment long after the oil stopped flowing into the Gulf of Mexico.

6.5.2 Overview of BP Response

Within a week of the explosion, BP embarked on what would become a massive effort to generate containment options, either by adapting shallow-water technology to the Deepwater environment, or by designing entirely new devices.

Even after the blowout during efforts to contain the spill BP continued to demonstrate overconfidence: "The government saw its pushback as essential because BP would not, on its own, consider the full range of possibilities. According to one senior government official, before the increased supervision, BP 'hoped for the best, planned for the best, expected the best.'"

> *"Though willing to fund and carry out the response, BP had no available, tested technique to stop a Deepwater blowout other than the months-long process of drilling a relief well."*
>
> *Oil Spill Commission, 2010b: Congestions al testimony*

BP's response plan revealed how ill-equipped the firm was in dealing with such a crisis. BP had named Peter Lutz as a wildlife expert on whom it would rely; he had died several years before BP submitted its plan to the MMS. BP listed seals and walruses as two species of concern in case of an oil spill in the Gulf; these species never see Gulf waters. And a link in the plan that purported to go to the Marine Spill Response Corporation website actually led to a Japanese entertainment site.

The response has required the development of extensive systems, procedures and organizational capabilities to adapt to changing and unique conditions. As the Deepwater Horizon spill continued despite efforts at the wellhead, the response effort progressed, expanded, and took on not just new tasks and directions but new personnel and resources. As a result, from source to shore, existing systems were evolved and expanded and new ones developed to advance workflow, improve coordination, focus efforts and manage risks. The adoption of these systems will ensure the ability to respond more rapidly at scale with a clear direction as to personnel, resource and organizational needs.

Early-Warning Signs

The original well at Macondo was started by the *Transocean Marianas,* but halted due to damage from Hurricane Ivan. This highlighted the challenging environments and importantly set the schedule back by many weeks, creating significant time pressure on BP management and the subcontracting support companies.

Transocean chose a 'condition based' inspection and maintenance schedule, in contrast to Inspection status of the BOP. Cameron specified that the BOP should be disassembled and inspected every 3 to 5 years; this was not implemented by Transocean or BP.

Lost drill. The well collapsed at 12000 feet, and had to be drilled again circumventing the collapsed well section. While this is not uncommon, the fragile nature of the formation was demonstrated and merits additional precaution.

Disagreement in the drill team and BP on well design, in particular on use of centralizers[30].

Several changes to well design which were very rapidly approved by clearly overburdened MME engineering in the New Orleans South office[31].

Excessive pressure (x4) to convert the flow valves. The manufacturer states that the maximum pressure was 260 psi to convert the valves (e.g. change the reversal of flow, so that cement could flow and would not be pushed back into the drill pipe). The metering indicated x4 times greater after several attempts – engineers interpreted the data 'optimistically' assuming a 'bladder effect' (reserved pressure) could cause the anomaly.

[30] OSC - Oil Spill Commission (2011a)
[31] OSC - Oil Spill Commission (2011a)

Halliburton cement formulation. In testing during April 2010, cement engineers found it very difficult to create a nitrogen gas-rich mix that would set at the pressures and time required. No information to this effect was passed to the rig. Later tests by Chevron after the accident with comparable materials showed the cement formulation was generally unstable.

Negative pressure test left inconclusive results. The drill team used the kill-line pressure to indicate the cement was sealed properly against high well pressure.

Increasing pressure in the well after negative pressure testing was concluded. The rig crew was busy with replacing some 8300 feet of drilling mud with seawater to set a high-level cement plug. The returned mud was assessed to detect hydrocarbon ('sheen test'); no oil was visible at that moment. This was a 'kick indicator'; showing that the well had been comprised and gas or oil was entering the well bore. A driller, assistant driller, or mudlogger watching the Sperry-Sun monitors screen could have seen it.

At 21.40 PM, Mud erupted on to the rig in a geyser, raining down on the drilling platform and the nearby support ship[32]. Sometime between 21.40 and 21.43 PM, mud overflowed onto the rig floor, shot up to the top of the derrick, and poured down onto the main deck[33].

Gas could be heard rushing out of the well with the mud in a high-pitched hiss for some minutes. Gas alarms were turned off in the drilling area, and only went off when gas was detected in a very wide area covering the rig, seconds before the first explosion.

Conclusions of BP and External Investigations

With recovery and analysis of the BOP, and extensive simulation and analysis, the technical sequence Macondo blow-out and oil spill is essentially complete. A sequence of management and operational decisions, along with failure of multiple technical elements prevented the crew of avoiding the disaster at multiple instances.

---

[32] OSC - Oil Spill Commission (2011c)
[33] OSC - Oil Spill Commission (2011c)

The National Commission's report to the President quoted the Board that investigated the loss of the Columbia space shuttle, "Complex systems almost always fail in complex ways."

BP's investigation emphasized the complexity of the environment: "The team did not identify any single action or inaction that caused this accident. Rather, a complex and interlinked series of mechanical failures, human judgements, engineering design, operational implementation and team interfaces came together to allow the initiation and escalation of the accident. Multiple companies, work teams and circumstances were involved over time[34]."

Nevertheless, the Commission's report found that the accident was caused by "the cumulative risk that resulted from these decisions and actions was both unreasonably large and avoidable[35]" and "could have been prevented[36]". Specifically, the commission concludes 'BP's fundamental mistake was its failure…to exercise special caution (and, accordingly, to direct its contractors to be especially vigilant) before relying on the primary cement as a barrier to hydrocarbon flow[37]."

Response to the spill was also hampered by years of underinvestment. "Investments in safety, containment, and response equipment and practices failed to keep pace with the rapid move into Deepwater drilling[38]."

---

[34] BP (2010)
[35] OSC - Oil Spill Commission (2011a)
[36] OSC - Oil Spill Commission (2011a)
[37] OSC - Oil Spill Commission (2011a)
[38] OSC - Oil Spill Commission (2011a)

Additional findings from BP investigation are:

Well Design

- BP's decision to choose a well design consisting of a long string production casing instead of a liner led to a higher risk of cement failure.
- BP installed only six centralizers on the production casing instead of the recommended 21 centralizers. Furthermore, BP neglected to inform Halliburton of the number of centralizers installed.
- BP replaced 3,300 feet of heavy drilling mud with lighter seawater and this put unnecessary stress on the cement job.

Risk assessment

- BP made multiple changes to the temporary abandonment procedures in the weeks prior to the blow out but the changes did not go through any sort of formal risk assessment or review process.

Monitoring

- When the BP and Transocean staff on the rig noted an anomalous pressure reading while attempting to convert float valves they concluded that the pressure gauge they had been relying on was broken. "BP's team appears not to have seriously examined why it had to apply over four times the 750 psi design pressure to convert the float valves."
- In the minutes prior to the blowout the Transocean crew failed to notice an increase in pressure in the well—they failed to recognize that a natural gas kick was occurring until it was too late and the blowout was uncontrollable.
- The Commission cites a lack of automated alarms in the displays used to monitor well pressures as a contributing factor.

Training

Failure of the Deepwater Horizon's Blow-out Preventer, possibly due to poor maintenance, was a major contributing factor in the blowout.

Training of key engineering and rig personnel was inadequate.

Communication

There was a lack of communication within BP - for instance between offshore and onshore staff and poor communication between BP and its contractors. Information was compartmentalized and not fully shared.

6.5.3 Coding and Categorisation of Data from BP Deepwater Horizon

Warning – Develop advance warning system

Examples:

- Manage distractions during well pressure monitoring (which inhibited early detection).
- Implement gas detection systems for early warning (drill floor level alarm was turned off).
- Provide shift change information from night to day shift (missing on the morning of event)
- Assure usability (Driller's display screen was difficult to interpret; pressure anomaly went unnoticed).
- Provide on-shore real time monitoring facility.

Codes: monitoring, training, roles, preparation, warning, real-time and remote

The *Deepwater Horizon* had a number of alarm systems installed, including one to alert the crew to presence of potentially explosive gas. The alarms on the rig floor had both visual and sound indicators. However, according to Mike Williams, some were turned off (inhibited, in his words) "the explanation I got was that they did not want people woke up at 3:00 o'clock in the morning due to false alarms" referring to instruction from the Offshore Installation Manager. Had the alarm system been active in key areas, the Emergency Disconnect Sequence would have shutdown the equipment at risk, and alerted the crew to presence of gas in dangerous areas.

Andrea Fleytas was the Transocean DPO on duty in charge of the alarm panel at the time of the blowout. After feeling a first jolt and noticing multiple combustible gas alarms sounding throughout the rig, she did not immediately hit the general alarm. At the time, she received a call from the engine control room asking what was going on but did not instruct them to shut down the engines despite the multiple combustible gas alarms sounding throughout the rest of the rig. Fleytas said in her testimony, when asked why she hesitated "It was a lot to take in. There

was a lot going on." Fleytas said that Transocean provided no formal training or simulations on how to respond to combustible gas alarms.

Decision	Was There A Less Risky Alternative Available?	Less Time Than Alternative?	Decision Maker
Not waiting for more centralisers of preferred design	Yes	Saved Time	BP on shore
Not waiting for foam stability test results and/or redesigning slurry	Yes	Saved Time	
Not running cement evaluation log	Yes	Saved Time	BP on shore
Using spacer made from combined lost circulation materials to avoid disposal issues	Yes	Saved Time	BP on shore
Displacing mud from riser before setting surface cement plug	Yes	Unclear	BP on shore
Setting surface cement plug 3,000 feet below mud line in seawater	Yes	Unclear	BP on shore (Approved by MMS)
Not installing additional physical barriers during temporary abandonment procedure	Yes	Saved Time	BP on shore
Not performing further well integrity diagnostics in light of troubling and unexplained negative pressure test results	Yes	Saved Time	BP (and perhaps Transocean) on Rig
By passing pits and conducting other simultaneous operators during displacement	Yes	Saved Time	Transocean (and perhaps BP) on Rig

Table 29: Examples of Decisions that Increased Risk at Macondo while Potentially Saving Time

Source: OSC-Oil Spill Comission (2010c)

Stress testing – Conduct stress test

Examples

- Testing prior to deployment of equipment (e.g. BOP was not tested).
- Testing for stability (Positive and negative pressure tests of well integrity).
- Verification of inputs (Incorrectly interpreted cement testing during formulation by Halliburton)

Codes: testing, modelling and verification

BP contracted a number of tests to be performed by Halliburton, the contractor responsible for cement formulation and pumping, and the Transocean crew that would run a set of positive and negative pressure test.

To prevent oil and gas from escaping an exploration or abandoned well, and assure stability of product wells, cement is used to reinforce the well. Specially formulated

cement slurry is used according to the characteristics of the well such as pressure, temperature, depth and surrounding fluids.

Cement slurry requires testing on shore prior to use. Because the pressure and temperature at the bottom of a well can significantly alter the strength and curing rate of a given cement mix - and because storing cement on a rig can alter its chemical composition over time - companies like Halliburton normally fly cement samples from the rig back to a laboratory shortly before pumping a job to make sure the cement will work under the conditions in the well. The laboratory conducts a number of tests to evaluate the slurry's viscosity and flow characteristics, the rate at which it will cure, and its eventual compressive strength.

On February 10, soon after the Deepwater Horizon began work on the well, Halliburton laboratory personnel ran a series of pilot tests on the cement blend stored on the Deepwater Horizon that Halliburton planned to use at Macondo. Halliburton sent the laboratory report to BP on March 8 as an attachment to an e-mail in which he discussed his recommended plan for cementing an earlier Macondo casing string.

According to the Commission, experienced cement engineers would immediately see that the February foam slurry design was unstable. Halliburton did not comment on the evidence of the cement slurry's instability, and there is no evidence that BP examined the foam stability data in the report at all. It appears that Halliburton never reported the results of the earlier February test to BP.

Halliburton conducted another round of tests in mid-April, just before pumping the final cement job. By then, the BP team had given Halliburton more accurate information about the temperatures and pressures at the bottom of the Macondo well, and Halliburton had progressed further with its cementing plan. Using this information, the laboratory personnel conducted several tests, including a foam stability test, starting on approximately April 13. The first test Halliburton conducted showed once again that the cement slurry would be unstable. The Commission does not believe that Halliburton ever reported this information to BP. Instead, it appears that Halliburton personnel subsequently ran a second foam stability test, this time doubling the pre-test conditioning time to three hours.

Negative Pressure test

"The negative-pressure test was accepted although well integrity had not been established. The Transocean rig crew and BP well site leaders reached the incorrect view that the test was successful and that well integrity had been established. " .

Not all agreed, including Whelan Weeler, an experienced drilling engineer badly in injured in the blow-out. "Wheeler was "convinced that something wasn't right," recalled Christopher Pleasant, a subsea supervisor. Wheeler couldn't believe the explanations he was hearing. But his shift was up.

Failure to run final tests

During the rig's daily 19.30 operations conference call to BP in Houston, engineer Morel discussed the good news that the final cement job at the bottom of the Macondo well was successful. To ensure the job did not have any problems, a three-man Schumberger team was scheduled to fly out to the rig later that day, able to perform a suite of tests to examine the well's new bottom cement seal. According to the BP team's plan, if the cementing went smoothly, as it had, they could skip Schlumberger's cement evaluation, saving time and the USD 128,000 fee.

Blow Out Preventer (BOP)

Through a review of rig audit findings and maintenance records, the investigation team found indications of potential weaknesses in the testing regime and maintenance management system for the BOP. In fact, the Commission identified many areas where BP saved time or money by avoiding test procedures.

Training – Implement training

Examples

- Educate staff on failure modes (Blow out prevention school for key engineers).
- Provide online information resources (Online electronic bulletins and document databases).

Codes: training, learning, communication and teamroom

Influx of high-pressure oil and gas was not recognized until hydrocarbons were in the riser, connecting the well with the rig. With the negative-pressure test having

been accepted, the well was returned to an overbalanced condition, preventing further influx into the wellbore. Later, as part of normal operations to temporarily abandon the well, heavy drilling mud was again replaced with seawater, under balancing the well. Over time, this allowed hydrocarbons to flow up through the production casing and passed the BOP. Indications of influx with an increase in drill pipe pressure are discernable in real-time data from approximately 40 minutes before the rig crew took action to control the well. The rig crew's first apparent well control actions occurred after hydrocarbons were rapidly flowing to the surface. The rig crew did not recognize the influx and did not act to control the well until hydrocarbons had passed through the BOP and into the riser.

Well control response actions failed to regain control of the well. The first well control actions were to close the BOP and diverter, routing the fluids exiting the riser to the Deepwater Horizon mud gas separator (MGS) system rather than to the overboard diverter line. If fluids had been diverted overboard, rather than to the MGS, there may have been more time to respond, and the consequences of the accident may have been reduced. The float collar used in the cementing process did not initially operate as intended and required 9 attempts with higher than usual pressures to function properly. Moreover, the float test performed after cementing may not have been definitive, leading to concern that there may have been contamination of the cement due to density differences between the cement and the drilling mud.

Teamwork – Create integrated response team

Examples

- Establish integrated response team (BP and related parties setup a response team known as the 'Unified Command").
- Establish investigation team (BP set up an internal investigation team).

Codes: investigation, cross-functional, learning, war-room and communication

BP created an integrated response team called 'Unified Command'. This command structure was established to manage the response to the disaster. It subsumed the spill's "responsible party" (in this case, BP) with federal and state officials in a single organization. The Coast Guard established its Unified Area Command -

headquarters for the regional spill response—on April 23 in Robert, Louisiana, later moving it to New Orleans.

Learning – Learning from previous events

Examples

- Investigate root cause.
- Establish forums to accumulate and manage learning.

Codes: investigation, learning, root cause, external, industry, expert, litigation and criminal

A number of formal bodies were established or involved in capturing the lessons learned from the event, with documentation in the public domain including:

- National Commission on BP Deepwater Horizon Oil Spill Offshore Drilling.
- Chief Counsel's Report.
- Coast Guard ISPR and BOEMRE Joint Investigation
- DNV BPO Report on key equipment
- Department of Justice Investigation on potential criminal liability.

These investigations provided input to investigation of potential criminal liability. Upon reading the BP internal report, Richard Sears, the Commission's Chief Scientific and Engineering Advisor, commented "it appeared that for BP the accident happened at 9:49 p.m., on April 20; whereas in some ways, the blowout began in early 2009 when they initially designed the well."

As the largest of the off-shore exploration and drilling companies, both BP and Transocean had access to a wealth of experience – successes and challenges – from which to learn. Nevertheless, previous events had occurred and while investigation was performed, the lessons were not necessarily made sufficiently visible to otherwise trained personnel on the *Deepwater Horizon.*

For example, a set of incidents occurred at the Grangemouth Complex, Scotland, one of Europe's largest refineries that process a significant percentage of North Sea oil. Three separate incidents – Power failure on 29th May, a steam rupture on the 7th of June, and fire in a Catalytic Cracker Unit on 10th June 2000 did not cause loss of life, but highlighted important lessons and resulted in BP being fined some GBP 1M. The report highlights that "BP Group and Complex Management did not

detect and intervene early enough on deteriorating performance" as stated in the Grangemouth executive report.

More broadly, it stated "Major accident hazards should be actively managed to allow control and reduction of risks. Control of major accident hazards requires a specific focus on process safety management over and above conventional safety management."

Also in the North Sea, the BP Forties Alpha production platform was flooded with methane when a gas line ruptured. Unlike the calm conditions that contributed to gas formation on the Horizon, wind moved gas from the Forties Alpha and no ignition source was present. BP admitted breaking the law by allowing pipes to corrode on the Forties Alpha and paid a USD 290,000 fine."

Other platforms were not as lucky. Occidental Petroleum's Piper Alpha exploded and sank, with 167 fatalities. Common contributing factors included inadequate safety assurance, worker training, and evacuation procedures. Poor communication and confusion about lines of authority amplified the death toll in at least two of the accidents.

The Commission also cited Transocean's failure to communicate lessons from an earlier near-blowout in the North Sea some months earlier. The crew of the Deepwater Horizon was not aware of this event nor the safety lessons gained from it. On December 23, 2009, gas entered the riser while the North Sea rig was displacing a well with seawater during a completion operation. Following similar procedures to the *Deepwater Horizon* team, the crew had already run a negative pressure test on the lone static barrier between the pay zone and the rig and deemed it successful. The tested barrier failed during displacement. Hydrocarbons flowed into the well, and mud spewed from the rig floor. Unlike at Macondo, the crew was able to shut in the well before a blowout occurred but not until nearly one metric ton of oil-based mud had spilled into the ocean. The incident cost Transocean 11 days of additional work and more than GBP 5 Million.

The Macondo Prospect was referred to as the "well from hell", as stated by Natalie Roshto in congressional testimony, due to similarities to a unsuccessful, ultimately abandoned well known as Devil's Tower that share many characteristics. Ms.

Roshto was quoting her husband Shane Roshto, an experienced toolpusher who died during the explosion. Shane Roshto told her "Mother nature just doesn't want to be drilled here[39]" some weeks before the accident occurred. The BP drilling engineer responsible for the well design echoed that sentiment, sending an email on 14 April "this has been nightmare well which has everyone all over the place.[40]"

External communication – Establish frequent communications with partners

Examples

- Improve communication with key suppliers (e.g. Halliburton communication of cement test results was incomplete).
- Increase frequency of press and public communications-daily press briefings.
- Use Real-time video camera feed ('spillcam)'.
- Participate in formal testimony (Congressional hearings after the event.)
- Create new one-to-many networking systems (Radio relay network for thousands of ships and team to coordinate response)
- Invite external experts (academic, industry) to assist in design.

Codes: communication, partner, frequency, testing, verification, public, press, frequency, real-time, video, investigation, coordination, expert and industry

Halliburton, the cementing contractor, advised BP to install numerous devices to make sure the pipe was cantered in the well before pumping cement, according to Halliburton documents, provided to congressional investigators and seen by the Journal. Otherwise, the cement might develop small channels that gas could squeeze through.

Relationship with Competitors – Established relationship with competitors

Examples

- Outsource tasks before or after event (Chevron for cement testing).
- Add capacity from competitors (Shell help BP adding capacity by provides ships for clean up).

---

[39] Oil Spill News (2010)
[40] Keim (2010)

- Create industry group to increase capacity, reserve and experience (Marine Well Company formed after event to facilitate recovery and reduce cost of reserve).

Codes: competitor, capacity, industry and reserve

The Vessels of Opportunity program was a way for BP to provide some income to local residents outside of a formal claims process. Through the program, BP employed private vessels to conduct response efforts such as skimming, booming, and transporting supplies. Vessels of opportunity made between USD 1,200 and USD 3,000 per day, depending on the size of the boat. Individual crewmembers made USD 200 for an eight-hour day.

In response, the State of Louisiana began its own program, as did several local governments. The Unified Command struggled to coordinate this floating militia of independent vessels and to give them useful response tasks. Having hundreds of vessels look for oil did not contribute significantly to the response, because aircraft were more effective at spotting oil. Placing boom requires skill and training, and responders differed in their judgements of how much the vessels contributed.

Marine Well Containment Co. is a new organisation; it was formed after the Deepwater Horizon even in 2010 by some of the largest firms operating in the Gulf of Mexico including ExxonMobil, Chevron, ConocoPhillips, Shell and eventually BP. The not-for-profit organization is tasked with bringing together expertise and systems for addressing a range of blowout and spill scenarios. The initial investment to construct new subsea and modular process equipment is expected to be approximately USD 1 Billion, in a large part based on the techniques developed during the Macondo disaster.

Employee capacity - Assure management and employee capacity

Examples

- Protect staff (Rig was quickly abandoned to avoid further casualty)
- Leverage staff for immediate response (Rig personnel who survived the blast were pressed into fire-fighting duty).
- Assure safety of all employees (Search for survivors for about 27 hours).

Codes: capacity, employee, reserve

Production capacity – Increase capacity by improving recovery capacity

Examples

- Add recovery capacity (Extend recovery and oil burning with additional support ships and rigs).
- Source new type of capacity (Hire and re-purpose fishing vessels unable to operate, solving capacity and political pressures through commercial partnership with those affected by the spill).
- Replicate core production capacity (Employ Transocean rigs for drilling relief wells)
- Source capacity widely (Leasing of clean-up from across the industry world-wide, e.g. *Q4000* ship).

Codes: capacity, sourcing, flexibility

Product design – Develop new products by implement most robust solution

Examples

- Implement solution with highest assurance to succeed (Initiate Relief well drilling as soon as feasible).

Codes: speed, risk

Increase flexibility – Improve operational scope of scare equipment

Examples

- Redesign equipment for faster deployment across different use-cases (more flexible rig and seafloor equipment to reduce points of failure and costly re-tooling).

Codes: design, flexibility, speed

6.5.4 Response Time at BP Deepwater Horizon

D1 - Detection of the Event

According to an extensive set of interviews by BP internal investigation, the national commission and in congressional hearing after the event and the monitoring data accumulated offshore, there were numerous signs prior to the well-blow out when BP and its partners could have anticipated the event and initiated mitigation action.

While earlier detection may not have enabled the team to avoid loss of well control – maintenance and testing of equipment did not assure all preventative systems were working – faster reaction could have enabled more appropriate steps.

D2 – Design of a Solution

BP was in the process of reorganizing its management structure at the time of the blowout to clarify reporting relationships for engineers. The reorganization complicated the task of identifying the precise lines of authority and areas of responsibility, both at the time of and in the months leading up to the blowout. In addition, because of the reorganization, many of the managers overseeing the Macondo team had only a few months of experience in their respective positions at the time of the blowout.

Internal Organisation

At the beginning of April, BP conducted a major reorganization of its exploration business unit, including the BP Macondo team, creating separate reporting structures for engineering and operations. The reorganization also led to questions about authority and accountability.

In March, for example, operations to control the well after a kick led to disagreements between BP's managers on the Macondo team. BP engineering team leader David Sims wrote BP well team leader John Guide: "We cannot fight about every decision.... I will hand this well over to you in the morning and then you will be able to do whatever you want."

Internal and External Expertise

BP did not always use its internal technical experts effectively. "Yeah, well no one told us what the actual decision was, so we thought y'all were going with the liner...." BP is now developing standards on how to consult internal experts and hiring more cementing experts.

Every stage of the exploration and production cycle in hydrocarbon energy industry involves a significant number of parties, who in turn will often source individual engineers and workers on a contracting basis.

In addition to sharing real time information to the BP Houston centre, a number of other mechanisms were used to communicate between teams including email.

D3 – Deployment of the Solution

According to the Rand Corporation, "Remedies must be designed and tested to work under the actual operating conditions. This is the biggest lesson from the Deepwater Horizon spill. All of the remedies fielded during the first 40 days of the spill were not effective because they had not been tested or proven to work in deepwater drilling conditions."

In managing the oil spill, following the failure of the top kill, BP engineers turned away from attempting to shut the well in, for fear that instability in the well could lead to an "underground blowout," with oil and gas flowing into the ocean from many points on the sea floor. This would make containment nearly impossible, at least until the completion of a relief well. Thus, in the aftermath of the top kill, BP and the government focused on trying to collect the oil, with the relief wells still providing the most likely avenue for killing the well altogether.

It became increasingly clear in the weeks after the explosion that neither BP, its industry partners nor the government had the experience and resources to quickly deal with an oil spill on the scale of the Macondo disaster.

The Commission identified three gaps in the government's existing response capacity: (1) the failure to plan effectively for a large-scale, difficult-to-contain spill in the deepwater environment or potentially in the Arctic; (2) the difficulty of coordinating with state and local government officials to deliver an effective

response; and (3) a lack of information and understanding concerning the efficacy of specific response measures, such as dispersants and berms.

BP had a team ready to proceed with new collection tools almost immediately. On May 29, the company and the government announced that BP would attempt to cut off the portion of the riser still attached to the top of the BOP and install a collection device - the "top hat" - which would then be connected via a new riser to the *Discoverer Enterprise* above. By June 8, the *Discoverer Enterprise* was collecting nearly 15,000 barrels of oil per day.

BP also developed a system to bring oil and gas to the surface through the choke line on the BOP. BP outfitted the *Q4000*, a vessel involved in the top-kill effort, with collection equipment, including oil and gas burner imported from France. After it became operational on June 16, the *Q4000* system was able to process and burn up to 10,000 barrels of oil per day.

On occasion, BP was overly optimistic about the percentage of the oil it could remove or collect, with officials saying that the approach would allow for the collection of the "vast majority" of oil. But when the *Q4000* came online in mid-June, the two vessels' joint capacity of 25,000 barrels per day was still insufficient. Not all mechanisms proved effective, and some were used primarily for political reasons.

Financial and Legal Impact

The oil spill may prove to be one of the costliest industrial accidents ever.

A USD 20 Billion fund known as the Gulf Coast Claims Facility, was created by BP under the direction of the US Federal Government to cover costs related to environmental damage, personal injury, clean-up and lost earnings by affected Gulf Coast businesses. By the end of 2010, the fund had paid out USD 2.7 Billion to address nearly 168,000 claims.

In the weeks following the blow-out, BP's share price dropped from USD 60.57 to a low of USD 27.02 on 25 June 2010, wiping 100 Billon from its market capitalisation (NYSE). The share price recovered to USD 47.41 (10 March 2011),

with downstream prices reaching historic highs as political turbulence disrupted activities in oil-producing countries in the Middle East.

BP faces, in the view of some experts, 20 years of litigation. The US Federal government is suing for USD 21 Billion in fines, and has consolidated all criminal investigations under the Deepwater Horizon Task Force. Citigroup estimated at that time that an additional USD 6 Billion in lawsuits could be filed.

In 2011, BP plc. announced it would be selling substantial refinery capacity (Texas City, Carson City), for an anticipated USD 5 Billion, to help offset expected pay-out from the disaster. Table 30 shows a summary of finding from BP Deepwater Horizon in related to the 3-D framework.

Tailored approaches	Examples from BP Response to Deepwater Horizon Oil Spill	D1	D2	D3
Develop advanced warning system	• Well pressure monitoring: distractions while working prevented early detection. • Gas detection systems for early warning (example: drill floor level was alarm was turned off) • Lack of shift change information from night to day shift. • Driller's display screen (Sperry-Sun) difficult to interpret, e.g. (pressure anomaly unnoticed) • No on-shore real-time monitoring facility.	◆ ◆ ◆ ◆ ◆		
Conduct stress testing	• Engineering tests prior to deployment of equipment (example: BOP was not tested). • Positive-pressure tests of well integrity. • Negative-pressure test of well integrity. • Cement testing during formulation by Halliburton.	◆ ◆ ◆ ◆	 ◆	
Develop scenario plan and modelling capability	• Model of gas flow and explosion on the rig. • Cement model software at Halliburton • Independent testing of cement formulation by Chevron and CSI. • OLGA software well-flow modelling. • Simultaneous Operations using storyboarding to coordinate operations after the event. • Oil spill modelling after the event. • Forensic study of BOP after it was retrieved from the sea floor (flow modelling, finite element modelling).	◆	◆ ◆ ◆ ◆ ◆	◆ ◆ ◆
Leverage preparedness plan	• Blow-out procedures during well completion. • Rig abandonment procedures.		◆ ◆	◆
Implement training	• Blow out prevention school for key engineers • Online electronic bulletins and document databases.	◆		◆
Establish frequent communications with supply chain partners	• Improve communication with key suppliers: e.g. Halliburton communication of cement test results was incomplete. • Increased frequency of press and public communications-daily press briefings. • Real-time video camera feed ('spillcam)'. • Congressional hearings after the event. • Radio relay network for thousands of ships and team to coordinate response. • Invite external experts (academic, industry) to assist in design.		◆ ◆	◆ ◆ ◆ ◆ ◆

Tailored approaches	Examples from BP Response to Deepwater Horizon Oil Spill	D1	D2	D3
Establish relationship with competitors	• Outsourcing key tasks (Halliburton, Chevron, etc.) before and after event. • Shell help BP adding capacity by provides ships for clean up. • Marine Well Company formed after event to facilitate recovery and reduce cost of reserve.			◆ ◆ ◆
Create integrated response team	• BP internal investigation team. • Established integrated response team called "Unified Command".		◆	◆ ◆
Establish learning from past events and during the events	• BP investigation team on root-cause and possible mitigation. • National Commission on BP Deepwater Horizon Oil Spill Offshore Drilling • Chief Counsel's Report • Coast Guard ISPR and BOEMRE Joint Investigation • DNV BPO Report on key equipment. • Department of Justice Investigation on potential criminal liability.		◆	◆ ◆ ◆ ◆ ◆
Assure management and employee capacity	• Rig was abandoned relatively quickly to avoid further casualty. • Leverage rig personnel in immediate fire-fighting operations. • Extensively staffed 27 hours search for survivors.			◆ ◆ ◆
Increase capacity	• Oil recovery and burning facilities put in place to reduce impact of spill. • Hire wide group of existing fishing vessels to assist in recovery ('Vessels of Opportunity')			◆ ◆
Develop product or solution extensions	• Initiate Relief Well drilling immediately. • Develop new design solutions in place (Top Hat, Oil Boom, Artificial Barrier, Top Kill, Skimmers, Junk Shot, BOP activation)		◆	◆ ◆
Acquire additional suppliers	• Relief well drilling using capacity from Transocean. • Leasing of clean-up equipment from across the industry.			◆ ◆
Increase flexibility	• Design of rigs for multiple operations (exploration, drilling, production on both gas and oil)		◆	◆
Increase inventory	• Deploy remotely operated vehicle (ROV) with more flexible tooling			◆

Table 30: A Summary of Finding from BP Deepwater Horizon

Chapter 7
Validation with Disruption at BP Texas City

7.1 Company Overview

BP Products North America Inc. is part of BP plc with headquarters in London, England. In 2005, it was the third largest energy company and fourth largest company by revenue of any kind. The Texas City refinery, where the explosion occurred, was BP's largest oil refinery with thirty process units spread over 1,200 acres and 1,600 permanent employees. There were approximately 800 additional contractor staffs are on site for significant turnaround work at the time of the incident. Prior to 1999, Amoco owned the refinery. BP merged with Amoco in 1999 for GBP 67 Billion and BP subsequently took over operation of the plant. It was the largest corporate acquisition ever[41].

The plant processes over 430,000 barrels of crude oil a day and produce about 11 million gallons of gasoline a day. The refinery also produces jet fuels, diesel fuels and chemical feedstocks. It is one of five BP refineries in North America, produces 30 percent of BP's North American gas supply and 3 percent of the U.S. supply (2005)[42]. About 31,000 people live within a three-mile radius of the refinery, according to Census data.

The refinery ranks as the eighth largest polluter in the state of Texas (disregarding March 23, 2005 explosion). It released 5.1 million pounds of pollutants in 2002, according to the latest data, including some chemicals that are known carcinogens and cause other serious health effects.

Texas City is also the site of the worst industrial accident in U.S. history. In 1947, a fire aboard a ship at the Texas City docks triggered a massive explosion that killed 576 people and left fires burning in the city for days.

---

[41] CBS (2007)
[42] OSHA (2005)

7.2 Background of BP Texas City Refinery Explosion

At 13.20 PM on March 23, 2005, a series of explosions occurred at the BP Texas City refinery during the restarting of a hydrocarbon isomerization unit. Fifteen BP employees and contractors were killed and 180 others were injured. Many of the victims were in or around work trailers located near an atmospheric vent stack, in violation of safety regulations. The explosions occurred when a distillation tower flooded with hydrocarbons and was over pressurized, causing a geyser-like release from the vent stack. The event triggered an extensive review of management and operational practices in BP and the refining industry.

7.3 Companies and Parties Involved

After the shock of the explosion, the site was secured and four agencies team were established to immediately determine the causes of the explosion on 24 March 2005. An overview of the investigations is presented below.

United States Chemical Safety and Hazard Investigation Board (CSB)

The U.S. Chemical Safety and Hazard Investigation Board, also known as the Chemical Safety Board or CSB, is a U.S. federal agency charged with investigating industrial chemical accidents. Headquartered in Washington, DC, the agency's board members are appointed by the President and confirmed by the Senate. The CSB conducts root cause investigations of chemical accidents at fixed industrial facilities, looking into all possible causes of chemical accidents, ranging from equipment failure to safety management.

<u>The scope of the investigation</u>

The board conducted the broadest investigation of the plant explosion, initially estimated to take at least a year. It was not restricted just to determining BP compliance with state or federal regulations. It interviewed witnesses and employees independently of other federal agencies. "We look at the whole issue of management systems, root causes, and we come up with recommendations," said chemical safety board member John Bresland. The board held one public meeting halfway through the investigation, and another at the conclusion. The Board does not assess fines, but can recommend them to other federal agencies.

Conduct of the investigation

Investigators from the CSB arrived at the facility on the morning of March 24, 2005. During the investigation, the CSB reviewed over 30,000 documents; conducted 370 interviews; tested instruments; and assessed damage to equipment and structures in the refinery and surrounding community. Electronic data from the computerized control system and process information from five years of previous startups were also examined. The CSB investigation team was supplemented by experts in blast damage assessment, vapour cloud modelling, pressure relief system design, distillation process dynamics, instrument control and reliability, and human factors.

The results of the agency's investigation

Two years after the tragedy in BP's Texas plant, on March 20th, 2007, the CSB published its Final Investigation Report consisting of incident overview, analysis of safety system deficiencies in unit startups, incident investigation system deficiencies, other safety system problems and also analysis of BP's safety culture, description of root and contributing causes of BP's safety problems and recommendations for future improvement..

Environmental Protection Agency (EPA)

The Environmental Protection Agency (EPA) is an agency of the federal government of the United States charged with protecting human health and with safeguarding the natural environment: air, water, and land. The EPA began operation on December 2, 1970, established by President Richard Nixon.

The scope of the investigation

The EPA was charged with determining whether the explosion or fire released hazardous material into the environment. The agency began air monitoring at the plant and up to four miles away in surrounding communities, and one-half mile downwind of the site. No dangerous chemicals were detected..

United States Occupational Safety and Health Administration (OSHA)

The United States Occupational Safety and Health Administration is the agency of the United States Department of Labor.

The OSHA mission is to assure the safety and health of America's workers by setting and enforcing workplace standards. Most American workers come under OSHA jurisdiction. Investigators first secure the scene of a chemical plant accident, interview employees and management and then look at the operation of the plant and maintenance of equipment prior to the accident. By law, the team has up to six months to complete its investigation.

The results of the agency's investigation

On September 22nd 2005 OSHA and BP reached the agreement following OSHA's investigation of the accident. Under terms of the settlement, BP Marketing agreed to:

- Pay USD 21,361,500 in penalties and abate all hazards for which it was cited.
- Complete a review of the ISOM unit to determine how it can be operated safely and alert OSHA if and when a decision is made to start up the unit in the future; retain a firm with expertise in process safety management (PSM), including pressure relief systems, safety instrumented systems, human factor analysis and performing process safety audits, to conduct a refinery-wide comprehensive audit and analysis of the company's PSM systems.
- Hire an expert to assess and report on communication within and between management, supervisors, and authorized employee representatives and non-management employees and the impact of the communication on implementation of safety practices and procedures.
- Submit to OSHA and BP Products' authorized employee representative, every six months for three years, logs of occupational injuries and illnesses ("OSHA 300 Logs") and all incident reports related to PSM issues.

Notify the OSHA area office of any incident or injury at the Texas City facility that results in an employee losing one or more workdays during the same three-year period.

Texas Commission on Environmental Quality (TCEQ)

Texas Commission on Environmental Quality or TCEQ is the state's environmental control agency, operates the most extensive pollution-monitoring network in the country. It works with the federal EPA to measure whether harmful agents were released by the accident. A spokesman for the state agency said that their monitoring has not detected any dangerous emissions. Runoff from the water and foam used to fight the fire was contained within the facility and did not enter the storm drains, said spokesman Terry Clauson. The agency also inspected for compliance with permits at the time of the explosion.

The results of the agency's investigation

The 2005 annual average benzene concentrations reported near the Texas City Ball Park site (1.06 ppbv), and BP-sponsored site (2.70 ppbv) are above the long-term, health-based ESL of 1 ppbv. The comparison of the 2005 and 2004 annual average concentrations indicated an increase at both sites, with an approximate 35% increase at the BP-sponsored site. An evaluation of source identification near the BP-sponsored site was performed using the hourly autoGC data from the BP-sponsored site (see attachment 4.) indicates that higher benzene concentrations were associated with winds blowing from the south. The 2005 annual averages reported near both the BP-sponsored site and the Texas City Ball Park site were attributed to frequent episodes of elevated benzene concentrations stemming from an onsite explosion on March 21st, 2005 and a power outage due to Hurricane Rita on October 3, 2005.

BP Internal Investigation

A BP group executive was assigned to lead the initial investigation and another three individual from outside of the Refining business were formed to the team. They took over the evidences gathering on March 26, 2005.

The preliminary investigation was performed over five weeks at the BP Texas City. The investigation included the broadest evidences collection, visiting the incident site, reviewing whole documents, interview the witnesses, tested instruments and assessed damage on equipment and structures of refinery and surrounding community. Photographs were taken as supporting documents on the investigation.

Electronic data from computerized control system and process information from five years of previous start-ups were also examined. Chemical analysis and trial also taken place and collected as part of the investigation.

All preliminary evidences gathered have been shared with four agencies team for further investigation. The main outstanding work of publication of the report was from:

- Various process samples analysis.
- Process instrument and equipment testing, such as relief valves.
- Internal inspection of the Raffinate Splitter and Blowdown Drum and Stack.
- Process and explosion modelling.

7.4 Timeline of the Disruption

A summary timeline of BP response to refinery explosion in Texas is shown in Figure 28. Timeline of BP Response to the Refinery Explosion in Texas City. In this study, the date 23 March 2005 is defined as 'the event' for purposes of analysis.

A full timeline of BP refinery explosion is shown in Table 31. (See also Appendix 5)

Date	Time	Events
21 February 2005		Raffinate splitter section of the ISOM unit is shut down; the 12-hour consecutive day shift schedule begins.
26 February2005		Operators try to open/close the pressure control (3-pound) valve from the control board; valve is unresponsive.
10 March 05		A revised work order to replace leaking isolation valves is added to the list of turnaround work so that the level transmitter can be fixed.
22 March 2005		Operators again try to open/close the 3-pound valve from the control board, but valve is unresponsive.
		Supervisor A tells instrument technicians to stop checking the critical alarms because the unit is starting up and there is not enough time to complete the checks.
23 March 2005	2.15 AM	The Night Lead Operator begins filling the tower with raffinate feed from the satellite control room.
	3.09 AM * This study defined this point of time as 'the event' in analysis.	The tower high level alarm sounds when the level in the tower reaches 7.6 ft in the tower (72% on the transmitter).
		The redundant high level alarm switch does not sound when the tower level reaches 7.9 ft (78% on transmitter).
		The Night Lead Operator fills the tower, stopping when the transmitter reads 99%, which should have been 8.95 ft (2.7 m) in the tower, but is actually 13.3 ft (4 m).
	5.00 AM	The Night Lead Operator leaves the refinery a little over an hour before his scheduled shift leave time.
	6.06 AM	The Day Board Operator arrives at the refinery.
	6.23 AM	The Night Board Operator leaves the refinery.
	7.15 AM	Supervisor A arrives for his shift.
	9.27 AM	Operators open 8-inch NPS chain valve to remove nitrogen; the pressure in the tower drops to near 0 psig (0 kPa).
		A verbal miscommunication occurs between operations personnel regarding feed-routing instructions.
	9.40 AM	The Day Board Operator opens the tower level control valve to 70% output for 3 minutes, then closes the valve.
	9.51 AM	Start-up of the raffinate unit recommences and the tower begins receiving more feed from the ARU.
		The Day Board Operator observes a 97% transmitter reading (which should have been an 8.85 ft, or 2.7 m, tower level) when he starts circulation.
	9.55 AM	Two burners are lit in the raffinate furnace.
	10.47 AM	Supervisor A leaves the refinery due to a family emergency; no supervisor or technically trained personnel replaces him.
	11.16 AM	Two additional burners in the furnace are lit; the level transmitter reads 93%, which should have been a tower level of 8.65 ft (2.6 m); but is actually 67 ft. (20 m).
	11.50 AM	Fuel to the furnace is increased; the actual tower level is 98 ft, but the transmitter reads 88% (8.4 ft.; 2.6 m).
	12.41 PM	The tower's pressure rises to 33 psig (228 kPa); operators reduce pressure by opening the 8-inch NPS chain valve.
	12.42 PM.	Fuel gas to the furnace is reduced; the actual tower level is 140 ft (43 m), but transmitter reads 80% (8 ft; 2.4 m).
	12.42 PM	The Day Board Operator opens the tower level control valve to 15% output, then tries several times to increase output over the next 15 min.
	12.45 PM	Approximately 25 people attend a safety meeting in the main control room until ~13.10 PM.
	12.59 PM	Heavy raffinate flow out of the unit finally begins.
	13.02 PM	Heavy raffinate flow out of the tower matches the flow of raffinate into the unit.
	13.04 PM	The actual level in the tower is 158 ft (48 m) but transmitter reading has declined to 78% (a level of 7.9 ft; 2.4 m).
	13.11 PM	Supervisor A and Lead Operator talk; Supervisor suggests opening a bypass valve to relieve tower pressure.
	13.14 PM	Hydrocarbon flows out of the tower into overhead piping; tower pressure spikes to 63 psig (434 kPa); all three-relief valves open.
		The Board Operator begins troubleshooting the pressure spike; he notices the drum alarm had not sounded, so he resumes moves to reduce pressure believing there is a residual buildup of non-combustibles in the tower.
	13.15 PM	Fuel gas to the furnace is reduced.
	13.16 PM	The Board Operator fully opens the heavy raffinate level control valve.
	13.17 PM	The overhead reflux pump is started by outside operators.
	13.19.59 PM	The Day Lead Operator shuts off fuel gas to the furnace from the satellite control room.
	13.20.04 PM	Vapour cloud ignites and explodes.

Table 31: Timeline of BP Refinery Explosion in Texas City

Timeline of BP Response to the Refinery Explosion in Texas City

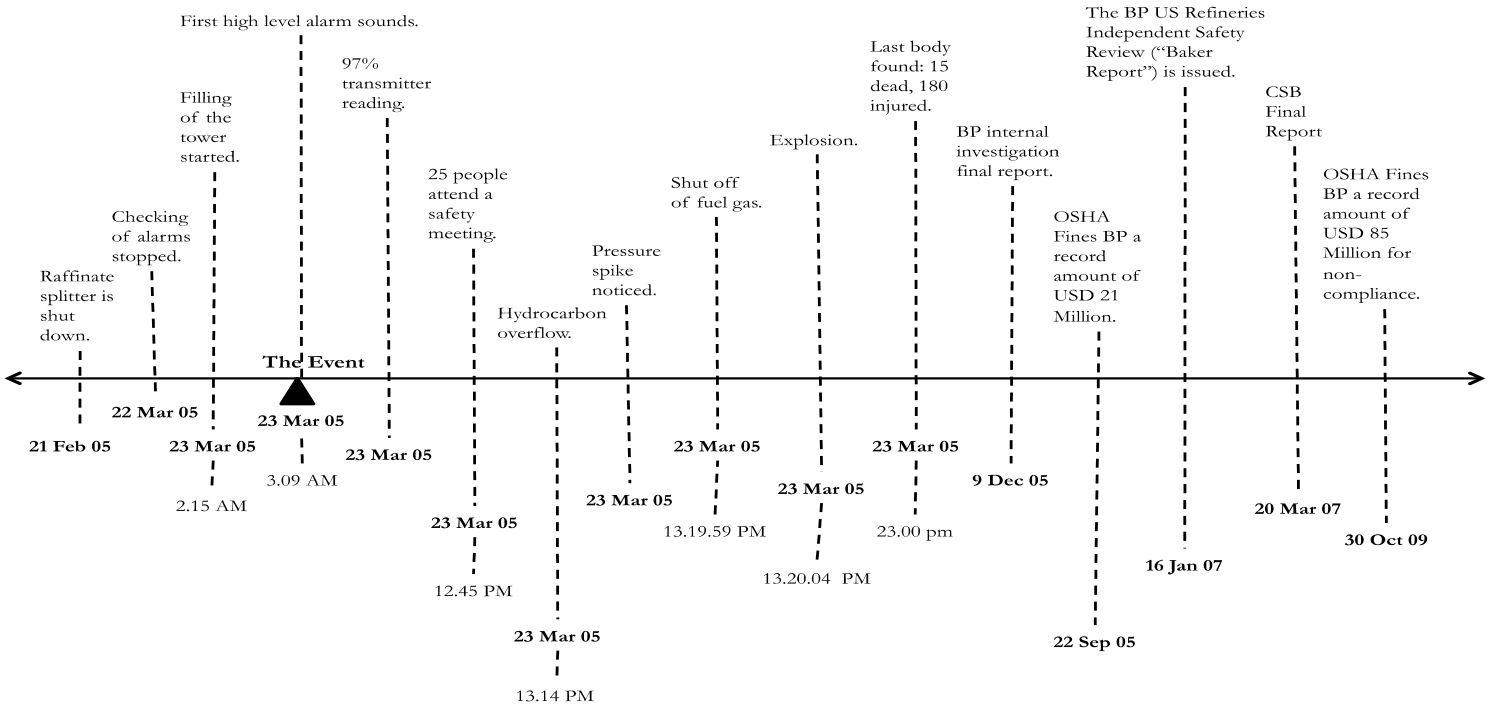


Figure 28: Timeline of BP Response to the Refinery Explosion in Texas City

7.5 Handling of Disruption by BP

7.5.1 Assessment of Causes

Recovery from the Texas City disaster presented BP with significant challenges on a number of levels and on a range of time scales.

Its first response was focussed on assuring the safety of employees and contractors, and to contain the fires that continued to burn at the plant. The immediate loss of life was tragic but limited, with the last body recovered the same day under rubble and the majority of injured treated. The Texas City facility was large and only partially closed.

Notably, the first phone call by the on-site management after the event was made to a BP lobbyist in Washington, even before the site manager and the local executive team were notified. Clearly, reputation risk was triggered by the event, in the context of previous BP environmental and safety issues.

Process safety was also of immediate concern. The facilities were in an unknown condition with an unknown volume of hydrocarbon discharged into the sewers and atmosphere. Immediately, all non-essential personnel were restricted, and changes were implemented to address the close proximity of trailers and meeting rooms to process equipment.

BP faced litigation from the environmental damage and loss of life. BP was already one of the largest polluters in Texas, and the event would increase by many factors the volume of toxic chemicals in the air over the nearby population. It was essential to secure all paper and electronic records and information that would be needed for internal and external investigation.

BP had to understand not only the mechanics of the event but also the cultural, policy and business factors that made the event possible. Four factors were identified in the Internal BP investigation report – 'Fatal accident investigation report' which was finished on 9 December 2009:

- Loss of containment.
- Raffinate Splitter Start-up Procedures and application of knowledge and skills.
- Control of Work and Trailer Siting.
- Design and Engineering of the Blowdown stack.

The failure to take emergency action resulted in loss of containment of hydrocarbons, leading to the explosion. The inappropriate siting of work trailers close to the blowdown stack put hundreds of employees and contractors at grave risk. Had a warning been sounded, more could have escaped serious harm. Well-understood system design and engineering would have reduced the risks of such an event occurring, had recommended changes been implemented.

Longer term, BP faced a challenge in changing its management culture and policies, not only to avoid such events, but also to respond faster when catastrophic failure occurs.

7.5.2 Overview of BP Response

BP launched and completed the internal investigation that cooperated with other agencies that carried out their own investigations. As stated in the BP's statement on CSB's final investigation report, BP produced to CSB over 6,300,000 pages of documents and made over 300 witnesses available for CSB interviews. More importantly, BP created an Independent Panel, to assess process safety management and safety culture (proper operation of equipment and handling of hazardous materials) at BP's US refineries. The Independent Panel undertook investigations, and issued their report in January 2007. According to Panel's findings, BP gained false confidence in its safety culture before the blast as the result of effort put in providing personal safety (meaning preventing workers' falls or slips). This finding is stated as opposed to CSB's conclusion that the safety lapses had been clearly linked to the budget costs in the 1999.

In the June 2007 BP, prompted by the Panel, appointed an independent monitor whose task is to oversee safety improvements. For this position, Duane Wilson, a retired vice president of refining, marketing, supply and transportation for ConocoPhillips was chosen.

BP also reached an agreement with OSHA. Under terms of the settlement BP agreed to fulfil six requirements (among them: to pay more than USD 21 Million in penalties, complete a review of the ISOM unit, retain a firm with expertise in PSM, hire an expert to assess and report on communication within and between management, supervisors, and authorized employee representatives and non-management employees and the impact of the communication on implementation of safety practices and procedures, submit to OSHA and BP Products' authorized employee representative, every six months for three years, logs of occupational injuries and illnesses, notify the OSHA area office of any incident or injury at the Texas City facility that results in an employee losing one or more workdays during the same three-year period[43].

7.5.3 Coding and Categorisation of Data from BP Texas City

Warning – Early warning before the event

Examples

- Assure function of alarm system (High-level alarm sounded two minutes late when much higher liquid level was received).
- Visually inspect equipment (Broken physical sight equipment was present).
- Alert worker population (No general alarm sounded, instead radio reports and shouting to notify workers in the area).
- Testing of alarms, which had not been done as required by standard operating procedures.

Code: timing, warning, alarm, training, maintenance, monitoring, communication, verification, testing

Before the explosion and the fire in March 23, 2005, BP had long history of safety incidents, as follows, with 23 workers were killed in the 30 years prior to the ISOM event.

In March 2004 there was a blast and fire at a BP refinery in Texas City, about 35 miles southeast of Houston. That explosion forced the evacuation of the plant for

[43] OSHA (2005)

several hours, but no one was injured. The Occupational Safety and Health Administration fined the refinery USD 63,000 in that blast after finding what it called serious safety violations, including problems with the emergency shutdown system and employee training. OSHA also fined the refinery this month for safety violations after two employees were burned to death by superheated water in September.

In August 2000, a fire erupted in a cooker unit at the plant, then known as BP Amoco oil refinery. About 20 workers escaped without injury.

The fire caused extensive damage to a unit used to make dry by products of the gasoline refining process and turn them into coke — a hard, coal-like substance sold and used for fuel in industrial furnaces.

In 1992, the Occupational Safety and Health Administration cited BP predecessor Amoco Oil Co. for using equipment, including a splitter — the same type of machinery at the centre of the current investigation — in a manner "that allowed toxic gases to vent to the atmosphere ... thus exposing employees to flammable or toxic gases." The four-month investigation was part of a broader initiative launched by OSHA after a string of fires at industrial facilities[44].

In 1993, Amoco Oil Co. agreed to pay USD 20 million in damages to the family of a worker who died after an April 1992 explosion at the Texas City plant.

In July 1995, an explosion rocked the Texas City facility. No one was seriously injured though at least 105 people were taken to local hospitals with breathing problems and burning eyes. The incident happened after oil began leaking from a catalytic cracker, which produces gasoline components from oil.

---

[44] Houston Chronicle (2005)

Modelling – Develop scenario plan and modelling capability

Examples

- Model key process lows (Gas flow modelling).
- Perform major risk analysis (Major accident risk analysis performed in 2003, however using limited scope and only generic industry data).

Codes: modelling, analysis and learning

Other types of testing either failed or were not implemented. Simulation for training on disaster management was not available to the process operators. In its place, so-called 'gun drills' – verbal discussions of hazardous operations – were inconsistently used; either technique was recommended in 2001 but not in evidence in 2003 and 2004.

Other types of systems testing was postponed or eliminated. The level indicators, for example, were not calibrated for the typical or extreme liquid temperature conditions: when the splitter was full and at the high temperature (300 degrees), it would read 78% - it should have been adjusted or training provided to indicate 100%. The datasheet, which would have been used for calibration, was more than 30 years old and never updated. Physical sight glass, which would normally allow visual inspection of fluid levels, were too dirty for use and could not be removed until leaking valves were repaired. These levels were important for calibration of other instruments and alarms. The same leaks prevented testing of the alarms that failed. Finally, the blowdown drum high level alarm which failed to sound was found to have material wear and would not have sounded – giving crucial 2 minutes to evacuate the area. The test procedures used by BP were simpler than those recommended by the manufacturer, and would not have revealed the malfunction (Goettsche, 2005).

Process, knowledge, mechanical and systems testing of the production environment could have contributed to avoidance or earlier detection of the incident. Focus on reducing employee fatality and injuries from previous accidents contributed to a false sense of improvement in the robustness of the site; reduction in training and testing budgets left a significant risk of catastrophic failure.

Internal communication – Shorten lines of communication

Example: BP created a new communication structure for safety related issues.

Codes: communication and safety

Lack of communication contributed directly to the accident and delayed awareness of the growing risk. Specifically, operations personnel on the 23rd of March failed to communicate firstly, the required routing of products from the raffinate splitter and secondly, the degree to which the splitter was filled. Normally this information is conveyed from management and supervisors and between operations shifts during hand-over. With the lack of emphasis on communications by BP management, this critical information was not recorded in any logbook or passed on when the day shift arrived. The need for clearly defined roles and responsibilities regarding communications is cited by the CSB, in particular during time so of sensitive operations and changes of personnel.

Often near misses and early warning signs foreshadow serious accidents, as noted by the CCPS in its 'Guidelines for Investigating Chemical Process Incidents (1992). Further, the CSB report cites James Reason on the organizational causes of accidents, who states that effective safety culture, relies on the organization being informed (Reason, 1997). BP Texas City had many incidents that went unrecorded and unreported – site risk management, issued before the March explosion, was that "the site was not reporting all incidents in fear of consequences."

Extensive organization changes after the Amoco merger, and continued re-organization since, had a negative impact on the vertical communications within the BP group. Important findings on safety, for example, were not communicated to executives. BP's outgoing refining chief testified in a deposition in 2006 that he first learned of serious safety concerns at the company's Texas City refinery in March 2005, after the event.

Modelling – Develop scenario planning

Example: Provide business planning on major risks

Codes: business planning, risk, disruption, forecasting

Manzoni also was shown a January 2005 business plan that stated among key risks, Texas City "kills someone in the next 12-18 months." Manzoni said part of business planning was to articulate risks. "It is not a prediction. It is a planning mechanism[45]".

Employee capacity – Increase employee capacity

Examples

- Increase employee shifts to 12 hours.
- Manage safety of employees (in this case, reduced physical safety buffer by placing personnel close to production equipment).

Codes: capacity, distraction, layout, labour reallocation

Ever stricter profitability targets reduced investment in physical plant and staff over the years. This also led to inadvertent reduction of safety zones, e.g. the siting of trailers close to high-volume hydrocarbon production. Similarly, lax control of the work environment led to overloaded staff – 'stepped up' employees and contractors took on multiple roles without additional training. Shifts ran 12 hours on a regular basis during the shut-down and start-up phase around the time of the accident, leading to employee fatigue. In the control room, where numerous visual distractions were evident and phone calls took place during monitoring, operators could not easily detect anomalies nor react quickly. Recommendations were based by the CSB to improve this labour 'reserve' – running staff until failure was no more safe than running equipment to failure, as was the BP practise.

[45] Houston Chronicle (2007)

Relationship with governments

Example: Management of relationship with regulatory bodies (EPA, OSHA)
Codes: government, regulation, relationship

BP has been in the radar of various agencies on environmental and employee protection. As mentioned earlier, the very first management action at Texas City was a phone call to its lobbyist in Washington.

Teamwork – Create integrated response team

Example: Creation of cross-function investigation team within BP in first 24 hours.
Codes: team, investigation and cross-functional

Within 24 hours, BP formed an investigation team with participation from executives, permanent and hourly workers, and its subcontractors. As stated in the BP's statement on CSB's final investigation report, BP produced to CSB over 6,300,000 pages of documents and made over 300 witnesses available for CSB interviews. BP created an Independent Panel, to assess process safety management and safety culture (proper operation of equipment and handling of hazardous materials) at BP's US refineries. The Independent Panel undertook investigations, and issued their report in January, 2007. According to Panel's findings, BP gained false confidence in its safety culture before the blast as the result of effort put in providing personal safety (meaning preventing workers' falls or slips). This finding is stated as opposed to CSB's conclusion that the safety lapses had been clearly linked to the budget costs in the 1999.

The Chemical Safety Board expanded on this work and provided a much more critical external view in its final report 24 months after the event. Because of delays by BP in implementing early recommendations, the CSB expanded its investigation and later a new committee chaired was formed. This panel review refinery safety across five BP sites, and its findings echoed the CSB.

Planning – Leverage preparedness by update procedures

Example: Updated procedures were implemented (Staff did not follow standard shutdown or emergency procedures).

Codes: procedures, training, emergency

As is discussed in the response, both prevention and mitigation procedures were not adequately updated or followed in this event.

Implement Training – Provide training on detection and response

Example:

- Provide employee training on leading indicators.
- Leverage external resources (Trained local fire fighting personnel and ambulance services).

BP Texas City implemented and updated training programs on leading indicators to detect anomalies as well as training to external parties in the event of major disruption.

7.5.4 Response Time at BP Texas City

D1 - Detection of the event

Since the Amoco merger, Texas City plant managers faced strict targets on maintenance investment. Targets were set on improving capital performance, to the extent that local management fought to reverse some of the scheduled cuts.

The reduction in maintenance was visible at a technical level, with faulty alarm systems, reduced training, even simple visible liquid level indicators on key equipment being 'blackened' and unreadable already for years. BP debated the inadequate level of investment; the fact remains that equipment was faulty and process status difficult to verify. Investment in physical plant has a parallel requirement for human capital and equivalent shortfall; though the operating team was fully staffed at the time of the accident, key-operating personnel had minimal training or experience.

D2 – Design of a Solution

All the disaster, in the words of one BP executive, 'was years in the making', the process failure took hours and the explosion occurred literally in seconds. Without adequate warning, little could be done at the moment to avoid full scale destruction of much of the unit. To find a longer-term solution to avoid impact of the same underlying causes, intensive investigation was warranted. It was one of the worst industry accidents in the country; the risk of repeating such an event in a critical energy supply chain had to be reduced.

D3 – Deployment of the Solution

Speaking to a conference on process safety, BP Senior VP John Mogford related what they saw as key causes and lessons from the event:

"Firstly, over the years the working environment had eroded to one characterized by resistance to change and lack of trust, motivation and purpose. Expectations around supervisory and management behaviour were unclear. Rules were not followed consistently. Individuals felt disempowered from suggesting or initiating improvements.

Secondly, process safety, operations performance and systematic risk reduction priorities had not been set nor consistently reinforced by management. Safety lessons from other parts of BP were not acted on.

The changes in site layout were made permanent, increasing the safety margin through greater work area. 'Hot' work – where high temperatures are involved, such as from welding, were also separated and controlled during critical periods.

In summary, BP found critical importance in the following recommendations:

- Real-time management awareness of activities taking place.
- Capturing the right metrics on process safety.
- Up-to-date and implemented procedures.
- Two-way communications.

- Investigating process incidents and loss of containment incidents and documenting all incidents thoroughly.
- Sharing what is learned.
- Training programs.
- Keeping non-essential personnel out of process areas.

BP was investigated by OSHA a number of times after 2005, and due to continued violation was fined a record USD 87M in 2009: "The U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) today announced it is issuing USD 87 Million in proposed penalties to BP Products North America Inc. for the company's failure to correct potential hazards faced by employees. The fine is the largest in OSHA's history. The prior largest total penalty, USD 21 Million, was issued in 2005, also against BP." (OSHA)

BP also reached an agreement with OSHA. Under terms of the settlement BP agreed to fulfil six requirements (among them: paying USD 21 Million in penalties, complete a review of the ISOM unit, retain a firm with expertise in PSM, hire an expert to assess and report on communication within and between management, supervisors, and authorized employee representatives and non-management employees and the impact of the communication on implementation of safety practices and procedures, submit to OSHA and BP Products' authorized employee representative, every six months for three years, logs of occupational injuries and illnesses, notify the OSHA area office of any incident or injury at the Texas City facility that results in an employee losing one or more workdays during the same three-year period[46]).

In the June 2007 BP, prompted by the Panel, appointed an independent monitor whose task is to oversee safety improvements. For this position, Duane Wilson, a retired vice president of refining, marketing, supply and transportation for ConocoPhillips was chosen.

---

[46] OSHA (2005)

A Summary of the findings in related to the 3-D framework from Texas City case in shown in Table 32.

Tailored approaches	Examples from BP Texas Refinery Explosion	D1	D2	D3
Develop advanced warning system	• Failed alarm systems, e.g. high-level alarm sounded two minutes late when much higher liquid level was received. • Broken physical sight equipment for visual inspection. • No general alarm sounded, instead radio reports and shouting to notify workers in the area. • Alarms not tested prior as required by standard operating procedures.	◆ ◆ ◆ ◆		
Conduct stress testing	• No approval of facilities layout (dangerous positioning of trailers). • Lack of process review during sensitive shut down / start up phases.	◆		◆
Develop scenario plan and modelling capability	• Gas flow modelling. • Major Accident Risk analysis performed in 2003, however using limited scope and generic industry data.	◆	◆	
Leverage preparedness plan	• Standard shutdown procedures. • Standard emergency procedures.		◆	◆ ◆
Implement training	• Employee training on leading indicators to sense possible disruptions. • Local trained emergency response services from Texas City fire and ambulance services.	◆		◆
Establish frequent communications with supply chain partners	• Participation in congressional hearings. • Baker panel on BP refinery safety to review implementation of recommended changes. • CSB investigations on root-cause and management background to the event. • EPA investigations on adherence to regulation and environmental impact. • OSHA investigations on root-cause and employees safety.		◆ ◆ ◆ ◆	◆ ◆ ◆ ◆ ◆
Create integrated response team	• Creation of cross-functional investigation team within BP in first 24 hours.		◆	
Shorten lines of communications within the organisation	• BP created a new communication structure for safety related issues.	◆	◆	
Establish learning from past events and during the events	• Independent panel to determine critical factors. • Updated physical site layout recommendations. • Numerous recommendations on engineering, process, management, training.	◆ ◆	◆ ◆	◆
Assure management and employee capacity	• Improved safety procedures for employees. • Improved control over dangerous ('hot') work areas and general operations during sensitive start-up and shutdown sequence.			◆ ◆
Increase capacity	• Improved staffing to reduce employee fatigue and improve alertness and response speed. • Reduce distractions in control room. • Allocate time to complete testing. • Geographic reserve – greater spacing of activities for improved Simultaneous Operations, e.g. trailer siting.	◆ ◆ ◆		◆
Develop product or solution extensions	• Changes in system design (e.g. removing out-of-date blowout preventor).			◆

Table 32: A Summary of the Findings from BP Texas City Case

Chapter 8
The Emergent Theory

8.1 Introduction

This chapter addresses the findings of the study after all data have been coded, categories identified, the properties and the links between categories established and the emerging theory has been delimited. A detailed explanation of the core concepts and related categories is provided here.

8.2 Integrating Categories and Their Properties

During the open, axial and selective coding of data from interviews and data other sources in three cases, properties of and links between the categories and sub-categories became explicit. At this stage of analysis, the focus is on integrating the core categories with their sub-categories and creating suitable definition to be applicable beyond the current data sources.

Based on this approach, four major factors can be shown to have an impact on the time in which organizations can respond to catastrophic risk in the supply chain are: Preparation, Partnership, Organization, and Reserve (Figure 29). The findings show that the presence – or lack of – these factors can have a major influence on the response speed for the effective management of disruption.

These factors can require significant investments and trade-offs in resource allocation, and have – as discussed – varying impact during the typical phases of response.. An evaluation of return on investment before, during and after a catastrophic event is evident in the approach taken by each firm. Some tailored approaches used by the firms showed interaction between multiple factors: reserve capacity can be both internal to the organization, as in the mothballed Nicole production lines at PHARMA, or externally with partners, as in the oil recovery ships from Shell, a traditional competitor to BP. Such external partnerships, for example, reduce the cost of holding or internally pooling reserve capacity.

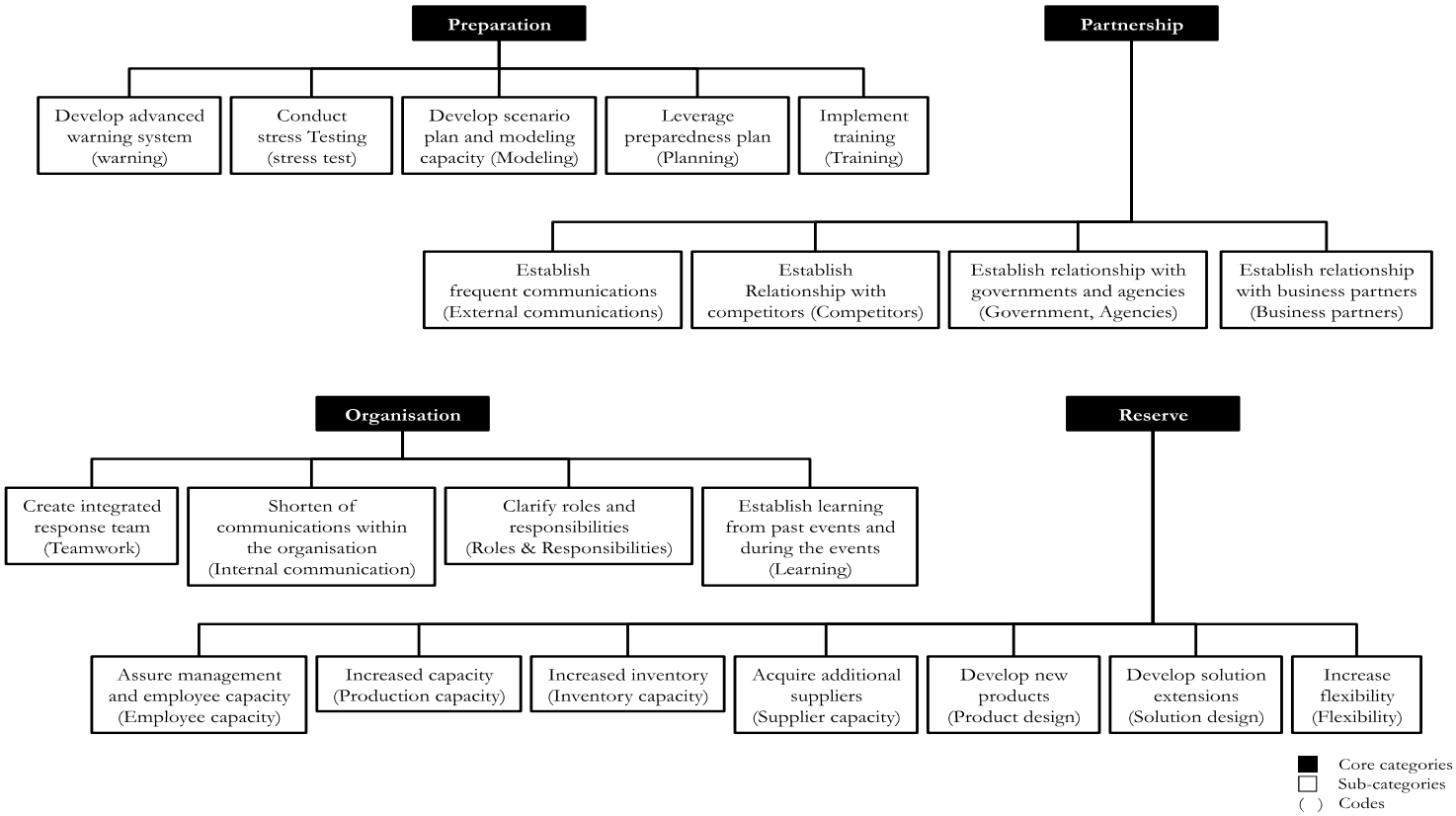


Figure 29: An Overview of the Core Categories and Sub-Categories Following Completion of the Analysis of Three Cases

8.3 Factors Underlying Response Time

As the primary outcome of the study, sub-categories derived and confirmed from the cases are depicted in Figure 30 illustrating the tailored approach each organization took to contribute to the four factors (Preparation, Partnership, Organization, Reserve), which underlie response time.

Preparation includes approaches implemented prior to the event such as creating advance-warning systems; stress testing, scenario planning and modelling and training. *Partnership* includes management of the external relationships to improve response time, such as suppliers and customers, but also other influences and even competitors. *Organization* covers the steps taken in coordination, communication, roles and responsibilities, and learning within the border of the firm. *Reserve* covers the full complement of resources, attributes of supply chain resources, and techniques to improve capacity in a timely fashion, such as flexibility, inventory, management and employee capacity and product or production line extensions.

Each factor has a positive effect on the firm's ability to reduce response time; this in turn reduces the negative impact of catastrophic disruption on the supply chain. The characteristics and relationships of the core categories are explored in detail below (see also Figure 30):

1. Preparation
2. Partnership
3. Organisation
4. Reserve

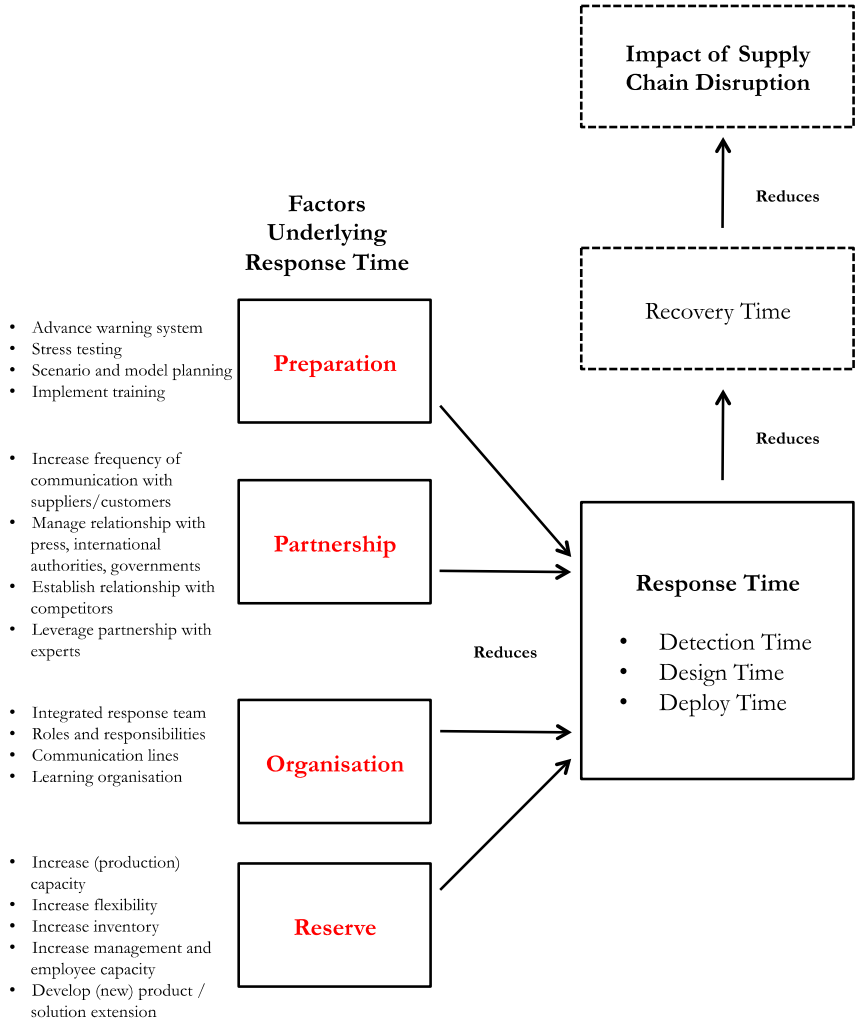


Figure 30: Factors Underlying Companies' Response to Supply Chain Disruption

8.4 Preparation

Preparation can be considered to consist of the tailored approaches made prior to detection of an event that contribute positively to the organization's speed of response. Preparation can be mandated by industry or government regulation, grow out of experience with previous events, or come from fortuitous alignment with supply chain optimization for normal operations.

Preparedness is defined here as the degree to which the organization has executed activities and investments are identified during the cases to prepare an organization to handle disruption.

From the data, there is a clear focus in preparation on information access and interpretation within the organization and also extending to information gathering partners along the supply chain. Viewed along a time dimension, this preparation takes the form of response review and post-event learning ('lessons learned'). Assessment of organizational preparedness is linked to improved avoidance and rapid response. Having plans such as contingency (recovery) plans, business continuity plans, and preparedness plans in place and ready to use will shorten the response time to different types of disruption. This can have a positive impact on design lead-time as well as reducing deployment lead-time.

8.4.1 Develop Advanced Warning System

Early detection of impending events or anticipation of the impact of disruption is implemented through one or more advanced warning systems. These systems must help distinguish routine operational events and those that indicate elevated risk of disruption. Event correlation is a key capability – advanced warning of disrupted production and sudden influx of orders, for example, would elevate priority of the coincident data. Failure to detect deteriorating safety culture and increasing frequency of accidents is another example of the need for event correlation.

Advanced warning systems can take a range of forms and inputs, from automated systems and through processes of observation and notification, using data from monitoring internally and externally along the supply chain.

> Early warning of potential or impending events relies, on information access and interpretation. At a most mechanical level, this is illustrated by failure of the Deepwater Horizon to correctly monitor on the rig – or offshore in real-time – the ominous increase in well pressure, foreshadowing an imminent blowout. Had the crew been alert, and taken the right action to redirect the erupting mix of mud and gas overboard, the resulting explosion could have been delayed or mitigated. Failed monitoring processes and equipment contributed directly to the disaster at Texas City. PHARMA stated that much information was first visible in the public press, both at the outside and at later stages of the pandemic.

8.4.2 Conduct Stress Testing

Stress testing is an exercise that helps managers identify and prioritize potentially vulnerability of the supply.

Creating different scenarios and rehearse simulations runs/drills is seen to enhance the company's ability to respond more quickly. Sodhi and Tang (2009, P.36)

addressed that "the deployment time accounts for the preparation time to launch the selected recovery plan, scenario planning and stress tests are effect mechanisms for reduce deploy lead time."

Targeted testing of components, systems and processes in the supply chain can reveal vulnerability before risks escalates. Where this is not feasible, live testing can be replaced or supplemented with modelling, and this is found in each of the cases.

> While PHARMA runs successful preparedness exercises each year, investigation of BP Texas City revealed that pressure to reduce cost had reduced frequency of fire drills from bi-weekly to monthly. This division of BP was also noted for its 'run to failure' use of infrastructure, rather than implement rigorous testing of technical systems and processes. Likewise, prior to the BP Deepwater Horizon disaster, BP Upstream failed to assure that its partner Transocean had met recommended procedures for periodic testing of the Blowout Preventer (BOP). Transocean had a 'condition based' approach, e.g. testing was done based on experience of equipment use and failure, in some way corresponding to the 'run to failure' approach of BP. Failure to accurately predict increasing risk of failure of such components led to elevated risk exposure.

That said, stress testing itself could elevate systemic risks, as in the case of the Chernobyl nuclear disaster, which failed during a test procedure. Pressure testing of the oil well prior to production triggered the immediate failure, which caused the well blow-out on BP Deepwater Horizon:

> Stress testing of concrete formulation by Halliburton was not communicated in full to the BP Horizon drill team – only a final successful test was confirmed; previous failures that revealed instability were not disclosed until after the accident. Further, misinterpreted 'negative pressure' test results at BP Deepwater Horizon, which the drill team erroneously interpreted to indicate successful securing of the well, exposed the rig to disaster during subsequent steps. This is reminiscent of the nuclear meltdown on 26 April 1986 at the Chernobyl Nuclear Power Plant in the Ukrainian SSR which was caused by poorly designed recovery procedures during stress testing of the reactor control systems.

8.4.3 Develop Scenario Plan and Modelling Capability

Modelling of potential risks was used in each of the companies, both before and after the event. As a technique for encapsulating experience and reducing the skill burden during operations, modelling and simulation provide a useful avenue for both disaster avoidance and optimizing deployment of scarce human resources and other assets.

This tailored approach can also include development of a risk map – identification of potential risks and assessment of impact. This was implemented, in the case of PHARMA, as a two-dimensional matrix, estimating event frequency and severity. In an engineering scenario, the risk map is expressed as a fault tree – where failure of an element could trigger certain symptoms, and therefore such symptoms or warnings, when present, could be traced back to potential faults. However, these risk map representations may not accurately express heightened risk conditions, e.g. coincident events can elevate total risk. This is the case when safety systems fail at the same time as production systems, as seen in the BP Deepwater Horizon case.

It is important to point out as well modelling, just as with stress testing – can also increase risk or create false confidence if a false sense of security if this testing no longer corresponds to actual conditions and system behaviour.

> Given the very complex response to the BP Deepwater Horizon oil spill, in which dozens of ships and thousands of staff were working in unprecedented proximity of each other and thousands of barrels of explosive hydrocarbons, each operation required close coordination and control. A simulation facility for 'Simultaneous Operations' was developed where the design of possible solutions could be tested and each stage of deployment could be carefully modelled to avoid further disaster or delay.

8.4.4 Leverage Preparedness Plan

Advanced planning, including up-to-date roles and responsibilities (an approach recorded as part of the Organization factor), are identified as being key to rapid response. From the cases under study, this includes response procedures for each geographic, organizational or functional business unit. The currency – how up-to-date- these plans and structures are – was shown to the effectiveness of such plans in the response process.

> PHARMA observed that while its emergency plans were correctly in place for lines of business and physical plant locations, reorganization through a corporate efficiency program resulted in many staff identified in the plans as having taken new roles. Further, some newly assigned staff who were responsible for site-level deployment were unaware that they had been assigned such a task. At BP Texas City, after frequent management reorganization and the speed of possible events made it policy to allow for any staff person to initiate the emergency response. In contrast, on the BP Deepwater Horizon, the captain of the Deepwater Horizon scolded its young, inexperienced ship-positioning operator for taking the liberty to officially make the Mayday distress call, despite the fact that the rig was very close to total destruction.
>
> At BP Texas City, the first response by management was to call its government Public Relations staff, secondly to inform the Business Unit Leader by phone – an issue in corporate priorities that was highly critical of BP during litigation against the firm.

8.4.5 Implement Training

Training of organization staff, suppliers and customers is identified as a key element of rapid event detection and solution implementation. Skills are shown to be essentially for early detection of impending events, as well of course as avoiding the underlying root cause, for example, where a trigger is found in misjudged or erroneously executed procedures. Adequate training internally and externally, beyond typical operational requirements, allows rapid redeployment of skills for greater capacity reserve and flexibility. Training of staff across multiple roles and skills could assure continuity in the event that some staff were unavailable and also create increased capacity where resources needed to be shifted, for example as production was reallocated in the PHARMA case.

> After the BP Deepwater Horizon disaster, an important learning point was made retrospectively for the otherwise experienced operators on the rig. The team erroneously believed that ill-fitting data from a 'successful negative pressure test' was caused by a 'bladder effect' (higher pressure due to configuration of the drilling fluid). No such effect exists – this was a propagated myth among some field engineers – and ultimately cost the life of the veteran drilling engineer who erroneously believed that explanation. Sadly, he died the day before he was scheduled to leave active work and to begin teaching at the company's well control school. Recommendations by various panels after the BP Texas City also focussed on training to help staff identify the 'early indicators' of increasing risk.

8.5 Partnership

Management of external relationships is shown to be an important dimension in the response to disruption. They can further trace the impact of each disruption along the supply chain from upstream partners to downstream customers. This requires productive relationships and communication between supply chain partners. This requires productive relationships and communication between supply chain partners. Creating a common awareness of different types of disruptions and the impact on both parties could decrease the risk for all parties; "Companies must identify ways to share the information with their supply-chain partners and to get similar information from them" (Sodhi & Tang, 2009 p: 36).

> Due to the nature of complex and global supply chains, large investment in specialized skills and capital, the firms studied here operate with extensive partnerships. Only seven of 126 employees on the Deepwater Horizon were actual employees of the 'responsible party', BP Upstream. All of the dead in the Texas City disaster were from companies contracting to BP. Indeed the disruption to supply chains, or in the case of PHARMA's response to swine flu, had an impact far beyond each organization. Accordingly, Partnership is identified as an important category of capabilities related to risk response. Many companies identify potential disruptions to

business according to their impact and likelihood as part of their Business Continuity Plans.

8.5.1 Establish Frequent Communication with Supply Chain Partners

Communication between supply chain partners is identified as a critical element of response. As events evolve, control of communication to external parties is prioritized, in particular where the catastrophic impact of the disruption is visible in the public sphere. First information about events, in fact, is itself in public media.

> PHARMA was asked to comment in press interviews on public perception of 'price gouging' of scarce medicines and made forced to make public statements on its distribution policy. BP Texas City issued a number of press releases and enlisted its mid-tier international executives in communications. Learning from previous failures to communicate effectively with government, the public and its partners, BP Upstream deployed real-time video feeds to show the actual, live flow of oil into the Gulf from 5,000 feet below the surface. Direct disclosure of frequent information is driven today by new forms of media and a need to retain trust and brand confidence in an increasingly online world. Legal restrictions and litigation, however, can make sharing of information difficult if not impossible. Facing huge fines, each party in the Deepwater Horizon case was reluctant to provide unfettered access to staff or engineering data. The failed equipment, recovered from the sea floor, remained as of this writing under close guard on US Federal government property. It is expected to remain there to support litigation for several decades.

8.5.2 Establish Relationship with Governments and Agencies

Governments, local and federal, along with a plethora of government and regulatory agencies play an increasingly important role in the allocation of resources, protection of employees and environment, parameters of trade and license to operate complex supply chains. In the case studied, the government plays a key influencing role and direct role as supplier (of right to drill, for example) or customer (for purchase of medicines on behalf of the population). It is natural that the relationship between the firm and various government agencies is a focal point for response.

> In a global supply chain, a number of activities including sourcing, manufacturing, distribution and marketing will fall under the control or influence of various local and international governments and agencies. These external bodies have considerable influence on the regulatory environment and can have a dramatic affect on the operating environment of a supply chain before and after a major disruption. The policy and operating relationship with such agencies is an explicit element of risk response. For downstream partners, close coordination and information exchange was important – PHARMA proactively contacted relevant organisations such as the WHO, the CDC, the Department of Health and Human Service in the US, The European Centre for Disease Prevention and Control and different governments

around the world. Being in direct contact with these parties helped PHARMA understand their needs and develop estimates for manufacturing capability and the timing of possible production as well as determine the benefit of developing additional technology for the production of a pandemic vaccine. PHARMA worked with its government customers to allocate scarce capacity ('proportional response'). The first phone call made from BP Texas City was to its lobbyist in Washington. Lack of participation of the US President and the CEO of BP in the early stages of the BP Deepwater Horizon disaster was equally vocally critised.

8.5.3 Establish Relationship with Business Partners

The relationship with upstream and downstream business partners is by definition a key control point in the supply chain. Management of such external relationships during the response to a catastrophic event takes on new priority and new mechanisms maybe established in the context of these relationships. In one of the most studied supply chain cases, that of the fire at a Philips Electronics chip factory in Arizona, Nokia has quickly moved to capitalize and extend a closer working relationship that its rival Ericsson, enabling Nokia to secure scare inventory and remaining production capacity. This led Ericsson Mobile to tremendous financial and market share losses and eventual merger with Sony.

PHARMA has defined certain risk management processes for external suppliers. PHARMA had a team looking at external suppliers, because a significant portion of the supply chain is outside PHARMA and it must be ensured that those sites are considered in the BCP. For example, PHARMA assessed if it had any outsourcing or external contractors in Mexico in addition to its own site. Medically critical products or revenue-critical products could be affected by production or transport shutdown. Accordingly, on 29 April 2009 PHARMA gave antiviral drugs to its employees in Mexico to assure their safety as well as manufacturing and supply continuity.

8.5.4 Establish Relationship with Competitors

Competitors who may play an adversarial role during routine business can play a very different role in the risk response, in particular where the event affects multiple supply chains and can put either the entire industry or downstream customers under stress. The nature of the relationship with competitors has both tactical (event response) and strategic (market-shaping) aspects in the events under study. Parallel to the shift from normal organizational design to crisis response within the organization, each case shows the unique competitive and supply chain configuration required to accelerate response in crisis.

BP Refining and Marketing shared findings with industrial competitors. BP Upstream, while protective of proprietary data on geologic information and drilling techniques (it refused to provide information to medical staff that was treating injured workers, so

as not to disclose formulation of drilling fluid), later joined a consortium of competitors to form a dedicated, not-for-profit disaster recovery organization – with investment of more than GBP 600 Million.

BP Upstream also leveraged support from erstwhile competitor Chevron to model and stress test cement composition, in an effort to identify root-cause of the Deepwater Horizon Disaster. BP drew on partners that it harmed – local fisherman – through a special program, 'Vessels of Opportunity' which gave financial reward to affected fisherman for assisting in oil spill recovery. This novel approach of supporting such a widely affected group of downstream partners – tens of thousands of individuals participated – created logistic demands and administrative burden, however capped exposure to litigation, reduced public brand damage, and provided some capability in oil spill control. The technical mechanism, such as a purpose built radio-relay system, as well as lessons learned for both effective and ineffective spill control, are a key contribution of BP to the industry initiative on protecting the Gulf from subsequent disaster.

8.6 Organisation

Organization refers to investments and strategies that are directed to the structure and internal management capabilities of the organization. In all three cases, the companies refer extensively to their organizational structures and work culture. Communication and decision-making are a key component of these factors. Clarity and speed of communication as a consequence of organizational structure are highlighted as relevant attributes for fast response.

The lack of investment in organizational capabilities is traced to increased likelihood and impact of disruption.

BP was known to have a culture of austerity, acquiring many older firms with aging equipment and under investing, as stated by its own site management. PHARMA had designed a new line of communications and assigned a communications manager after it became aware of the 'noise' during the few weeks of the outbreak. Following Van Wassenhove (2006), effective coordination has three forms: (1) centralized coordination by command (2) coordination by consensus and information sharing and (3) coordination by default, e.g. through routine communication. PHARMA applied coordination by command during the design and deployment phases. According to Sodhi and Tang (2009), these two phases need to take central command for collecting and analysing information to design a recovery plan and disseminating information regarding the deployment of the selected recovery plan. In PHARMA's case, the central command was the MSC pandemic team.

8.6.1 Create Integrated Response Team

After detection of the events, each organization assigned an integrated team to investigate and respond to the event, indicating that internal structures for routine supply chain operation may not be adequate for rapid response. This integrated response team was supplemented by external expertise and capacity.

> PHARMA assigned working groups at each level of the organization. After initial failures by BP Upstream to stem flow of oil into the Gulf, growing frustration with the company prompted the US federal government to extend the mission of the Coast Guard's Incident Management team under a "Unified Command". BP Texas City managed an integrated investigation team with representation from executive, 'salaried' and 'hourly' workers to get a complete picture on possible changes in responding to the event.

8.6.2 Shorten Lines of Communications within the Organisation

Fast and direct communication was mentioned as a critical capability in developing and deploying possible solutions. In the case of PHARMA, this was evident where information would be cascaded through different layers of the organization through multiple functional groups, e.g. production, HR, etc. The delay and potential miscommunication inherent in relayed communication forced a rapid restructuring of communications to reduce confusion. Electronic means, such as a shared online team room, were employed to shorten lines of communication.

> PHARMA mentioned the importance of collaborative techniques such as online team rooms to support deployment. BP claimed to significantly change its internal communications culture to encourage faster risk response.

8.6.3 Establish Learning from Past Events and During the Events

While major disruption is by definition rare, explicit learning from such events becomes even more a priority. Study of events faced competitors, historical events, comparable scenarios are all part of a learning process to understand best practices. PHARMA implemented an After event executive review; BP Texas City and BP Deepwater Horizon triggered ongoing highly technical and broad organizational investigation that continue to influence preparation by all industry participants.

> PHARMA could leverage experience with previous types of Influenza, in processes as well as possible supply chain solutions. Incentives and rewards have a strong influence on internal communication and learning, according to executives at PHARMA. In contrast, BP Deepwater Horizon's owner, Transocean, failed to keep its engineers informed of very similar events in the Northsea drilling, where the same type of well design and engineering approach resulted in loss of well control just weeks earlier. Investigation in each case by internal and external parties can be seen to have two components: root-cause analysis, in part to prepare for litigation, and recommendations going forward. In the case of BP Refining and Marketing, failure to implement many recommendations made after Texas City was cause for the company to be investigated again (Baker Commission) and heavily fined (more than GBP 50 Million).

8.6.4 Clarify Roles and Responsibilities

Well-defined roles and responsibilities may be explicitly defined for each of phase of handling disruption. The authority to manage the crisis, for example, at PHARMA rested politically with plant and site managers, however the expertise was with specialists. Names mentioned in some plans were out-of-date; this is an issue of maintaining Preparation (see above).

> PHARMA observed that while its emergency plans were correctly in place for lines of business and physical plant locations, reorganization through a corporate efficiency program resulted in the prior year left many staff identified in the plans as having taken new roles. Further, some newly assigned staffs that were responsible for site-level deployment were unaware that they had been assigned such a task

8.7 Reserve

The category of Reserves covers the affordable additional resource beyond those required for routine operations, which are immediately available for the firm to mount an effective response, in detection (e.g. redundant alarm systems), in design (e.g. scientific staff on board) or deployment.

Chopra and Sodhi (2009) discuss a range of techniques for tailoring reserves to mitigate risk. Companies can extend their reserves by increasing capacity, acquiring redundant suppliers, improving responsiveness, increasing inventory, increasing flexibility, pooling or aggregating demand and increasing production capability. However, the cost of building up a reserve must be balanced against the level of risk. According to Chopra and Sodhi (2009), when the cost of building a reserve is low, the reserves can be decentralized. Where costs are high, the reserves should be centrally pooled. Similarly, they state that when the level of risk is low, the strategy should focus on cost reduction. When the risk is high, the focus should be on mitigation to reduce the likelihood of occurrence.

They also proposed 'three time-tested approaches' (Figure 31) which can be used to help managers and companies mitigate inventory risk, are: (1) pooling inventory, (2) creating common component across product lines and (2) postponing or delaying the last stage of production.

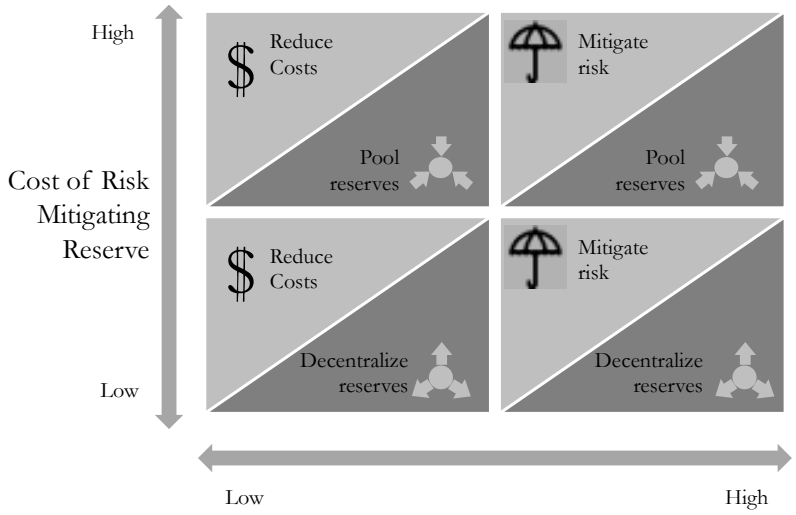


Figure 31: Rule of Thumb for Tailored Risk Management

Source: Chopra & Sodhi (2004)

Internal capacity, above and beyond the mechanisms for routine supply chain management, is shown as an important factor in risk response in the cases studied here.

> This is visible in terms of moth-balled production lines (PHARMA) that were quickly activated, also the availability of drilling rigs and support ships from Transocean already in the Gulf of Mexico that were not otherwise scheduled. The lack of such additional reserve is evident there was well: specialized fuel-burning equipment was weeks in transit from France, needed to safely burn-off the recovered oil where dozens of other ships were active in close proximity.

8.7.1 Assure Management Capacity and Employee Capacity

Protection of employee and management capacity was one of the first and most rapidly implemented steps in each case under study. Both management skill and employee resources are seen as critical to response speed. The threat to employees from the event could trigger a delay or reduction in ability to respond, for example through illness, as well as increase in actual demand for intermediate or end product. Rapid isolation of key skills was implemented, for example by restricting out-of-country travel for country and site management at PHARMA. Immediate abandonment of the BP Deepwater Horizon rig served to limit casualties.

PHARMA required its mangers to remain in country. BP Refining and Drilling has focussed on employee safety before and during the event, however mistakenly neglecting to cover process safety in the same fashion – and non-employees were obviously at full risk. BP Deepwater Horizon management chose to immediately abandon the rig; no further deaths occurred after the initial explosions. Able rig workers who survived were immediately pressed into service to fight the explosion from arriving support craft, and all were heavily involved in the investigation – legal and technical – after the event.

8.7.2 Increase (Production) Capacity

Ramping up production capacity along the supply chain is an explicit goal in the crisis response. This can take on both physical dimension of goods and equipment, but is also implemented in the greater concentration and availability of human capital, in terms of better structuring management, expertise and skills to improve capacity.

Geographically diverse supply chains, such as commodity oil and gas, by their nature require distributed investment in capacity. Spare drilling rigs can be moved, albeit slowly; fixed production equipment cannot. However, higher-value intermediate products, as well as critical skills and knowledge, can be accumulated centrally to support faster response. PHARMA, for example, stockpiled active ingredients and had implement procurement contracts in place for rapid acceleration of production. In the engineering- and science-intensive field of hydrocarbon exploration, BP Upstream maintains an offshore centre in Houston that has a myriad of engineers and facilities working in frequent, often real-time, cooperation with offshore teams. This centralized capability is a key design for reducing expensive offshore deployment, but was also critical to rapid design, evaluation and control of the various attempts to resolve the oil spill.

8.7.3 Develop Product or Solution Extension

Each organization studied maintained a portfolio of possible response solutions, which were extended to address requirements for flexibility, speed of response, and more rapid increase in capacity growth. These measures could be implemented for example in simplification of production steps (PHARMA), increased flexibility of technology or techniques (BP), changing design parameters and regulations (BP Texas City).

Following the natural reassortment of viruses to form new pathogens, PHARMA can recombine existing active ingredients, vaccines, and delivery mechanisms to scale-out and scale-up production. BP Upstream had minimal experience with possible solutions to well blow-out, and other than the relief well, and struggled to find or develop a workable solution to the Deepwater conditions of the disaster at Macondo. In fact, many weeks and hundreds of millions of pounds was spent on adapting, modelling, and deploying solutions that failed – while million gallons (equating to tens of millions of dollars in environmental damage fines) of oil flowed unhindered into the Gulf. It became evident that nothing in oil spill recovery had evolved since the Exxon Valdez disaster some twenty years earlier; the same techniques were tried and failed on a grand scale. BP Refining and Marketing identified hundreds of

recommendations at Texas City, however had failed to implement previous lessons and recommendations on plant design and layout which could have reduced the scale of impact – more explicitly, the number of deaths and serious injuries.

8.7.4 Acquire Additional Suppliers

Capacity constraints on components, supplies, labour and distribution, to name a few restrictions, can hinder rapid expansion or recovery of supply chain capacity. Despite growing fluidity in faster, typically on-line sourcing procurement, protection of intellectual property (PHARMA) and regulatory control make it essential that firms 'prepare' to rapidly acquire additional suppliers.

PHARMA was fortunate, in responding to the demand from China and LDCs, that it had explored a voluntary licensing arrangement two years prior. Governments, under the same stress of rapid growth in demand, correspondingly had 'Advanced Purchase Agreements' in place on pre-negotiated terms to acquire Influenza medicines.

8.7.5 Increase Flexibility

An additional reserve of supply chain capacity is found through flexibility. This can be the redeployment of production equipment or staff resources in the supply chain, adaptable tooling (such as undersea equipment for deepwater operations, reducing the need to resurface equipment), but also in policy such as the scarce-product allocation in PHARMA.

PHARMA could shift production – labour resources – from two different lines to increase Influenza medicine availability while retaining a robust production capability for unrelated lines. BP Upstream used a multi-purpose rig, the Deepwater Horizon, for both exploration and establishing production readiness. This flexibility can come at a cost: such a rig, for example, is at the top-end of daily rates (USD 1 Million per day for certain operations). The recovery operation also created new modes of flexibility for its remotely operated vehicles (ROVs), which could rapidly exchange tooling without resurfacing from the seafloor – saving many hours on every step.

8.7.6 Increase Inventory

Traditional supply chain optimization often seeks an 'optimal' stock of inventory to reduce working capital or increase design flexibility. Sudden spikes in demand or disruption of supply to inventory can obviously diminish the firm's ability to respond. As the evolution of a disruption may be unpredictable, the firms studied here sought to increase inventory to cover variance in the supply chain.

Sharp increase in demand or sudden disruption in the supply chain will have an immediate shift in the optimal availability of inventory. Increasing inventory is an explicit goal in this data, as part of the solving disruption remedy itself - e.g. emergency equipment - and as part of meeting existing or increased demand. Where competitors are affected in the same disruption, increase in inventory on scarce inputs becomes a competitive priority. While a carrying cost can be significant, 'strategic' inventory – as PHARMA refers to stock of key materials – is shown in these cases to support faster recovery. PHARMA, for example, reduces the dependency on shared machinery with limited capacity by over-producing secondary products in the supply chain. BP Upstream could assemble a remarkable fleet of support ships for oil recovery through its partnerships, though often operated at the extreme edge of internal capacity in many of its operations. Similarly, BP Refining and Marketing had driven its production capacity to the limit – employee exhaustion, reduced testing, reduced training, reduced supervision, reduced operating maximum pressure of aging equipment, etc. all pointed to a lack of 'inventory' in a broad sense that made incident detection and management far more difficult.

8.8 Core Categories in Related to the 3-D Framework

This research has used diverse examples of catastrophic events to argue that firms can use a time-based risk management concept to reduce the response lead-time (detection time (D1) + design lead-time (D2) + deploy lead-time (D3)), which will in turn reduce the impact of a disruption.

Through an iterative process of coding and categorisation, each tailored approach is identified which is expressed in observations of relevant actions performed by the firm or related parties. Some approaches are seen as lacking, but suggested in the subsequent root cause analysis or after-the-fact recommendations made by the firm.

The four factors are explained earlier in the previous section. These factors may have significance across one or more phases of the response lifecycle. The use of each tailored approach in the cases is shown in the following (Table 33) across the lifecycle of detection-, design- and deployment lead-time. Moreover, while some approaches may be uniquely effective in the context of catastrophic risk management – for example cooperation in recovery with direct competitors – the most effective approaches may have a positive effect on operational performance, prior to an event.

Table 33 summarizes the observed actions in each case, indicated as follows:

- Actions were explicitly identified and taken by the firm to improve response time.

- Actions were identified after the event, and are considered by the firm as potential improvements in response for comparable events in the future.
- Actions were not taken nor identified by the firm or its partners, but might have had a positive impact on response speed.
- Actions were not taken nor identified by the firm or its partners, and would be unlikely to have had a relevant or positive effect on response speed.

The first two are indicated by a diamond symbol [◆], the second by a dash [-]. As this study is in the early stages of building the framework, only positive observations can be confirmed. Investigation on the effectiveness of each approach, impact of withholding the tailored approach or possible risks for each would be appropriate in further study of the same or new cases in management of disruption risk.

Table 34 shows a summary of examples from three cases by grouping the actions and initiatives taken by each company in detection and response to the disruption. Data display was used in an organised, compressed way according to Miles and Huberman (1994) for the purpose of data reduction. The table suggest tailored approached activities that would enable the firms to reduce the respond lead-time, which affect the impact of supply chain disruptions. Correspondingly, as evidenced by investigation and retrospective recommendations, lacks of such capabilities hinder companies in detecting and responding in a timely fashion to severe disruption.

Time	Factors	Tailored approaches	PHARMA	BP Deepwater	BP Texas
Detection Time (D1)	Preparation	Develop advanced warning system	◆	◆	◆
		Conduct stress testing	◆	◆	◆
		Develop scenario plan and modelling capability	-	◆	◆
		Leverage preparedness plan	-	-	-
		Implement training	-	◆	◆
	Partnership	Establish frequent communications with supply chain partners	◆	◆	-
		Establish relationship with local and international agencies, business partners and competitors	◆	◆	-
	Organisation	Create integrated response team	-	-	-
		Shorten lines of communications within the organisation	-	-	◆
		Clarify roles and responsibilities	-	-	-
		Establish learning from past events and during the events	-	-	◆
	Reserve	Assure management and employee capacity	-	-	-
		Increase capacity	-	-	◆
		Develop product or solution extensions	-	-	-
		Acquire additional suppliers	-	-	-
		Increase flexibility	-	-	-
		Increase inventory	-	-	-
Design Lead-Time (D2)	Preparation	Develop advanced warning system	-	-	-
		Conduct stress testing	-	-	-
		Develop scenario plan and modelling capability	◆	◆	-
		Leverage preparedness plan	◆	◆	◆
		Implement training	-	-	-
	Partnership	Establish frequent communications with supply chain partners	◆	◆	◆
		Establish relationship with local and international agencies, business partners and competitors	-	-	-
	Organisation	Create integrated response team	◆	◆	◆
		Shorten lines of communications within the organisation	◆	-	◆
		Clarify roles and responsibilities	◆	-	-
		Establish learning from past events and during the events	◆	◆	◆
	Reserve	Assure management and employee capacity	-	-	-
		Increase capacity	-	-	-
		Develop product or solution extensions	◆	◆	-
		Acquire additional suppliers	◆	-	-
		Increase flexibility	◆	◆	-
		Increase inventory	-	-	-

Time	Factors	Tailored approaches	PHARMA	BP Deepwater	BP Texas
Deploy Lead-Time (D3)	Preparation	Develop advanced warning system	-	-	◆
		Conduct stress testing	◆	◆	-
		Develop scenario plan and modelling capability	-	◆	◆
		Leverage preparedness plan	◆	◆	◆
		Implement training	◆	◆	◆
	Partnership	Establish frequent communications with supply chain partners	◆	◆	◆
		Establish relationship with local and international agencies, business partners and competitors	◆	◆	-
	Organisation	Create integrated response team	◆	◆	-
		Shorten lines of communications within the organisation	◆	-	-
		Clarify roles and responsibilities	-	-	-
		Establish learning from past events and during the events	-	◆	◆
	Reserve	Assure management and employee capacity	◆	◆	◆
		Increase capacity	◆	◆	◆
		Develop product or solution extensions	◆	◆	◆
		Acquire additional suppliers	-	◆	-
		Increase flexibility	◆	◆	-
		Increase inventory	◆	◆	-

Table 33: A Summary of Findings from Three Settings in Related to 3-D Framework

Factors underlying response lead time	Tailored approaches	Examples from PHARMA H1N1 2009 Influenza Pandemic	Examples from BP Response to Deepwater Horizon Oil Spill	Examples from BP Texas Refinery Explosion
Preparation (PR)	Develop advanced warning system	• Assigned staff to monitor the information and process flow.	• Well pressure monitoring: distractions while working prevented early detection. • Gas detection systems for early warning (example: drill floor level was alarm was turned off) • Lack of shift change information from night to day shift. • Driller's display screen (Sperry-Sun) difficult to interpret, e.g. (pressure anomaly unnoticed) • No on-shore real-time monitoring facility.	• Failed alarm systems, e.g. high-level alarm sounded two minutes late when much higher liquid level was received. • Broken physical sight equipment for visual inspection. • No general alarm sounded, instead radio reports and shouting to notify workers in the area. • Alarms not tested prior as required by standard operating procedures.
	Conduct stress testing	• Pandemic stress testing each year (July).	• Engineering tests prior to deployment of equipment (example: BOP was not tested). • Positive-pressure tests of well integrity. • Negative-pressure test of well integrity. • Cement testing during formulation by Halliburton.	• No approval of facilities layout (dangerous positioning of trailers). • Lack of process review during sensitive shut down / start up phases.
	Develop scenario plan and modelling capability	• Modelling the second wave of pandemic to estimate demand of medicines.	• Model of gas flow and explosion on the rig. • Cement model software at Halliburton • Independent testing of cement formulation by Chevron and CSI. • OLGA software well-flow modelling. • Simultaneous Operations using storyboarding to coordinate operations after the event. • Oil spill modelling after the event. • Forensic study of BOP after it was retrieved from the sea floor (flow modelling, finite element modelling).	• Gas flow modelling. • Major Accident Risk analysis performed in 2003, however using limited scope and generic industry data.
	Leverage preparedness plan	• Assessment and update site pandemic preparedness plan.	• Blow-out procedures during well completion. • Rig abandonment procedures.	• Standard shutdown procedures. • Standard emergency procedures.
	Implement training	• Assure skill availability for managing risk.	• Blow out prevention school for key engineers • Online electronic bulletins and document databases.	• Employee training on leading indicators to sense possible disruptions. • Local trained emergency response

Factors underlying response lead time	Tailored approaches	Examples from PHARMA H1N1 2009 Influenza Pandemic	Examples from BP Response to Deepwater Horizon Oil Spill	Examples from BP Texas Refinery Explosion
				services from Texas City fire and ambulance services.
Partnership (PA)	Establish frequent communications with supply chain partners	• Proactive contact with governments to anticipate orders and allocate stock proportional to need. • Increase frequency of press and public communications. • Establish direct line of communication with external suppliers.	• Improve communication with key suppliers: e.g. Halliburton communication of cement test results was incomplete. • Increased frequency of press and public communications-daily press briefings. • Real-time video camera feed ('spillcam)'. • Congressional hearings after the event. • Radio relay network for thousands of ships and team to coordinate response.	• Participation in congressional hearings. • Baker panel on BP refinery safety to review implementation of recommended changes. • CSB investigations on root-cause and management background to the event. • EPA investigations on adherence to regulation and environmental impact. • OSHA investigations on root-cause and employees safety.
	Establish relationship with government, agencies, press, business partners and expertise	• Coordination with international agencies e.g. CDC and WHO. • Establish relationship with experts in the industry.	• Invite external experts (academic, industry) to assist in design.	•
	Establish relationship with competitors	• N/A	• Outsourcing key tasks (Halliburton, Chevron, etc.) before and after event. • Shell help BP adding capacity by provides ships for clean up. • Marine Well company formed after event to facilitate recovery and reduce cost of reserve.	• N/A
Organisation (O)	Create integrated response team	• Create pandemic management organisation chart. • Established integrated response team called "Crisis Management Team". • Create frequent communication with site directors. • Set up a War room at headquarters. • Established online team room for document sharing.	• BP internal investigation team. • Established integrated response team called "Unified Command".	• Creation of cross-functional investigation team within BP in first 24 hours.
	Shorten lines of communications within the organisation	• Modify organisation hierarchy to shorten lines of communication.	• N/A	• BP created a new communication structure for safety related issues.
	Clarify roles and responsibilities	• Revised logistics pandemic BCP and site pandemic	• N/A	• N/A

Factors underlying response lead time	Tailored approaches	Examples from PHARMA H1N1 2009 Influenza Pandemic	Examples from BP Response to Deepwater Horizon Oil Spill	Examples from BP Texas Refinery Explosion
		preparedness plan. • Revised and updated roles and responsibilities as formally documented in RACI diagram.		
	Establish learning from past events and during the events	• Learning from past epidemics (e.g. H5N1 Avian Flu).	• BP investigation team on root-cause and possible mitigation. • National Commission on BP Deepwater Horizon Oil Spill Offshore Drilling • Chief Counsel's Report • Coast Guard ISPR and BOEMRE Joint Investigation • DNV BPO Report on key equipment. • Department of Justice Investigation on potential criminal liability.	• Independent panel to determine critical factors. • Updated physical site layout recommendations. • Numerous recommendations on engineering, process, management, training.
Reserves (R)	Assure management and employee capacity	• Distribute H1N1 antiviral medicines to employees. • Lockdown managers in-country and restrict travel to at-risk areas (Mexico). • Recruiting contingency workers to cover peak period and move to 24/7 shifts for greater production capacity in existing sites (Nicole).	• Rig was abandoned relatively quickly to avoid further casualty. • Leverage rig personnel in immediate fire-fighting operations. • Extensively staffed 27 hours search for survivors.	• Improved safety procedures for employees. • Improved control over dangerous ('hot') work areas and general operations during sensitive start-up and shutdown sequence.
	Increase capacity	• Reallocate labour resources to increase capacity of Nicole. • Leverage production load balancing by reducing load of production on some sites while increase production on main sites.	• Oil recovery and burning facilities put in place to reduce impact of spill. • Hire wide group of existing fishing vessels to assist in recovery ('Vessels of Opportunity')	• Improved staffing to reduce employee fatigue and improve alertness and response speed. • Reduce distractions in control room. • Allocate time to complete testing. • Geographic reserve – greater spacing of activities for improved Simultaneous Operations, e.g. trailer siting.
	Develop product or solution extensions	• Having easier-to-manufacture Nicole capsule inhaler product design in place and ready to produce. • Accelerate approval process for new products e.g. Nicole capsule inhaler and antiviral masks.	• Initiate Relief Well drilling immediately. • Develop new design solutions in place (Top Hat, Oil Boom, Artificial Barrier, Top Kill, Skimmers, Junk Shot, BOP activation)	• Changes in system design (e.g. removing out-of-date blowout preventor).
	Acquire additional suppliers	• Granting a production licence to a Chinese manufacturer.	• Relief well drilling using capacity from Transocean.	• N/A

Factors underlying response lead time	Tailored approaches	Examples from PHARMA H1N1 2009 Influenza Pandemic	Examples from BP Response to Deepwater Horizon Oil Spill	Examples from BP Texas Refinery Explosion
			• Leasing of clean-up equipment from across the industry.	
	Increase flexibility	• Using generic pack (vanilla pack) instead of market specific packaging. • Shift shared Hematol manufacturing capacity to Nicole. Shared same machine, labour, resources, warehouse, quality insurance etc.	• Design of rigs for multiple operations (exploration, drilling, production on both gas and oil)	• N/A
	Increase inventory	• Increase raw material by securing all available active pharmaceutical ingredients (API) from the suppliers. • Increase strategic stock of micronised ingredients.	• Deploy remotely operated vehicle (ROV) with more flexible tooling	• N/A

Table 34: A Summary of Examples from Three Settings

Chapter 9
Conclusion

9.1 Research conclusion

This empirical study of three cases of major supply chain disruption set out to contribute to the further development of a framework of time-based supply chain risk management and formulate propositions for further study and validation. Three additional objectives were stated, to examine how three global corporations perceive and manage risk, look at how companies incorporate techniques to reduce time, and finally identify, analyse and categorize the possible factors that underlying time of response.

The investigation of three major supply chain disruptions demonstrates that there are identifiable patterns to how global organizations attempt to manage time in responding to supply chain disruption, through action and structure in detection, design and deployment of solutions.

Grounded Theory methodology proved effective, where a Straussian approach was taken, using the time-based risk management framework as a lens to construct interview questions and case-based qualitative data collection. An adaptive approach is used to formulate core categories of tailored approaches that can reduce time of detection, design and deployment of solutions. The emerging framework was further developed using data from the second two cases.

Four propositions emerge, expressed below, stating that Preparation, Partnership, Organization and Reserve are key factors in reducing response time. The theoretical and management implications, and recommendations for further research are presented as follows.

9.2 Implications of the research

9.2.1 Theoretical implications

This research provides a first empirical examination of a time based risk management framework using Grounded Theory method.

Based on our empirical research and review of the literature, I propose the following relationship between response time and each of four constructs.

Proposition 1: Firm seeks to reduce response time to supply chain disruption through preparation by training, preparedness plans, stress testing, modelling or advance warning systems.

Proposition 2: Firm seeks to reduce response time to supply chain disruptions through organisational development on lines of communication, roles and responsibilities, learning or empowerment.

Proposition 3: Firm seeks to reduce response time to supply chain disruptions through partnerships among others suppliers, customers, technical and scientific experts, government agencies or public media.

Proposition 4: Firm seeks to reduce response time to supply chain disruptions with appropriate reserves such as increased capacity or increased inventory.

These propositions can augment existing knowledge related to time-based risk management but also support hypothesis testing for future research in the field of supply chain risk management.

9.2.2 Managerial implications

The study is based on a set of real-world cases of supply chain disruption that had broad impact within and external to the firms. As a direct benefit from using a Grounded Theory methodology, the concepts derived remain close to the real-world managerial perspective of the participants in each case. Managers can benefit from adapting risk-mitigation and risk-response measures through improving existing or new business continuity efforts. Investors and stakeholders such as lenders, investors, government and industry bodies have a keen interest in understanding risk management readiness. Improved agility and responsiveness is a direct outcome of a time-based risk management, benefitting overall supply chain performance through greater awareness of primary and secondary processes and improved communication.

Organizational factors internal and external to the organization are often mentioned. These are directly accessible for strategic management. The identified tailored approaches are qualitative in nature, and should prove to be complementary to traditional quantitative supply chain modelling and management.

The approach and framework of solutions may have benefits in general supply chain operational performance as well as improving speed of response during disruption. For example, lines of manufacturing in PHARMA that can handle multiple products provide supply chain scale, flexibility and reserve capacity. The flexibility added to equipment used at vast depths beneath the sea was essential to develop and trial possible solutions to the BP Deepwater Horizon disaster. The same techniques now greatly reduce the time and expense in handling routine operations on the sea floor.

This classification of factors can form the basis of a useful tool for supply chain managers to assess and balance investment in management of disruption risk in the supply chain.

This study used pharmaceutical industry and energy industry as examples, but the findings can be applied in other industries, which can be useful to practitioners. There are recent cases of disruption both natural and man-made from supply-chains

in the electronic, computer and automobile industries where this could apply, to name a few.

For instance, in mobile phone industry, one of the most referenced cases in supply chain disruption is the fire at the Philips microchip plant in Albuquerque, New Mexico in March 200, which simultaneously affected both Nokia and Ericsson. As the two major customers of the Philips plant, both firms were notified on the same Monday following the accident. Their very different reactions to this seemingly minor event have highlighted the importance of managing supply chain risk to other companies. While Ericsson took weeks to absorb the information and react, Nokia moved swiftly at all levels in its relationship with Philips and with alternate component suppliers, assuring continuity of product delivery towards its own customers. The impact was far-reaching – allowing Nokia to extend its market leadership (to 27% by 2002) and contributing to Ericsson's merger of its handset business with rival Sony with loss of USD 400 million in 2000.

The key lessons learned from this case can be structured using the proposed framework as follows:

1. The cost of reaction grows disproportionately with time. The company, which can shorten respond time can effective, reduce impact of supply chain disruption (*detection*).
2. By swiftly taking control of the supply of a critical component, Nokia secured its manufacturing its manufacturing capacity but also effectively blocked Ericsson from recovering in the same time-frame – this shows that Nokia had a superior *reserve* in term of production capacity and supplier capacity.
3. *Learning* and *organization* are important. Nokia had previously faced a similar event and had subsequently put in place the mechanisms to support a faster and more flexible response.

4. A strong *partnership* with other suppliers helped Nokia secure *reserve capacity* at other Philips plants and every other supplier that Nokia could find. While, Ericsson had no other component source. This costly disruption generate new *learning* to Ericsson – as they company defined new concepts, put in place new methods and *plans*, and *modelled* reaction time in dealing with the inevitable disruption event in the future.

During the primary cases were analysed, several comparable events underscored the need for a coherent time-based risk-management framework. In March 2011, an earthquake of the coast of Japan was quickly followed by a devastating tsunami. At least 15,000 people died and more than one million buildings were destroyed or damaged. This virtually shut down industry for months in the region, having a significant impact on export-oriented industries.

Just four months later, while Japan was still wrestling with near nuclear disaster at the damaged Fukushima power station and beginning the massive clean-up effort, catastrophic flooding hit Thailand, the worst for more than a century. Low-cost industrial production areas just north of Bangkok were among the areas worst hit, damaging production facilities in components and finished products such as automotive components, cameras, analog and semiconductors, and hard disks. Two of the largest disk makers, Western Digital and Seagate, had a large portion of their global manufacturing in the area and had to stop production, as did Toshiba whose motor supplier Nidec was unable to continue manufacturing. Shipment of disks dropped by 25% in the third quarter of 2011, causing price increase and supply shortage in the laptop and consumer market. The Thailand flooding was the second major natural disaster to affect Japan that year. Some 1,800 Japanese manufacturers operate in the country and 450 Japanese businesses are located in the flood-hit industrial parks. All major car manufacturers, for example, have significant supply chain operations in Thailand serving the domestic and regional markets, "HIS Automotive downgraded Thailand's light-vehicle forecast to 1.64 million units in the fourth quarter, down from 1.77 million units…these have affected vehicles to be exported to core market in the ASEAN region, Australia,

Japan and the Mille East where Thailand's exports account for 56 percent of total production.[47]"

These dramatic events, which affected millions of citizens as well as supply chain partners across the globe, provide a clear test of how quickly a global firm can respond and recover from disruption.

A less visible but equally far reaching event was triggered by a small fire in the Marl Chemical factory in Germany, part of Evonik Industries global manufacturing capabilities. Sadly, although the fire was quickly extinguished, two employees died, and there was some concern over environmental impact to the nearby town; luckily no major health risk faced the broader public. The plant produced a specialized resin used in the automotive industry to make brake and fuel lines. This relatively small event pushed US OEMs and suppliers to meet as an industry to discuss the global impact: "The shortage of the resin may impact the production of these components in the next few week. The shortage is real and immediate…the possibility of production interruptions at some of your facilities in the next few weeks is high[48]" said William Kozyra, chairman of Auburn Hills, Michigan-based TI Automotive.

This latest supply chain disruptions should further companies interest in evaluating and managing their supply chain risks. It is also urged the companies, for example, to look at a greater geographical (location) spread of their supply chain for new factories and in terms of suppliers or relocating production. The factors proposed in this paper can be used to evaluate response and improve response speed. Using this viewpoint, lessons learned from Tsunami and Thai floods include:

1. Risk factors were overlooked when businesses sought areas with low labour costs such as the industrial zones north of Bangkok.
2. Business should know their supply chain inside out – which includes knowing the business partners and understanding the risks they face and responses they might take.

[47] Zhang, F. (2008)
[48] Trudell et al., (2012)

3. Executives need to be aware of risks – this should be built into the culture of the organisation. Every level in the company must know about the risks to the supply chain and any contingency and mitigation plans in place.
4. Suppliers are a critical part of the supply chain and product development process, the relationship and frequent communications are critical to rapid response.
5. Visibility into key supplier performance and the ability to evaluate and simulate disruption (preparation: scenario planning and modelling) and constraints are as important as the internal operation planning process.
6. Risk mitigation and response management in the supply chain occurs at every level in the organization.
7. Where products are highly specialized, as in the Marl fire example, the supply chain requires specific reserve capacity in the form of stock, manufacturing, or alternatives.
8. Partnership with competitors or from exceptional relationships, such as in the nuclear response at Fukushima, which involved worldwide resources, can accelerate response.

9.3 Limitations of the Study and Future Work

While the methodology proved effective for the nature of event under study, the research has several limitations.

Only two industries are used and two cases are from derived from the same firm, albeit quite different divisions and business models. Applicability to other industries could be explored through further study.

A small set of cases was used, due to the intensity of study and duration. Ideally, this could be expanded to a larger set, where statistical and other quantitative methods can enhance the qualitative approach used here. As mentioned, new cases could be added, such as the 2011 Tohoku earthquake and tsunami in Japan, or flooding in recently developed industrial areas north of Bangkok.

Firms are global and of societal importance, putting great scrutiny on external communications and analysis. These cases are particularly well studied and scrutinized in the public eye and firms faced potential and real litigation. Legislation

and litigation were important factor, which may bias some response in first hand interview and availability of data outside formal testimony.

On a practical note, the use of software could facilitate the coding process for this or a following study.

This study provides a foundation for further research.

From a theoretical point of view, evaluation of the propositions can be used to validate or explore applicability of theories that address the cause, frequency and avoidance of disruption, in particular Normal Accident Theory versus High Availability Theory. From this study, it is apparent that several factors underlie early detection – line of communication as well as training, for example, as well as rapid response in total.

The second avenue for further research could empirically study the perception and use of factors as stated above in broader set of firms including those firms who have experienced major disruption as well as a test group who perceive their supply chain to have maintained planned supply chain operations.

A different perspective in empirical validation would be to explore the perceived trade-off between factors, for example effectiveness of training and fixed preparedness plans prior to an event versus the rapid solution development during an event response (e.g. new or modified solutions). In the case of the BP Deepwater Horizon oil spill, for example, established oil spill containment techniques were in some cases useless (e.g. artificial berms) and even potentially harmful (chemical dispersants). Under certain circumstances, it could be postulated that inappropriate plans may in fact delay the rapid development of more effective, new solutions, given the complex and infrequent nature of catastrophic disruption.

Lastly, further research is warranted to assess the cost / benefit aspects where the identified factors can imply a significant investment or create additional risk. It can be again postulated, for example, that close cooperation with competitors to leverage solutions or increase deployment capacity may reduce the imperative for a firm to invest sufficiently in internal reserve.

Data from a larger sample size of firms could be used to evaluate managerial decision-making, interdependence, and perceived cost / benefit for specific factors of response to low frequency and high-impact events.

This research examine events in two major corporations using a Grounded Theory approach to identify and characterize factors driving response lead-time in the face of significant supply chain disruption. Building on an emerging framework in time-based response, in the context of existing literature on supply chain complexity and supply chain management, these factors provide a vehicle for further research.

It is a starting point to highlight a potentially rich area of empirical research in supply chain risk using Grounded Theory. This study adds new concepts on improving response to disruption to literature that has been primarily focused on prevention of delays and disruptions through various means rather than on planning for post-incident recovery as it focuses on response rather than the capability to respond.

The factors are derived directly from observations and recommendations made by the firms and their stakeholders and occur in recognizable patterns – both in their presence with successful support to risk response and in their absence with contribution to delay and exponentially greater impact. Although the cases are found in different domains: a leading pharmaceutical response to a pandemic, upstream oil exploration under extreme and unfamiliar conditions, downstream energy refining in antiquated, profit-oriented industrial site, the commonality of factors in Preparation, Partnership, Organisation and Reserve between the cases suggest that further investigation can lead to an improved mitigation of catastrophic risk in complex supply chains.

Bibliography

60 mintues. (2010a) BP's deepwater horizon oil rig disaster 3. [Video] Available from: http://www.youtube.com/watch?v=Ubqfo0x0nLo&feature=related.

60 mintues. (2010b) BP's deepwater horizon oil rig disaster 3. [Video] Available from: http://www.youtube.com/watch?v=PLKTyYLJ54s&feature=related .

Achenbach, J. (2010) BP cost-cuting measures are focus of U.S. inquiry into gulf spill. *The Washington Post.* [Online] Available from: http://www.washingtonpost.com/wp-dyn/content/article/2010/10/08/AR2010100803145.html

Andreewsky, E. & Bourcier, D. (2000) Abduction in language interpretation and law making. *Kybernetes*, 29 (7/8), 836-845.

Ansoff, H. I. (1975) Managing strategic surprise by response to weak signals. *California Management Review*, 18 (2), 21-33.

Arora, V. K. & Boer, G. J. (2005) Fire as an interactive component of dynamic vegetation models. *Journal of Geophysics Research*, 110 (G02008), 1-20.

Arrow, K. J. (1965) *Aspact of Theory of Risk Bearing.* Helsinki, Yrjö Jahnssonin Säätiö Publishing.

Ashton, D. & Tippette, M. (2003) Systematic risk and empirical research. *Journal of Business Finance and Accounting*, 25 (9/10), 1325-1356.

Associatedpress. (2010) Engineer: Deepwater horizon alarm 'inhibited'. [Video] Available from: http://www.youtube.com/watch?v=9shhEjTeMhU.

Baird, I. & Thomas, H. (1990) What is ris anyway? In R. A. Bettis & H. Thomas (Eds.), *Risk, Strategy and Management*, 21-52. Greenwich: JAI Press.

Barnes, P. H. & Oloruntoba, R. (2005) Assurane of security in maritime supply chains: conceptual issues of vulberability and crisis management. *Journal of International Management*, 11 (4), 519-540.

Barney, J. B. & Ouchi, W. G. (1986) *Organisational Econonics*, San Francisco, CA: Jossey-Bass Publishers.

Baucus, D. A., Golec, J. H. & Cooper, J. R. (1993) Estimating risk-return relationships: an anlysis of measures. *Strategic Management Journal*, 14 (5), 387-396. Available from: DOI: 10.1002/smj.4250140506.

Beckera, N.C. and Lillemarkb, M. (2006) "Marketing/ R&D integration in the pharmaceutical industry", *Research Policy,* Vol. 35 No. 1, pp.105.20.

Benbasat, I., Goldstein, D. and Mead, M. (1987) "The case research strategy in studies of information systems", *MIS Quarterly,* September, pp.369-86.

Berlin, Frenkel, M. and Rudolf, M. (2005) *Risk Management: Challenge and Opportunity,* 2nd revised and expanded edition, Springer-Verlag.

Bernstein, P. (1996), *Against the Gods: The Remarkable Story of Risk,* Wiley, Chichester.

Billings, R. S., Milburn, T. W. & Schaalman, M. L. (1980) A model of crisis perception: A theoretical and empirical analysis. *Administrative Science Quarterly,* 25**,** 300-316.

Blackburn, J.D. (Ed.) (1991) *Time-based Competition: The Next Battleground in American Manufacturing*, Business One Irwin, Homewood, IL.

Blume, M. E. (1971) On the assessment of risk. *The Journal of Finance,* 26**,** 1-10.

Bockerstette, J.A. and Shell, R.L. (1993) *Time-based Manufacturing, Industrial Engineering and Management Press*, Norcross, GA.

Bode, C., Friederichs-Schmidt, S., Lindemann, E. & Sauer, R. (2007) Supply chain risiken und ihre versicherbarkeit. *Logistik Management,* 9**,** 8-22.

Bowersox, D.L and Closs, D.J. (1996) *Logistical Management,* The Integrated Supply Chain Process, McGraw-Hill, International Edition.

BP (2010a) BP'sdeepwater horizon oil rig disaster 2, Available from: http://www.youtube.com/watch?v=tXnFpkJ9au8&feature=related .

BP (2010c) Deepwater horizon accident investigation report, BP. Available from*:* http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/incident_response/STAGING/local_assets/downloads_pdfs/Deepwater_Horizon_Accident_Investigation_Report.pdf.

BP (2010d) Deepwater horizon accident investigation report appendixes abfgh, BP

BP (2010e) Deepwater horizon accident investigation report appendixes cde, BP.

BP (2010f) Deepwater horizon accident investigation report static presentation, BP.

BP (2010g) Deepwater horizon containment and response: Harnessing capabilities and lessons learned, BP. Available from: http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/incident_response/STAGING/local_assets/downloads_pdfs/Deepwater_Horizon_Containment_Response.pdf.

Brindley, C. (2004), *Supply Chain Risk*, Ashgate, USA.

British Standards Institute (1995) *BS7799- Code of Practice for Information Security Management*, BSI, London,

Burnes, B. and New, S. (1996) "New perspectives on supply chain improvement: purchasing power v supplier competence", *European Journal of Purchasing & Supply Management,* Vol. 2 No. 1, pp.21-30.

Burnes, B. and Dale, B. (Eds) (1998) *Working in Partnership,* Gower, Aldershot.

Burns, A., Mensbrugghe, D. and Timmer, H. (2008) Evaluating the economic consequences of Avian Influenza. *The World Bank's June 2006 Edition of the Global Development Finance* [Online] Available from: http://siteresources.worldbank.org/EXTAVIANFLU/Resources/EvaluatingAHIeconomics_2008.pdf

Cavinato, J. L. (2004) Supply chain logistics risks: From the back room to the board room. *International Journal of Physical Distribution & Logistics Management,* 34**,** 383-387.

Casselman, B. & Gold, R. (2010) BP decisions set stage for disaster The Wall Street Journal. Available: http://online.wsj.com/article/SB10001424052748704026204575266560930780190.html.

CBS (2007) Final investigation report. Available from: http://www.csb.gov/index.cfm?folder=current_investigations&page=info&INV_ID=52

Celly, K. S., Frazier, G.L. (1996) Outcome-based and behavior-based coordination efforts in channel relationships. *Journal of Marketing Research* 33**,** 200–210.

Charmaz, K. (2000) Grounded thoery: Objective and constructivist methods. In N.K. Denzin & Y.S. Lincoln (Eds., *Handbook of Qualitative Research* (2nd ed.). Thousand Oaks, CA: SAGE.

Charmaz, K (2004). Premises, principles, and practices in qualitative research: Revisiting the foundation. *Qualitative Health Research,* 14, 976-993.

Charmaz, K. (2006). *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*. Thousand Oask, CA: SAGE.

Chartered Management Institute (CMI) (2002), *Business Continuity and Supply Chain Management,* report available at: www.thebci.org/2809-01 Bu Continuity Summ.pdf. Accessed on 22 August, 2007

Child, J. and Faulkner, D. (1998), "Strategies of cooperation: managing alliances, networks, and joint ventures", Oxford University Press, 1998.

Chropra, S. and Sodhi, M. (2004) Managing risk to avoid supply chain breakdown. *Sloan Management Review*, 46(1): 53-61.

Chopra, S. and Sodhi, M. (2004), "Avoiding Supply Chain Breakdown", *Sloan Management Review,* Fall, Vol. 46 No. 1, pp.53-62.

Chow, K. V. & Denning, K. C. (1994). On variance and lower partial moment betas the equivalence of systematic risk measures. *Journal of Business Finance & Accounting,* 21**,** 231-241.

Christopher, M. (1992), *Logistics and Supply Chain Management: Creating Value-Adding Networks*, 3rd ed., Prentice-Hall, Harlow.

Christopher, M. (2002), *Supply Chain Vulnerability,* Cranfield University, Cranfield, final report on behalf of DTLR, DTi and Home Office.

Christopher, M. (2004), "Creating resilient supply chains", *Logistics Europe,* pp.14-21

Christopher, M. (2004),"Mitigating supply chain risk through improved confidence", *International Journal of Physical Distribution & Logistics Management,* Vol. 34 No. 5, pp.388-396.

Christopher, M. P., Helen (2002). Supply chain vulnerability. *Cranfield Research*.

Christopher, M. and Peck, H. (2004), "Building the resilient supply chain", *International Journal of Logistics Management,* Vol. 15 No. 2, pp.1-14.

Christopher, M. & Peck, H. (2004). Building the resilient supply chain. *International Journal of Logistics Management,* 15**,** 1-13.

Coase, R.H. (1939), *Business Organisation and Accountant.* Reprinted in J.M. Buchanan and G.F. Thirlby, eds, L.S.E. Essays on Cost (New York: New York University Press, 1981), pp.97-132.

Cohen, M.A. and Huchzermeier, A. (1999), "Global supply chain management: a survey of research and applications", in Tayur, S. and Ganeshan, R. (Eds), *Quantitative Models for Supply Chain Mnagement,* Kluwer, Boston, MA, pp.669-702.

Coleman, L. (2006). Frequency of man-made disasters in the 20th century. *Journal of Contingencies & Crisis Management,* 14**,** 3-11.

Cooper, M. C., Lambert, D. M. & Pagh, J. D. (1997). Supply chain management: More than a new name for logistics. *International Journal of Logistics Management,* 8**,** 14-11.

Cooper, M. C., Lambert, D. M. & Pagh, J. D. (1998). Supply chain management: Implementation issues and research opportunities. *International Journal of Logistics Management,* 9**,** 20-21.

Cortada, J.W. and Traser, H.E. (2005), "Mapping the future in science intensive industries: lessons from the pharmaceutical industry", *IBM Systems Journal,* Vol. 44 No. 1, pp.163-83.

Council of Logistics Management (CLM) (2003), http://www.clm1.org/aboutus_policy.asp#definitions. Accessed 22 August, 2007.

Cousins, P., Lamming, R.C. and Bowen, F. (2004), "The role of risk in environment-related initiatives", *International Journal of Operations & Production Management,* Vol. 24 No. 6, pp.554-65.

Covello, V.T. and Merkhofer, M.W. (1993), *Risk Assessment Methods- Approaches for Assessing Health and Environmental Risks,* Plenum Press, New York, NY.

Cox, A. and Townsend, M. (1998), *Strategic Procurement in Construction,* Thomas Telford, London.

Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J. & Handfield, R. B. (2007). The severity of supply chain disruptions: Design characteristics and mitigation capabilities. *Decision Sciences,* 38**,** 131-156.

Cresswell, J. W. (2003), *Research design: Qualitative, quantitative and mixed methods approaches (2nd ed.).* Thousand Oask, CA: SAGE.

Cucchiella, F. and Gastaldi, M. (2005), "Risk management in supply chain: a real option approach", *Journal of Manufacturing Technology Management,* Vol. 17 No. 6, pp.700-720.

Danermark, B. (2001), *Explaining Society: An Introduction to Critical Realism in the Social Sciences*, Routledge, Florence, KY.

Damodaran, A. (2007), *Strategic Risk Taking: A Framework For Risk Management*, Wharton School Publishing.

Damon, A. (2010), Deepwater horizon survivors told to take drug test before being allowed to call families. Available: http://www.wsws.org/articles/2010/may2010/deep-m06.shtml.

Daniels, N.C. and Essaides, G. (1993), *Time-based Competition*, Economic Intelligence Unit, London. DET NORSKE VERITAS. (2011b), *Final report for united states department of the interior, bureau of ocean energy management, regulation, and enforcement - forensic examination of deepwater horizon blowout preventer,* Washington, DC, OSC - Oil Spill Commission.

Dibb, S., Russell, I. and Simkin, L. (1997), "The EU marketing environment: pharmaceuticals and Japanese strategy", *European Management Journal,* Vol. 15 No. 2, pp.195-205.

Dickson, G. (1989), *Corporate Risk Management. Institute of Risk Management*, Witherby, London.

Dubois, A. and Gadde, L.-E. (2002), "Systematic combining: an abductive approach to case research", *Journal of Business Research*, Vol. 55, pp. 553-60.

Eisenhardt, K. (1989), "Building theories from case study research*", Academy of management Review*, Vol. 14 No 4, pp. 532-550.

Eisenhardt, M, K. (1989), "Agency theory: an assessment and review", *Academy of Management Review*, Vol. 14 No. 1, pp.57.

Elkins, D., Handfield, R. B., Blackhurst, J. & Craighead, C. W. (2005). 18 ways to guard against disruption. *Supply Chain Management Review,* 9**,** 46-53.

Elliott, D. and Smith, D. (1993), "Football stadia disasters in the United Kingdom: learning from tragedy", *Industrial and Environmental Crisis Quarterly,* Vol. 7 No. 3, pp.205-29.

Elliott, D., Swartz, E. and Herbane, B. (2002), *Business Continuity Managmenet. A Crisis Management Approach,* Routledge, London.

Elliott, L. (2005), "US trade deficit hits record after Boeing strike and hurricanes", *The Guardian,* 11 November, p.32.

Ellram, L.M. (1991a), "A managerial guideline for the development and implementation of purchasing partnerships", *Journal of Supply Chain Management,* Vol. 27 No. 3, pp.2-8.

Ellram, L.M. (1991b), "Supply chain management: the industrial organisation perspective" *International Journal of Physical Distribution & Logistics Management,* Vol. 21 No. 1, pp.13-22.

Ellram, L.M. (1996), "The use of case study in logistics", *Journal of Business Logistics,* Vol. 17 No. 2, pp.92-138.

Faisal, M.N., Banwet, D.K. and Shankar, R. (2006), "Supply chain risk mitigation: modelling the enablers", *Business Process Management Journal,* Vol. 12 No. 4, pp.535-52.

Financial Times (2011). Bp oil spill. Financial Times. Available: http://www.ft.com/indepth/bp-oil-spill.

Fink, S. (1986), *Crisis Management: Planning for the Inevitable,* American Management Association, New York, NY.

Fone, M. and Young, P. (2000), *Public Sector Risk Management*, Butterworth Heinemann, London.

Food and Agriculture Organisation (2010) Avian Influenza: continued support is required. *FAO* [Online] Available from: http://www.fao.org/avianflu/en/news/hpai_support.html

Frosdick, M. (1997), "The techniques of risk management are insufficient in themselves", *Disaster Prevention and Management,* Vol. 6 No. 3, pp. 165-772.

Gatignon, H. And Kimberly, J.R. (2004)*, The Insead-Wharton Alliance on Globalizing: Strategies for Building Successful Global Business,* Cambridge.

Giferenzer, G. (2002), *Reckoning With Risk*, Penguin Books, London.

Giunipero, L.C. and Brand, R.R. (1996), "Purchasing role in the supply chain management", *The International Journal of Logistics Management,* Vol. 7 No.1, pp.29-37.

Glaser, B. G. (1978). *Theoretical Sensitivity: Advances in the Methodology of Grounded Theory.* Mill Valley, CA: Sociology Press.

Glaser, B.G. (1992). *Basics of Grounded Theory: Emergence vs. Forcing.* Mill Valley, CA: Sociology Press.

Glaser, B.G. (1998). *Doing Grounded Theory: Issues and Discussions.* Mill Valley, CA: Sociology Press.

Glaser, B.G. (2001). *The Grounded Theory Perspective: Conceptualization Contrasted with Description.* Mill Valley, CA: Sociology Press.

Glaser, B.G. (2003). *The Grounded Theory Perspective II Description's Remodelling of Grounded Theory Methodology.* Mill Valley, CA: Sociology Press.

Glaser, B.G. (2005). *The Grounded Theory Perspective III: Theoretical Coding.* Mill Valley, CA: Sociology Press

Glaser, B.G. & Strauss, A.L. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research.* Hawthrone, NY Aldine de Gruyter.

Goldenberg, S. (2010). Deepwater horizon survivor describes horrors of blast and escape from rig. *The guardian.* Available at: <http://www.guardian.co.uk/environment/2010/may/20/survivor-deepwater-horizon-gulf-oil-explosion>

Golilic, S. L., Davis, D. F., McCarthy, T., Mentzer, J.T. (2002), "The impact on e-commerce on supply chain relationships", in *International Journal of Physical Distribution and Logistics Management,* Vol. 32 No. 10, pp.851-871.

Grayson, D. & Denyer, D. (2010), Reflections on the bp oil spill crisis. Cranfield Univeristy. Available: http://www.som.cranfield.ac.uk/som/p15276/Think-Cranfield/2010/September-2010/Reflections-on-the-BP-Oil-Spill-Crisis?utm_source=thinkcranfield&utm_medium=email&utm_term=operations&utm_content=think_article1&utm_campaign=think_sept2010&guid=26C87F0E-A2A6-4.

Greis, N.P. and Kasarda, J.D. (1997), "Enterprise logistics in the information era", *California Management Review,* Vol. 39 No.3, pp.55-79.

Grose, V. (1992), "Risk management from a technological perspective", *The Geneva Paper on Risk and Insurance,* Vol. 12 No. 64, pp.335-42.

Hallikas, J., Virolainen, V., Tuominen, M. (2002), "Risk analysis and assessment in network environments: a dyadic case study", International Journal of Production Economics, Vol. 78 No.1, pp.45-55.

Hamel, G. (1994), *Competing for the Future,* Harvard Business School Press, Prahalad.

Handfield, R. and Nichols, E.L. Jr. (1999), *Introducion to Supply Chain Management,* Prentice-Hall, Upper Saddle River, NJ.

Harland, C., Brenchley, R. and Walker, H. (2003), "Risk in supply networks", *Journal of Purchasing and Supply Management,* Vol. 9 No. 2, pp.51-62.

Harland, C., Zheng, J., Johnsen, T. & Lamming, R. (2004). A conceptual model for researching the creation and operation of supply networks1. *British Journal of Management,* 15**,** 1-21.

Hazarika, S. (1987), *Bhopal. The Lessons of a Tragedy,* Penguin Books, New Delhi.

Helferich, O. K. & Cook , R. L. (2002). *Securing the supply chain,* Oak Brook, IL, Council of Logistics Management.

Hendricks, K.B. and Singhal, V.R. (2002) "How supply chain glitches torpedo shareholder value", *Supply Chain Management Review 6*, No. 1, pp.18-24.

Hendricks, K.B. and Singhal, V.R. (2003), The effect of supply chain glitches on shareholder value", *Journal of Operations Management,* Vol. 21 No. 5, pp.501-22.

Hendricks, K.B. and Singhal, V.R. (2005), "An empirical analysis of the effects of supply chain disruption on long-run stock price performance and equity risk of the firm", *Production and Operations Management*, Vol. 14 No. 1, pp.22-53.

Heracleous, L. and Murray, J. (2001), "The urge to merge in the pharmaceutical industry", *European Management Journal,* Vol. 19 No. 4, pp.430-7.

Hermann, C. F. (1963). Some consequences of crisis which limit the viability of organizations. *Administrative Science Quarterly,* 8**,** 61-82.

Hiles, A. and Barnes, P. (Eds) (2001), *The Definitive Handbook of Business Continuity Management,* J. Wiley & Sons, Chichester.

Hill, T., Nicholson, A. and Westbrook, R. (1999), "Closing the gap: a polemic on plant-based research in operations management*", International Journal of Operations & Production Management*, Vol. 19 No. 2, pp.139-156.

Ho, S. S., Pike, R.H. (1992). Adoption of probabilistic risk analysis in capital budgeting and corporate investment. *Journal of Business Finance and Accounting,* 19**,** 387–405.

Hood, C. and Rothstein, H. (2000), "Business risk management in government: pitfalls and possibilities", *National Audit Office: Supporting Innovation- Managing Risk in Government Departments,* National Audit Office, London.

Hood, J. & Young, P. (2005). Risk financing in UK local authorities: Is there a case for risk pooling? *International Journal of Public Sector Management,* 18**,** 563-578.

Houlihan, J.B. (1985), "International supply chain management", *International Journal of Physical Distribution and Materials Management,* Vol. 15 No. 1, pp.22-38.

Hudson, L.A. and Ozanne, J.L. (1988), "Alternative ways of seeking knowledge in consumer research", *Journal of Consumer Research,* Vol. 14, pp.508-521.

Hum, S. and Sim, H. (1996), "Time-based competition: literature review and implications for modelling*", International Journal of Operations & Production Management*, Vol. 16, pp.75-90.

In-Pharma (5 October 2006) GSK lets Chinese firm manufacture flu drug. *In-Pharma Technologist* [Online] Available from: http://www.in-pharmatechnologist.com/Regulatory-Safety/GSK-lets-Chinese-firm-manufacture-flu-drug

Janssens, M. (2000), *Introduction to Mathematical Fire Modelling,* Second edition, CRC publisher.

Johnson, M.E. (2001), "Learning from toys: lessons in managing supply chain risk from the toy industry", California Management Review, Vol. 43 No.3, pp.106-24.

Jones, T.C. and Riley, D.W. (1985), "Using inventory for competitive advantage through supply chain management", *International Journal of Physical Distribution and Materials Management,* Vol. 15 No. 5, pp.16-26.

Juttner, U. (2005), "Supply chain risk management understanding the business requirements from a practitioner perspective", *The International Journal of Logistics Management,* Vol. 16 No. 1, pp.120-141.

Jüttner, U., Peck, H. & Christopher, M. (2003). Supply chain risk management: Outlining an agenda for future research. *International Journal of Logistics: Research & Applications,* 6**,** 197-210.

Keim, B. (15 June 2010) BP's 'Nightmare' Well: Internal documents uncover negligence. *Wired Science* [Online] Available from: http://www.wired.com/wiredscience/2010/06/bp-nightmare-email/

Kent, J.L. and Flint, D.J. (1997), "Perspectives on the Evolution of Logistics Thought", *Journal of Business Logistics*, Vol.18 No. 2, pp.15-29.

Khan, O. and Burnes, B. (2007), "Risk and supply chain management: creating a research agenda", *The International Journal of Logistics Management,* Vol. 18 No. 2, pp.197-216.

Kirkeby, O.F. (1990), "Abduktion", in Andersen, H. (Ed.), Vetenskapsteoriochmetodlara. Introduktion, (translated by Liungman, C.G.), Studentlitteratur, Lund.

Kleindorfer, P.R. and Saad, G.H. (2005), "Managing disruption risks in supply chains", *Production and Operation Management,* Vol. 14 No.1, pp.53-68.

Kieindorfer, P. R. & Van Wassenhove, L. N. (2004). Managing risk in global supply chains. *In:* GATIGNON, H., JOHN, R. K. & ROBERT, E. G. (eds.) *The insead-wharton alliance on globalizing.* Cambridge, UK: Cambridge University Press.

Knight, F.H. (1921), *Risk, Uncertainty and Profit*, Houghton Mifflin, Boston, MA.

Kor, Yasemin Y. and Mahoney, Joseph T., "Edith Penrose's (1959) Contributions to the Resource-based View of Strategic Management*", Journal of Management Studies*, Vol. 41, No. 1, pp. 183-191.

Kotzab, H., Seuring, S., Muller, N. and Reiner, G. (2005), *Research Methodologies in Supply Chain Management,* Phhysica-Verlag.

Kovacs, G. and Spens, K.M. (2005), "Abductive reasoning in logistics research", *International Journal of Physical Distribution & Logistics Management*, Vol. 35 No. 2, 2005.

Kovoor-Misra, S., Clair, J. A. & Bettenhausen, K. L. (2001. Clarifying the attributes of organizational crises. *Technological Forecasting and Social Change,* 67**,** 77-91.

Kraljic, P. (1983), "Purchasing must become supply management", *Harvard Business Review,* Vol. 61 No. 5, pp.109-17.

Lambert, D.M., Cooper, M.C. and Pagh, D. (1997), "Supply chain management: more than a new name for logistics", *The International Journal of Logistics Management* 8.1, pp.1-14.

Lambert, D.M., Cooper, M.C. and Pagh, D. (1998), "Supply chain management: implementation issues and research opportunities", *The International Journal of Logisitcs Management 9,* Vol. 1-19.

Lambert, D.M. and Cooper, M.C. (2000), "Issue in supply chain management", *Industrial Marketing Management,* No. 29, pp.65-83.

Lee, H. (2004), "The Triple-A Supply Chain," *Harvard Business Review*, pp.102-112.

Lee, H. L. & Billington, C. (1993). Material management in decentralized supply chains. *Operations Research,* 41**,** 835-847.

Lee, H. L. & Wolfe, M. (2003). Supply chain security without tears,. *Supply Chain Management Review,* 7**,** 12-20.

Leonard-Barton, D. (1990), "A dual methodology for case studies: synergistic use of a longitudinal single site with replicated multiple sites", *Organisation Science,* Vol. 1 No. 1, pp.248-66.

Lin, Z., Zhao, X., Ismail, K. M. & Carley, K. M. (2006). Organizational design and restructuring in response to crises: Lessons from computational modeling and real-world cases. *Organization Science,* 17**,** 598–618

Lonsdale, C. (1999), "Effectively managing vertical supply relationships: a risk management model for outsourcing", *Supply Chain Management: An International Journal,* Vol. 4 No. 4, pp.176-83.

Losch, A. (2006), "Combining qualitative methods and Grounded Theory for researching E-Reverse auctions", Department of Information and Communication, Manchester Metropolitan University, Manchester, UK.

Lowrance, W.W. (1980), "The nature of risk", in Schwing, R.C. and Albers, W.A. (Eds), *How Safe is Safe Enough?*, Plenum Press, New York, NY.

Lupton, D. (1999), *Risk*, Routledge, London.

Maanen, J.V. (1983), *Qualitative Methodology,* Sage Publication.

Macrae, F. (18 January 2010) The false pandemic: drug firms cashed in on scare over swine flu, claims Euro health chief. *Mail Online*. [Online] Available from: http://www.dailymail.co.uk/news/article-1242147/The-false-pandemic-Drug-firms-cashed-scare-swine-flu-claims-Euro-health-chief.html

Maccrimmon, K. R. & Wehrung, D. A. (1986). *Taking risks: The management of uncertainty,* New York, Free Press.

Malnight, T.W. (2001), "Emerging structural patterns within multinational corporations: toward process-based structures", *Academy of Management Journal,* Vol.44 No.6, pp.1187-210.

Manuj, I. & Mentzer, J. T. 2008. Global supply chain risk management strategies. *International Journal of Physical Distribution & Logistics Management,* 38**,** 192-223.

March, J.G. and Shapira, Z. (1987), "Managerial perspectives on risk and risk taking", Management *Science*, Vol. 33 No. 11, pp.1404-18.

Markowitz, H.M. (1959), *Portfolio Selection Efficient Diversification of Investment,* New Haven and London, Yale University press.

Martha, J. & Subbakrishna, S. (2002). Targeting a just-in-case supply chain for the inevitable next disaster. *Supply Chain Management Review,* 6**,** 18.

Mason-Jones, R. and Towill, D. (1998), "Shrinking the supply chain uncertainty cycle", *Control,* September, pp.17-22.

Mayring, P. (2002), "Qualitative Inhaltsanalyse", *British Medical Journal* Vol. 324, pp.838-842.

McGinnis, M.A., Boltic, S.K. and Kochunny, C.M. (1994), "Trends in Logistics Thought: An Empirical Study", *Journal of Business Logistics*, Vol. 15 No. 2, pp. 273-303.

Mckinnon, A. (2006). Life without trucks: The impact of a temporary disruption of road freight transport on a national economy. *Journal of Business Logistics,* 27**,** 227-250.

Members of the Subcommittee on Oversight and Investigations (2010), *Key questions arising from inquiry into the deepwater horizon gulf of mexico oil spill*.

Mentzer, J.T. and Kahn, K.B. (1995), "A framework of logistics research", *Journal of Business Logistics,* Vol. 16 No. 1, pp.231-251.

Mentzer, J.T. and Flint, D.J. (1997), "Validity in logistics research", *Journal of Business Logistics,* Vol. 18 No. 1, pp.199-216.

Mentzer, J.T. DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D. and Zacharia, Z.G. (2001), "Defining supply chain management", *Journal of Business Logistics,* Vol. 22 No. 2, pp.1-25.

Meredith, J. (1993): Theory building through conceptual methods, in: Journal of Business Logistics, 18(2): 199-216

Meredith, J. (1998): Building operations management theory through case and field research, in: Journal of Operations Management, 16(4): 439-452

Merna, A. and Smith, N.J. (1999), "Privately finaced infrastructure for the 21st century", *Proceedings of the Institution of Civil Engineers,* 132, pp.167-73

Merton, R.K., Fiske, M. and Kendall, P.L. (1990). *The focused interview: A manual of problems and procedures* (2n ed.), New York: Free Press.

Milburn, T. W., Schuler, R. S. & Watman, K. H. (1983). Organizational crisis. Part i: Definition and conceptualization. *Human Relations,* 36**,** 1141.

Miller, W.L., Crabtree, B.F. (1992), "Primary case research: A multimethod typology and qualification road map. In: Crabtree, B.F., Miller, W.L (Eds.), *Doing Qualitative Research*. Sage Publications, Newbury Park, CA.

Minahan, T.A. (2005), *The Supply Risk Benchmark Report,* Aberdeen Group, Boston, MA.

Mintzberg, H., Ahlstrand, B. and Lampel, J. (1998), *Strategy Safari: A Guided Tour Through The Wilds of Strategic Management,* Free press.

Mitchell, V-W. (1995), "Organisational risk perception and reduction: a literature review", *British Journal of Management,* Vol. 6, pp.115-33.

Mitroff, I. I. & Alpaslan, M. C. (2003). Preparing for evil. *Harvard Business Review,* 81**,** 109-115.

Mollison, D. (2003), *Epidemic Models: Their Structure and Relation to Data,* Cambridge University Press.

Moore, P.G. (1983), *The Business of Risk,* Cambridge University Press, Cambridge.

Mukherjee, A. Mitchell, W. and Talbot, F.B. (2000), The impact of new manufacturing technologies and strategically flexible production in: Journal of Operation Management, Vol. 18 pp. 139-168

Näslund, D. (2002), "Logistics needs qualitative research – especially action research", *International Journal of Physical Distribution & Logistics Management*, Vol. 32 No. 5, pp.321-338.

Newman, K. and Pyne, T. (1997), "Service Quality and Blood Donors – a Marketing Perspective", *Journal of Marketing Management*,, Vol.13, pp.579-599.

Newman, W.R., Hanna, M. and Maffei, M.J. (1993), "Dealing with the uncertainties of manufacturing: flexibilities, buffers and integration", *International Journal of Operations & Production Management,* Vol. 13 No. 1, pp.19-34

Norrman, A. & Jansson, U. (2004). Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution & Logistics Management,* 34**,** 434-456.

Norrman, A. and Lindroth, R. (2002), "Supply chain risk management: purchasers' vs. planners" view on Sharing Capacity Investment Risks in the Telecom Industry", *proceedings of the 11th International Annual IPSERA conference*, Twente University, 25th-27th March, pp.577-595.

Norrman, A. and Jansson, U. (2004), "Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident*", International Journal of Physical Distribution & Logistics Management*, Vol. 34 No. 5, pp. 434-56.

Oil Spill News (11 October 2010) Gulf of Mexico Oil Spill Blog Federal Hearings: Gulf of Mexico. [Online] Available from: http://www.oilspillnews.net/oil-spill-claims/gulf-of-mexico-oil-spill-blog-federal-hearings-gulf-of-mexico/

OSC - Oil Spill Commission (2011a), *Deep water: The gulf oil disaster and the future of offshore drilling - report to the president,* National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. Available at: http://www.oilspillcommission.gov/final-report.

OSC- Oil Spill Commision (2010b), *Congressional testimony,* Available at: http://www.oilspillcommission.gov/.

OSC - Oil Spill Commission (2010c), Macondo: The gulf oil disaster / chief council's report, National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.

OSC - Oil Spill Commission (2010d),*The history of offshore oil and gas in the united states - staff working paper no. 22,* National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling.

Osterholm, M.T. (5 May 2005) Preparing for the next pandemic. *The New England Journal of Medicine* [Online] Available from: http://www.nejm.org/doi/full/10.1056/NEJMp058068

OSHA (22 Septermber 2005) OSHA fines BP products North America more than USD 21 million following Texas City explosion. [Online] Available from: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=11589

Oxfam (2001) Briefing paper on PHARMA: Dare to lead, public health and company weath. [Online] Available from: http://www.oxfam.org.uk/

Pagell, M., Krause, D.R. (1999). A multiple method study of environmental uncertainty and manufacturing flexibility. *Journal of Operations Management* 17**,** 307–326.

Paraskevas, A. (2006), "Crisis management or crisis response system? A complexity science approach to organisational crises", *Management Decision,* Vol. 44 No. 7, pp.892-907.

Pearson, C.M. and Clair, J.A. (1998), "Reframing crisis management", *Academy of Management Review,* Vol. 23 No. 1, pp.59-76.

Peck, H. (2004), "Resilience: surviving the unthinkable", *Logistics Manager,* March, pp.16-18.

Peck, H. (2005a). Drivers of supply chain vulnerability: An integrated framework. *International Journal of Physical Distribution & Logistics Management,* 35**,** 210-232.

Peck, H. (2005b). Reducing risk in the defence supply chain. *Defend management journal.*

Peck, H. and Juttner, U. (2002), "Risk management in the supply chain" *Logistics & Transport Focus,* Vol. 4 No. 11, pp.17-22.

PHARMA (2007), *Annual Report*

PHARMA (2008), *Annual Report*

PHARMA (2009), *Annual Report*

PHARMA (2010), *Annual Report*

Pilling, B.K. and Zhang, L. (1992), "Cooperative exchange: rewards and risks", *International Journal of Purchasing & Materials Management,* Vol. 28 No. 2, pp.2-9.

Porter, M.E (1980), "Competitive Strategy", *The Free Press,* New York.

Porter, M.E (1985), *Competitive Advantage: Creating and Sustaining Superior Performance"* The Free Press collier Macmillan.

Porter, M.E (1996), "What is strategy?", *Harvard Business Review,* November-December, pp.61-78.

Preble, J.F. (1997), "Integrating the crisis management perspective into the strategic management process", *Journal of Management Studies,* Vol. 34 No. 5, pp.769-91.

Puto, C.P., Patton, W.E. and King, R.H. (1985), "Risk handling strategies in industrial vendor selection decisions", *Journal of Marketing,* Vol. 49, pp.89-98.

Quarantelli, E.L. (Ed.) (1998), *What is a Disaster? Perspectives on the question,*Routledge, London.
Rapier, R. (2011), A closer look at the commission report on the deepwater horizon disaster. Available: http://theenergycollective.com/robertrapier/52374/closer-look-commission-report-deepwater-horizon-disaster.

Reason, J.T. (1997), *Managing the Risks of Organisational Accidents,* Ashgate, Aldershot.

Remenyi, D., Williams, B., Money, A. and Swartz, E. (1998), *Doing Research in Business and Management: An Introduction to Process and Methods.* London, Sage Publications.

Rice, J. B., Jr. & Caniato, F. (2003). Building a resilient and secure supply chain.

Rice, J. B. and Caniato, F. (2004), "Supply chain response to terrorism: creating resilient and secure supply chains," *Supply Chain Response to Terrorism Project Interim Report*, MIT Center for Transportation and Logistics, MIT, Massachusetts.

Rice, J. B. J. & Tenney, W. 2007. How risk management can secure your business future. *Supply Chain Strategy - A Newsletter From the MT Center for Transportation & Logistics,* 3**,** 1-4.

Richard, G.D. (1995), "A general mathematical framework for modelling two dimensional wild land fire spread", *International Journal of Wild Land Fire,* Vol. 5, pp. 63-72.

Ritchie, B. and Brindley, C. (2007), "Supply chain risk management and performance: a guiding framework for future development*", International Journal of Operations & Production Management*, Vol. 27, pp. 303-322.

Robinson, P.J., Faris, C.W. and Wind, Y. (1967), *Industrial Buying and Creative Marketing,* Allyn and Bacon, Boston, MA.

Rowe, W. (1980), "Risk assessment: approaches and methods", in Conrad, J. (Ed.), Society, *Technology and Risk Assessment*, Academic Press, London.

Royal Society (1992), Risk: Analysis, *Perception and Management,* Royal Society, London.

Ruefli, T. W., Collins, J. M. & Lacugna, J. R. (1999). Risk measures in strategic management research: Auld lang syne? *Strategic Management Journal,* 20**,** 167-194.

Rumelt, R.P., Schendel, D., and Teece, D.J. (1994), *Fundamental issues in strategy: A research agenda,* Harvard Business School Press, Boston, Mass.

Salaam-Blyther, T. (23 June 2009) The 2009 Influenza Pandemic: U.S. Responses to Global Human Cases. *Federation of American Scientist* [Online] Available from: http://www.fas.org/sgp/crs/misc/R40588.pdf

Congressional Research Service, The 2009 Influenza Pandemic: U.S. Responses to Global Human Cases, 23 June 2009. Available from: http://www.fas.org/sgp/crs/misc/R40588.pdf

Sarathy, R. (2006). Security and the global supply chain. *Transportation Journal,* 45**,** 28-51.

Schoemaker, P. and Gunther, R. (2002), *Profiting from uncertainty: strategies for succeeding no matter what the future brings*, Free Pace.

Shapira, Z. (1995). *Risk taking: A managerial perspective,* New York, Russell Sage Foundation.

Sheffi, Y. (2005), "Building a resilient supply chain," *Harvard Business Review*, pp. 3-5.

Sheffi, Y. & Rice, J. B. 2005. A supply chain view of the resilient enterprise.

Simon, P., Hillson, D. and Newland, K. (1997), *Project Risk Analysis and Management Guide (PRAM*), Association for Project Management, Norwich.

Sitkin, S. B., Pablo, A.L. (1992). Reconceptualizing the determinants of risk behavior. *Academy of Management Review* 17**,** 9–38.

Slack, N. and Lewis, M. (2001), *Operations Strategy*, 3rd ed., Prentice-Hall, Harlow

Smeltzer, L.R and Siferd, S.P. (1998), "Proactive supply management: the management of risk", *International Journal of Purchasing and Material Management,* Vol.34 No.1, pp.38-45.

Smith, D. (1990b), "Beyond contingency planning- towards a model of crisis management", *Industrial Crisis Quarterly,* Vol. 4 No. 4, pp.263-75.

Smith, D. (2005), "Business (not) as usual: crisis management, service recovery and the vulnerability of organisations", *Journal of Services Marketing,* Vol. 19 No. 5, pp.309-320.

Smith, D. (2005), "For whom the bell tolls: imagining accidents and the development of crisis simulation in organisations", *Simulation and Gaming,* (forthcoming).

Smith, M.E, Thorpe, R. and Lowe, A. (1991), *Management Research: An Introduction,* Sage Publication.

Snider, H. (1991), "Risk management: a retrospective view", *Risk Management,* April, pp.47-54.

Sodhi, M. (2003) How to do strategic supply chain planning. *Sloan Management Review*, 45 (1), 69-75.

Sodhi, M. (2004) A tactical supply chain risk management model inspired by asset-liability management, SSRN.

Sodhi, M. (2005a) Tactical planning under demand risk for a global elecctronics company. *Production Operation Management*, 14(1), 69-79.

Sodhi, M. (2005b) LP modeling for asset-liability management: a survey of choices and simplifications. *Operation Research*, 53(2), 181-196.

Sodhi, M. (2006) Risk drivers and risk consequences: a framework for understanding risk management in global manufacturing companies, working paper, Cass Business School.

Sodhi M. and Tang, C.S. (2009) Time-based disruption management: a framework for managing supply chain disruption. In: Blackhurst J, Wu T (eds). *Managing Supply Chain Risk and Vulnerability: Tools and Methods for Supply Chain Decision Makers.* Springer, New York.

Sodhi, M., Son, B.G. and Tang, C.S. (2008) What employers demand from applicant for MBA-level supply chain jobs and the coverage of supply chain topics in MBC courses. *Interfaces* 38(6), 469-484

Souter, G., (2000), "Risk from supply chain also demand attention", *Business Insurance,* Vol. 34, Issue 20, pp.26-28.

Speckman, R.E. and Davis, E.W. (2004), "Risky business: expanding the discussion on risk and the extended enterprise", *International Journal of Physical Distribution & Logistics management,* Vol. 34 No. 5, pp.414-33.

Spens, K. (2001), "Managing Critical Resources Through Supply Network Management: A Study of the Finnish Blood Supply Network*", PhD Thesis Publication No 90*, Helsinki, Swedish School of Economics and Business Administration.

Spira, L.F. and Page, M. (2002), "Risk management: the reinvention of internal control and the changing role of internal audit", *Accounting, Auditing & Accountability Journal*, Vol. 16 No. 4, pp. 640-61.

Stalk, G. Jr, (1988), "Time-the next source of competitive advantage", *Harvard Business Review*, July-August, pp. 41-51.

Stalk, G. Jr and Hout, T.M. (1990), *Competing against Time: How Time-based Competition Is Reshaping Global Markets*, Free Press, New York, NY.

Stock, J.R. (1997), "Applying theories from other disciplines to logistics", *International Journal of Physical Distribution & Logistics Management*, Vol. 27 No.1, pp.515-539.

Strauss, A.L., and Corbin, J.M. (1998), *Basics of qualitative research: Techniques and Procedures for developing Grounded Theory,* London: Sage Publications Ltd.

Strauss, A.L. and Glaser, B.G. (1967), *The Discovery of Grounded Theory*. Aldine De Gruyter, NY.

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R., Samson, D. (2002): "Effective Case Research in Operations Management: A Process Perspective", in *Journal of Operations Management,* Vol. 20 No. 5, pp.419-433.

Swaminathan, J.M., Smith, S.F. and Sadeh, N.M., (1996), "A multi agent framework for modelling supply chain dynamics" *Technical Report,* The Robotics Institute, Carnegie Mellon University.

Swaminathan, J. M. (2003). Sars exposes risks of global supply chains. *Journal of Commerce,* 4**,** 38.

Svensson, G. (2000). A conceptual framework for the analysis of vulnerability in supply chains. *International Journal of Physical Distribution and Logistics Management,* 30**,** 731 -750.

Svensson, G. Ö. R. (2002). A conceptual framework of vulnerability in firms' inbound and outbound logistics flows. *International Journal of Physical Distribution & Logistics Management,* 32**,** 110.

Svensson, G. (2003), "Key, areas, causes and contingency planning of corporate vulnerability in supply chains: a qualitative approach", *International Journal of Physical Distribution & Logistics Management,* Vol. 34 No. 9, pp.728-748.

Tang, C.S. (2005), "Perspectives in Supply Chain Risk Management: A Review", *Decision, Operations, and Technology Management,* Paper CT39.

Tang, C. S. (2006a). Perspectives in supply chain risk management. *International Journal of Production Economics,* 103**,** 451-488.

Tang, C. S. (2006b). Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics: Research & Applications,* 9**,** 33-45.

Tang, C. and Tomlin, B. (2007), "The power of flexibility for mitigating supply chain risks", working paper, UCLA Anderson School.

Taylor, S.S., Fisher, D. and Dufresne, R.L. (2002), "The aesthetics of management storytelling: a key to organisational learning", *Management Learning*, Vol. 33 No. 3, pp.313-30.

Tchankova, L. (2002), "Risk identification – basic stage in risk management", *Environmental Management and Health*, Vol. 13 No. 3, pp. 290-7.

The Whitehouse (2010), Remarks by the president in a discussion on jobs and the economy in charlotte, north carolina. The White House. Available: http://www.whitehouse.gov/the-press-office/remarks-president-a-discussion-jobs-and-economy-charlotte-north-carolina.

Tracy, T. (2011), Criminal investigations into bp oil spill are consolidated. MarketWatch. Available: http://www.marketwatch.com/story/us-consolidates-bp-spill-probes-2011-03-07

Treleven, M. and Schweikhart, S.B. (1998), "A risk/ benefit analysis of sourcing strategies: single vs multiple sourcing", *Journal of Operation Management,* Vol. 7 No. 4, pp.93-114.

Treleven, M. D. (1988). A comparison of flow and queue time variances in machine-limited versus dual-resource-constrained systems. *IIE Transactions,* 1**,** 63–67

Trudell et al., (13 April 2012) Auto supplier warns of resin shortage disrupting output. *Businessweek* [Online] Available from: http://www.businessweek.com [Accessed 22 April 2012]

Tucker, R.B. (1991), *Managing the Future: Ten Driving Forces of Change for the '90s*, Putnam, New York, NY.

Turner, B. A. (1994). Causes of disaster: Sloppy management. *British Journal of Management,* 5**,** 215.

Vesely, W.E., "Robust risk analysis: the need for it in nuclear probabilistic risk evaluation", in Waller, R.A. and Covello, V.T. (Eds), *Low Probability High Consequence Risk Analysis,* Plenum Press, New York, NY, 1984.

Viswanadham, N. and Narahari, Y. (2001), "Queueing network modelling and lead time compression of pharmaceutical drug development", *International Journal of Production Research,* Vol.39 No. 2, pp.395-412.

Voss, C., Tsikritsis, N. and Frohlich, M. (2002), "Case research in operation management", *International Journal of Operations Management", International Journal of Operation & Production Management*, Vol. 22 No. 2, pp.195-219.

Wagner, S. & Bode, C. (2009). *Managing risk and security: The safeguard of long-term success for logistics service providers,* Bern, Haupt Verlag.

Wagner, S. M. & Bode, C. (2006). An empirical investigation into supply chain vulnerability.

Wagner, S. M. & Bode, C. (2008). An empirical examination of supply chain performance along several dimensions of risk. *Journal of Business Logistics,* 29**,** 307–325.

Wagner, S. M., Bode, C. & Koziol, P. (2009). Supplier default dependencies: Empirical evidence from the automotive industry. *European Journal of Operational Research,* 199**,** 150-161.

Wagner, S. M. & Johnson, J. L. (2004). Configuring and managing strategic supplier portfolios. *Industrial Marketing Management,* 33**,** 717-730.

Waring, A. E. & Glendon, A. I. (1998). *Managing risk: Critical issues for survival and success into the 21st century,* London, ITBP.

Waters, D. (2007), *Supply Chain Risk Management: vulnerability and Resilience in Logistics,* The Chartered Institute of Logistics and Transport (UK).

White, D. (1995), "Application of systems thinking to risk management: a review of the literature", *Management Decision,* Vol. 33 No. 10, pp.35-45.

Williamson, O. E. (1975). *Markets and hierarchies: Analysis and antitrust implications. A study in the economics of internal organization* The Free Press.

Williamson, O.E. (1979), "Transaction cost economics: the governance of contractual relations", *Journal of Law and Economics,* Vol. 22 No. 2, pp.233-261.

Womack, J. P., Jones, D. T. & Roos, D. (1990). *The machine that changed the world,,* New York, NY. Rawson Associates.

Wright, J. W. & Flak, L. Part 11-relief wells: Advancements in technology and application engineering make the relief well a more practical blowout control option. Available: http://www.jwco.com/technical-litterature/p11.htm.

Yates, J.F. and Stone, E. (1992), "The risk construct", in Yates, J.F. (Ed.*), Risk-taking Behaviour*, Wiley, Chichester.

Yin, R.K. (1994), *Case Study Research – Design and Methods,* Applied Social Research Methods Series*,* Vol. 5, Sage Publication, Thousand Oaks, CA.

Yin, R.K. (2003), *Applications of Case Study Research*, Applied Social Science Methods Series, Vol.34, Sage Publication, Thousand Oaks, CA.

Zhang, F. (31 October 2011), Thailand flood exerts broad impact on electronics supply chain. *iSuppli* [Online] Available from: www.isuppli.com [Accessed 2 April 2012].

Zsidisin, G. and Ellram, L.M. (1999), "Supply risk assessment analysis", *Practix, Best Practices in Purchasing and Supply Chain Management,* June, pp.9-12.

Zsidisin, G. (2001), "Measuring supply risk: an example from Europe", *Practix, Best Practices in Purchasing and Supply Chain Management,* June, pp.1-6

Zsidisin, G. A. 2003. A grounded definition of supply risk. *Journal of Purchasing & Supply Management* 9 217–224

Zsidisin, G.A., Panelli, A. and Upton, R. (2000), "Purchasing organisation involvement in risk assessments, contingency plans, and risk management: an exploratory study", *Supply Chain Management: An international Journal,* pp.187-197.

Zsidisin, G.A. and Ellram, L.M. (2003), "Agency theory investigation of supply risk management", *Journal of Supply Chain Management,* Vol.39 No.3, pp.15-27.

Zsidisin, G., Ellram, L., Carter, J., and Cavinato, J. (2004), "An analysis of supply risk assessment techniques," *International Journal of Physical Distribution and Logistics Management,* Vol. 34 No. 5, pp. 397-413.

Zsidisin, G. A., Gary, L. R. & Steven, A. M. (2005). The dark side of supply chain management. *Supply Chain Management Review,* 9**,** 46-52

Zsidisin, G.A., Melnyk, A.S. and Ragatz, G.L. (2006), "An institutional theory perspective of business continuity planning for purchasing and supply management", *International Journal of Production Research,* Vol. 43 No. 16, pp. 3401-3420.

Zsidisin, G. A., Ritchie, B. (2008). *Supply chain risk: A handbook of assessment, management and performance,* New York, Springer.

Appendices

Appendix 1: Acronyms PHARMA Case

AAR	After Action Review
APAs	Advanced Purchased Agreements
API	Active Pharmaceutical Ingredient
BCP	Business Continuity Plan
CCMT	The Corporate Crisis Management Team
CDC	Centres for Disease Control and Prevention
CET	Corporate Executive Team
CMT	Crisis Management Team
COE	Centre of Excellence
Defra	Department for Environment, Food and Rural Affairs
DH	Department of Health.
DOD	U.S. Department of Defence
ECDC	European Centre for Disease Prevention and Control
EH+P	Employee Health and Performance
EHM	Employee Health Management
EHS	Environment, Health and Safety
EMEA	European Medicines Evaluation
FAO	Food and Agriculture Organisation
FDA	The Food and Drug Administration
FPP	Flu Pandemic Plan
GQMP	Global Quality management Process in QMS
HHS	U.S. Department of Health and Human Services
HPA	The Health Protection Agency
IMT	Incident Management Team
ITCP	IT Continuity Plan
LDCs	Least Developing Countries
MSC	The Manufacture and Supply Chain
OIE	The World Organisation for Animal Health
PAHO	Pan American Health Organisation
PMT	Pandemic Management Team
ROCC	Risk Oversight and Compliance Council
SAGE	Scientific Advisory Group for Emergency
SARS	Severe Acute Respiratory Sydrome
SVP	Senior Vice President
USAID	U.S. Agency for International Development
WHO	World Health Organisation

Appendix 2: Acronyms BP Deepwater Horizon

AFE	Approval for Expenditure
AMF	Automatic mode function
APB	Annular pressure buildup
APD	Application for permit to drill
API	American Petroleum Institute
APM	Application for permit to modify
bbl	Barrels
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
BOP	Blowout preventer
bpm	Barrels per minute
BSR	Blind shear ram
CMMS	Computerized Maintenance Management System
DP	Dynamically positioned
DPO	Dynamic positioning officers
ECD	Equivalent circulating density
EDS	Emergency disconnect system
ERA	Efficient Reservoir Access
ESD	Equivalent static density
ETP	Engineering Technical Practice
FIT	Formation integrity test
gal/sack	Gallons per sack
gpm	Gallons per minute
HSSE	Health, safety, security, and the environment
LDS	Lockdown sleeve
LMRP	Lower marine riser package
LOT	Leak off test
MC 252	Mississippi Canyon Block 252
MD	Measured depth
MMS	Minerals Management Service
MOC	Management of change
MODU	Mobile offshore drilling unit
MUX	Multiplex
OIM	Offshore installation manager
OMS	Operating management system
PINC	Potential incidents and non-compliance
ppg	Pounds per gallon
PRV	Pressure relief valve
psi	Pounds per square inch
RCRA	Resource Conservation and Recovery Act
RMS	Rig Management System
ROV	Remotely operated vehicle
SG	Specific gravity
TD	Total depth
TIGER	Totally Integrated Geological and Engineering Resource
TOC	Top of cement
TVD	Total vertical depth
UWILD	Underwater Inspection in Lieu of Dry-docking

Appendix 3: Timeline of BP Deepwater Horizon Oil Spill

Date	Time	Events	Source
18 March 2008		BP pays USD 34 million for an exclusive lease to drill in Mississippi Canyon Block 252.	Oil Spill Commission
6 October 2009		Spudded Macondo well with Transocean's Marianas	OpenWells®
		Transocean's Marianas arrives on location and begins the drilling of the Macondo well.	Oil Spill Commission
8 November 2009		The Marianas drills for 34 days, reaching a depth of 9,090 feet. It then stops drilling and moves off-site to avoid Hurricane Ida. Hurricane Ida nevertheless damages the rig badly enough that it can no longer drill the well.	Oil Spill Commission
8-27 November 2009		Pull riser and evacuated Marianas for Hurricane Ida. Marianas subsequently damaged and moved to safe harbour for repairs.	OpenWells®
		Transocean's Deepwater Horizon on location to replace Marianas	
31 January - 6 February 2010		Six days of pre-job maintenance and testing of blowout preventer (BOP) followed	OpenWells®
		Drilling activities recommenced on 6 February.	
31 January 2010		Transocean's Deepwater Horizon arrives on location. Its first task is to lower its giant blowout preventer (BOP) onto the wellhead that the Marianas had left behind. The BOP is a stack of enormous valves that rig crews use both as a drilling tool and as an emergency safety device. Once it is put in place, everything needed in the well—drilling pipe, bits, casing, and mud—passes through the BOP.	Oil Spill Commission
10 February 2010		The Deepwater Horizon resumes the drilling of the Macondo well. Drilling Terminology: Drilling through the seafloor does not differ fundamentally from drilling on land. The crews on any drilling rig use rotary drill bits that they lubricate and cool with drilling mud—an ordinary name for what is today a sophisticated blend of synthetic fluids, polymers, and weighting agents that often costs over USD 100 per barrel. The rig crews pump the mud down through a drill pipe that connects with and turns the bit. The mud flows out holes in the bit and then circulates back to the rig through the space between the drill pipe and the sides of the well (the annulus), carrying to the surface bits of rock called cuttings that the drill bit has removed from the bottom of the well. When the mud returns to the rig at the surface, the cuttings are sieved out and the mud is sent back down the drill string. The mud thus travels in a closed loop	Oil Spill Commission
23 February - 13 March 2010		Pilot valve leak of 1 gpm noticed on yellow pod of BOP, leak reduced after switching to blue pod	OpenWells®
8 March 2010		Well control event at 13,305 ft. Pipe stuck; severed pipe at 12,146ft.	OpenWells®
		Halliburton personnel send BP the results of a foam stability test it ran in February on the cement blend it plans to use at Macondo. To the trained eye, the data showed that the cement slurry design was unstable. Halliburton personnel did not comment on the evidence of the cement slurry's instability, and there is no evidence that BP examined the foam stability data in the report at all.	Oil Spill Commission
12-22 March 2010		Contingency liner utilized, a new drilling liner was added and production casing changed to 9 7/8 in x 7 in. long string	Macondo well plan
		Minerals Management Service (MMS) approved changes	MMS applications
5-6 April 2010		Stripped drill pipe through upper annular preventer from 17,146 ft. to 14, 937 ft. while addressing wellbore losses	OpenWells®
9-14 April 2010		Total depth of 18,360ft. reached and data collected for five days. Reservoir sands contained hydrocarbons at pressures of approximately 11,850 psi.	OpenWells®
9 April 2010		After numerous instances indicating fractures in the formation over the past few weeks, BP elects to call total depth at 18,360 feet, short of the 20,200 feet initially planned. BP informs its lease partners Anadarko and MOEX that "well integrity and safety" issues require the rig to stop drilling further. Drilling Terminology: The weight of the column of mud in a well exerts pressure that counterbalances the pressure in the hydrocarbon formation. If the mud weight is too low, fluids such as oil and gas can enter the well, causing what is known as a "kick." But if the mud weight is too high, it can fracture the surrounding rock, potentially leading to "lost returns"—leakage of the mud into the formation. The rig crew therefore monitors and adjusts the weight (density) of the drilling mud as the well is being drilled—one of many sensitive, technical tasks requiring special equipment and the interpretation of data from difficult drilling environments.	Oil Spill Commission

Date	Time	Events	Source
11-15 April 2010		BP and its contractors spend five days logging the open hole with sophisticated instruments. Based on the logging data, BP concludes that it has drilled into a hydrocarbon reservoir of sufficient size (at least 50 million barrels) and pressure that it is economically worthwile to install a final production casing string that BP will eventually use to recover the oil and gas	Oil Spill Commission
13 April 2010		Halliburton personnel run a second set of tests on the now-slightly-altered cement blend they plan to use at Macondo. The foam stability test showed that the cement slurry would be unstable.	Oil Spill Commission
14-15 April 2010		After going back and forth, BP engineers choose a "long string" production casing—for a single continuous wall of steel between the wellhead, on the seafloor, and the oil and gas zone at the bottom of the well. The other option considered, a "liner," would result in a more complex—and theoretically more leak-prone—system over the life of the well. But it would be easier to cement into place at Macondo.	Oil Spill Commission
14 April2010		Halliburton Opticem cement model review concluded zonal isolation objectives could be met using 9 7/8 in x 7 in. long string as production casing	Halliburton 9 7/8 in. x 7 in. Production Casing Design Report
15 April2010		OptiCem model updated with open hole calliper and survey data. Input included 21 centralizers and 70% standoff above the top centralizer	Company emails
		Decision made to order 15 additional centralizer order placed	Company emails
		A Halliburton engineer informs BP engineers that computer simulations suggest that the Macondo production casing would need more than six centralizers (used to keep the casing string centered) to avoid channeling in the cement job. BP engineers order 15 additional centralizers—the most BP could transport immediately in a helicopter.	Oil Spill Commission
16 April 2010	11:51 AM	Fifteen slip-on bow spring centralizers delivered to rig by helicopter	OpenWells®
	12:48-12:53 PM	Mechanical integrity concerns regarding the bow spring centralizers. Decision made not to run bow spring centralizers.	Company emails Interview
		A helicopter delivers 15 additional centralizers to the rig. BP engineers decide the centralizers are the wrong kind and do not run them.	Oil Spill Commission
18 April 2010	20:58 PM	Partial lab test results, a new OptiCem model report (using seven inline centralizers) and Halliburton's cementing recommended procedure for the Macondo well cement job were provided to BP and Halliburton staff	Email from Halliburton in-house cementing engineer to BP and Halliburton staff
		Halliburton personnel run yet another set of tests on the cement slurry they plan to use at Macondo. The test would normally take 48 hours to complete. It is unclear whether Halliburton had results from the test in hand before it pumped the job. Halliburton did not send the results of the final test to BP until six days after the blowout.	Oil Spill Commission
18-19 April 2010		The Deepwater Horizon crew installs the long string production casing. The leading end of the casing, the "shoe track," began with a "reamer shoe"—a bullet-shaped piece of metal with three holes designed to help guide the casing down the hole. The reamer shoe was followed by 180 feet of seven-inch-diameter steel casing. Then came a Weatherford-manufactured "float collar," a simple arrangement of two flapper (float) valves, spaced one after the other, held open by a short "auto-fill tube" through which the mud in the well could flow. As the long string was lowered down the wellbore, the mud passed through the holes in the reamer shoe and auto-fill tube that propped open the float valves, giving it a clear flow path upward	Oil Spill Commission

Final Casing Run

Date	Time	Events	Source
19 April 2010	13:30 PM	Completed final (production) casing run to 18,304ft. (Job took 37 hours). The shoe track included a Weatherford float collar installed at the top and a reamer shoe at the bottom.	OpenWells®
	14:30-16:20 PM	Nine attempts made to establish circulation. Circulation established with 3,412 psi	OpenWells® Real-time data
	16:20-19:30 PM	Circulation pressure of 340 psi did not match modeling results of 570psi.	OpenWells®

Date	Time	Events	Source
19 April 2010		An explosion aboard the Deepwater Horizon drilling rig in the Gulf of Mexico, 52 miles (84km) south-east of Venice, Louisiana, kills 11 workers. Operator Transocean, under contract for BP, says it had no warning of trouble ahead of the blast.	BBC

Cement Job

Date	Time	Events	Source
19 April 2010		In preparation for cementing, the crew attempts to convert the float valves by pushing the tube downward. After nine attempts, the crew establishes circulation. Circulation pressure is lower than predicted, but the crew decides the pressure gauge is broken.	Oil Spill Commission
		The first compromise in BP's plan was to limit the circulation of drilling mud through the wellbore before cementing. Optimally, mud in the wellbore would have been circulated "bottoms up"—meaning the rig crew would have pumped enough mud down the wellbore to bring mud originally at the bottom of the well all the way back up to the rig. There are at least two benefits to bottoms up circulation. Such extensive circulation cleans the wellbore and reduces the likelihood of channeling. And circulating bottoms up allows technicians on the rig to examine mud from the bottom of the well for hydrocarbon content before cementing. But the BP engineers feared that the longer the rig crew circulated mud through the casing before cementing, the greater the risk of another lost-returns event. Accordingly, BP circulated approximately 350 barrels of mud before cementing, rather than the 2,760 barrels needed to do a full bottoms up circulation.	Oil Spill Commission
20 April 2010		The crew pumps cement into the well for the shoe track cement job. BP decides to pump the cement down at the relatively low rate of 4 barrels or less per minute. BP also decides to limit the volume of cement pumped to approximately 60 barrels—a volume that its own engineers recognized would provide little margin for error.	Oil Spill Commission
	19:30-00:36 PM	Cement job pumped as planned with full fluid returns observed. Bottom plug burst disk ruptured at higher-tan-planned pressure, 2,900 psi	OpenWells® Real-time data
		Cement job completed bumped top wiper plug at 00:3 hours.	Real-time data
20 April 2010	00:30 – 03:00 AM	BP and Halliburton personnel perform a check to see whether the float valves are closed and holding the cement in. While it is not clear how long the personnel watched for flow, they eventually concluded the float valves were holding.	Oil Spill Commission
	0:40 AM	Bled off 5 bbls of fluid to reduce drill pipe pressure from 1,150 psi to 0 psi. No flow observed after bleeding 5bbls.	Real-time data OpenWells®
	00:40-07:00 AM	Dril-Quip seal assembly installed in subsea wellhead. Two pressure tests successfully completed. Drill pipe pulled out of riser.	Real-time data OpenWells® Interview
	05:45 – 7:30 AM	BP and Halliburton personnel declare the cement job a success. BP decides to send home a team of Schlumberger technicians who had been standing by on the rig to perform a suite of cement evaluation tests.	Oil Spill Commission
	~ 07:30	BP and service providers discussed running cement bond log (CBL) during morning operations call.	Interviews
		Decision made, in accordance with pre-established BP Macondo well team decision tree, not to run CBL.	

Positive-pressure and Negative-pressure Tests

Date	Time	Events	Source
20 April 2010	10:43 AM	BP moves on to prepare the well for temporary abandonment. A BP engineer sends out an "Ops Note" to the rest of the Macondo team listing the temporary abandonment procedure for the well. The temporary abandonment procedure had undergone numerous	Oil Spill Commission

Date	Time	Events	Source
		modifications over a short period, none of which appear to have been subject to any formal risk assessment. The morning of April 20 was the first time rig personnel had seen the procedure they would use that day. The basic sequence for the procedure is as follows: 1. Perform a positive-pressure test to test the integrity of the production casing; 2. Run the drill pipe into the well to 8,367 feet (3,300 feet below the mud line); 3. Displace 3,300 feet of mud in the well with seawater, lifting the mud above the BOP and into the riser; 4. Perform a negative-pressure test to assess the integrity of the well and bottom-hole cement job to ensure outside fluids (such as hydrocarbons) are not leaking into the well; 5. Displace the mud in the riser with seawater; 6. Set the surface cement plug at 8,367 feet; and 7. Set the lockdown sleeve.	
	10:55 AM-12:00 PM	Successful positive-pressure test of the production casing	Real-time data Interviews
		Drill pipe run in hole to 8,367 ft. Displacement procedure reviewed in preparation for mud displacement and negative-pressure test.	
		The crew conducts a positive-pressure test to evaluate, among other things, the ability of the casing in the well to hold in pressure. The pressure inside the well remained steady, showing there were no leaks in the production casing through which fluids could pass from inside the well to the outside.	Oil Spill Commission
	12:00-15:04 PM	At 13L28 hours. Deepwater Horizon started offloading mud to M/V Damon Bankston.	Real-time data M/V Damon Bankston log
	12:00-15:04 PM	Mudlogger told assistant driller that pit levels could not be monitored during offloading. Assistant driller told mudlogger that notice would be provided when offloading to M/V Damon Bankston ceased.	Interview
	15:00-16:57 PM	The crew prepares to conduct a negative-pressure test, and displaces mud from a depth of 8,367 feet to above the blowout preventer. The negative-pressure test checks not only the integrity of the casing but also the integrity of the bottomhole cement job. At the Macondo well, the negative-pressure test was the only test performed that would have checked the integrity of the bottomhole cement job.	Oil Spill Commission
	15:04-15:56 PM	Seawater pumped into boost, choke and lines to displace mud. 1,2000 psi left trapped in the kill line (i.e., not blend off).	Real-time data
	15:56-16:53 PM	A total of 424 bbls of 16 ppg of freshwater pumped into well. Displacement completed with 352 bbls of seawater, placing the spacer 12 ft. above the BOP.	Real-time data M-I SWACO
20 April 2010		(From ~ 16:00 hours - 17:50 hours, trip tank was being cleaned. Recorded flow data unreliable during this period).	Displacement procedure
	16:54 PM	Upon shutting down pumps, drill pipe pressure was at 2,325 psi. Pressure in kill line remained at 1,200 psi.	Real-time data
		An annular preventer was closed for the negative pressure test.	Interview
	16:54-16:56 PM	Drill pipe pressure bled from 2,325 psi down to 1,220 psi in order to equalize with the 1,200 psi on the kill line.	Real-time data
	16:57-18:40 PM	The crew conducts a negative-pressure test on the drill pipe. For a successful negative-pressure test, the drill-pipe pressure must remain at zero psi after the pressure is bled off and the pipe is closed. The crew attempts to bleed drill-pipe pressure down to zero three times, but each time drill-pipe pressure builds back up. At the end of the test, drill-pipe pressure is 1,400 psi. BP and Transocean personnel discuss the pressure, apparently explaining it as a result of "the bladder effect." BP's Well Site Leader Don Vidrine insists on running a second negative-pressure test, this time on the kill line.	Oil Spill Commission
	16:57-16:59 PM	Kill line opened and pressure decreased to 645 psi, drill pipe pressure increased to 1,350 psi.	Real-time data Interview
		Attempt made to bleed system down to 0 psi. Drill pipe pressure decreased to 273 psi. Kill line pressure decreased to 0 psi. Kill line shut in.	
	16:59-17:08 PM	At 16:59 hours, drill pipe pressure increased from 273 psi to 1,250 psi in 6 minutes.	Real-time data MBI testimony
		Annular preventer closing pressure was increased from 1,500 psi to 1,900 psi to create a seal.	
		The riser was topped up with approximately 50 bbls of mud from the trip tank to replace the volume blend off through the drill pipe. (Spacer fluid was then across the BOP.)	
	17:08-17:27 PM	Drill pipe pressure decreased from 1,250 psi to 1,205 psi.	Real-time data

Date	Time	Events	Source
	17:17 PM	Mud offloading from Deepwater Horizon mud pits to M/V Damon Bankston ceased. Mudlogger not notified.	M/V Damon Bankston log Interviews
	17:27-17:52 PM	Drill pipe pressure reduced from 1,205 psi to 0 psi by bleeding off 15 bbls to 23 bbls of fluid to the cement unit.	Real-time data Interviews
		Rig crew and well site leader discussed negative pressure test procedure. Well site leader stated the negative-pressure test needed to be done on the kill line in accordance with the BP plan submitted to MMS.	
	17:52-18:00	Kill line opened to the cement unit	Real-time data Interview
		Cementer bled off 3 bbls to 15 bbls of seawater. A witness reported continuous flow from the kill line that spurted and was still flowing when instructed to shut in the line.	
	18:00-18:35 PM	Drill pipe pressure gradually increased to 1,4000 psi over 25 minutes. Build profile showed distinct pressure fluctuations at fairly uniform intervals.	Real-time data
		Discussion ensurd about pressure anomalies and negative pressure test procedure.	
	18:35-19:55	Seawater pumped into the kill line to confirm it was full.	Real-time data Interviews
		Opened kill line and bled 0.2 bbl to mini trip tank; flow stopped. Kill line opened and monitored for 30 minutes with no flow.	
		At 19:55 hours, the negative-pressure test was concluded and considered a good test.	

Well Monitoring and Simultaneous Operations

Date	Time	Events	Source
20 April 2010	20:00 PM	Internal blowout preventer (BOP) and annular preventer opened and pumping of seawater commenced down the drill pipe to displace mud and spacer from the riser.	Real-time data
	20:02 PM	The crew opens the annular preventer and begins displacing mud and spacer from the riser.	Oil Spill Commission
	20:50 PM	Pumps slowed for the spacer arriving at surface	Real-time data
	~ 20:52 PM	Calculated that the well went underbalanced and started to flow]	OLGA model
	20:58-21:08 PM	Flow out from the well increased	Real-time data Calculatons
		Tip tank was emptied into the flow-line at this time.	
		[Taking into account the emptying of the trip tank calculated a gain of approximately 39 bbls over this period.]	
	21:01 PM	After steadily decreasing for much of the displacement, drill-pipe pressure changes direction and begins increasing. This is an anomaly that apparently went unnoticed.	Oil Spill Commission
	21:01-21:08 PM	Drill pipe pressure increased from 1,250 psi to 1,350 psi at constant pump rate	Real-time data
	21:09 PM	Spacer observed at surface Pumps shut down to enable sheen test to be conducted	Real-time data Interviews
	21:08-21:14 PM	Pumps off, drill pipe pressure increased from 1,017 psi to 1,263 psi in 5 ½ minutes.	Real-time data Interviews Deepwater Horizon P&IDs OLGA model
20 April 2010		Overboard dump line opened during sheen test; Sperry-Sun flow meter by passed. Successful result from visual sheen test indicated that fluids could be discharged overboard. [OLGA well flow modelling calculated that in-flow to the well during this period was approximately 9bbls/min.]	
		The crew shuts down the pumps to perform a sheen test. With the pumps off, the drill-pipe pressure should have stayed constant or gone down. Instead, it went up by approximately 250 psi. Had someone noticed it, he would have recognized this as a significant anomaly that warranted further investigation before turning the pumps back on.	Oil Spill Commission
	21:14 PM	The crew turns the pumps back on and continues the displacement.	Oil Spill Commission
	21:14-21:31 PM	Pumps restarted to continue displacement	Real-time data Interviews
		Displaced well fluids discharged overboard.	
		Drill pipe pressure on continually increasing trend	
	21:17 PM	Pump no. 2 started ad pressure spiked to 6,000 psi. [Inferred that the pump likely started against a closed valve and the pressure lifted the	Real-time data MBI

Date	Time	Events	Source
		relief valve.]	testimony
	21:18 PM	Pumps no.2, no.3, no.4 were shut down. Pump no.1 stayed online (boost line)	Real-time data
		The pressure-relief valve on Pump No. 2 blows, and the driller organizes a group of crewmembers to go to the pump room to fix the valve.	Oil Spill Commission
	~21:18-21:20 PM	Toolpusher was called to rig floor	Interviews
	~21:20 PM	Assistant driller was called to either the pit room or the pumproom	Interviews MBI testimony
	~21:20 PM	Senior Toolpusher called toolpusher and ask how the negative-pressure test had gone. Toolpusher responded that the test result was good, and the displacement was "going fine."	MBI testimony
		The senior toolpusher calls the rig floor and asks about the displacement. The toolpusher responds, "It's going fine. . . . I've got this."	Oil Spill Commission
	21:20-21:27 PM	Pump no.3, and no.4 restarted. Some pressure started to build on pump no.2, reaching 800 psi at 21:27 hours	Real-time data
	21:26-21:30 PM	Drill pipe pressure declined by 400 psi at constant pump rate.	Real-time data
	21:30 PM	[Calculated that the space was fully displaced from the riser]	Real-time data OLGA model
		The driller notices an odd and unexpected pressure difference between the drill pipe and the kill line. The crew shuts off the pumps to investigate.	Oil Spill Commission

Well Control Response

Date	Time	Events	Source
20 April 2010	21:30 PM	Pumps shut down: first pump no.3 and no.4, then no.1 (boost pump)	Real-time data
	21:31-21:34 PM	Drill pipe pressure increased from 1,210 psi to 1,766 psi. ~21:33 hours, chief mate observed Toolpusher and driller discussing differential pressure". Toolpusher told chief mate that cement job may be delayed	Real-time data MBI testimony
	21:36-21:37 PM	The driller orders a floorhand to bleed off the drill-pipe pressure, in an apparent attempt to eliminate the difference. The drill-pipe pressure initially dropped off as expected, but immediately began climbing again. Despite the mounting evidence of a kick, neither the driller nor the toolpusher performed a visual flow check or shut in the well.	Oil Spill Commission
	21:36-21:38 PM	Over a 90 second period, drill pipe pressure decreased from 1,782 psi to 714 psi and then increased from 714 psi to 1,353 psi	Real-time data
		[Inferred to have been caused by opening and closing a 4 in. valve on the standpide manifold.]	OLGA model
	21:38 PM	[Calculated that at approximately 21:38, hydrocarbons passed from well into riser.]	OLGA model
	21:38-21:42 PM	Drill pipe pressure held briefly, then decreased steadily from 1,400 psi to 338 psi.	Real-time data
	21.40 - 21.43 PM	Drilling mud begins spewing from the rotary onto the rig floor. The crew closes one of the annular preventers to shut in the well and routes the flow to the mud-gas separator (rather than overboard into the sea). The flow continues and quickly overwhelms the mud-gas separator system.	Oil Spill Commission
	~21:40-21:48 PM	Chief electrician observed four personnel (including the assistant driller) completing repair of the pressure relief valve on pump no.2 at the time he left the area (~21:48 hours)	MBI testimony
		~21:40 hours – Mud overflowed the flow line and onto rig floor	
		~21:41 hours – Mud shot up through derrick.	
		~21:41 hours – Diverter closed and flow routed to mud gas separator (MGS); NOP activated (believed to be lower annular preventer).	
		~21:41 hours – M/V Damon Bankston was advised by Deepwater Horizon bridge to stand off 500 m because of a problem with the well. The ship began to move away.	
		~21:42 hours – Drill pipe pressure increased steadily from 338 psi to 1,200 psi over 5 minute period	
		~21:44 hours – Mud and water exited MGS vents; mud rained down on rig and M/V Damon Bankston as it pulled away from rig.	
20 April 2010	21:40-21:48 PM	~21:44 hours – Toolpusher called well site leader and stated they were "getting mud back" and that they had "diverted to the mud gas separator" and had either closed or were closing the annular	Real-time data Interviews

Date	Time	Events	Source
		preventer.	MBI testimony
		~21:45 hours – Assistant driller called the senior Toolpusher to report that "The well is blowing out…[the Toolpusher] is shutting it in now.	
		~21:46 hours - Gas hissing noise heard and high-pressure gas discharged from MGS vents towards deck.	
		~21:47 hours – First gas alarm sounded. Gas rapidly dispersed, setting off other gas alarms.	
		~21:47 hours – Roaring noise heard and vibration felt.	
		~21:47 hours – Drill pipe pressure started rapidly increasing from 1,200 psi to 5,730 psi.	
		[This is thought to have been the BOP sealing around pipe. Possible activation of variable bore rams [VBRs] at 21:46 hours.]	
		~21:48 hours – Main power generation engines started going into overspeed (no.3 and no.6 were online)	
		Rig power lost. Sperry-Sun real-time data transmission lost.	
	21.45 PM	The assistant driller calls the senior toolpusher and tells him the well is "blowing out."	Oil Spill Commission
	21.46 PM	The crew activates a variable bore ram to shut in the well.	Oil Spill Commission
	21:49 PM	First explosion occurred an estimated 5 seconds after power loss.	Real-time data Interviews MBI testimony
		Second explosion occurred an estimated 10 seconds after first explosion	
		The first explosion occurs. On the drilling floor, the Macondo disaster claims its first victims. A short time later, a second explosion occurs.	Oil Spill Commission
	21:52 PM	Mayday call made by Deepwater Horizon	M/V Damon Bankston log
	~21:52-21:57 PM	Subsea supervisor attempted to activate emergency disconnect sequence (EDS) for the BOP at the panel on the bridge. Lights changed on panel, but no flow was observed on the flow meter.	MBI testimony Interviews
		Lower marine riser package did not unlatch.	
		Deepwater Horizon master announced the activation of the EDS at 21:56	
	~22:00-23:22 PM	Transfer of 115 personnel including 17 injured, to M/V Damon Bankston	MBI testimony
		11 people were determined to be missing, and search and rescue activities ensued.	
		US. Coast Guard arrived on-site at 23:22 hours.	
		Sometime after the first explosion, Transocean personnel on the bridge attempt to activate the Emergency Disconnect System. Although the panel indicators lit up, the rig never disconnected.	Oil Spill Commission
22 April 2010	10:22 PM	Deepwater Horizon Sank	Unified Command
23 April 2010	17:00 PM	The search for the 11 missing people was suspended	
22 April 2011		The Deepwater Horizon sinks to the bottom of the Gulf after burning for 36 hours, raising concerns of a catastrophic oil spill. A Coast Guard official says the Macondo well, which the rig had been drilling, could be releasing up to 8,000 barrels of oil per day.	BBC

BOP Emergency Operation

Date	Time	Events	Source
21-22 April 2010	18:00-01:15 PM	Remotely operated vehicle (ROV) operations were initiated.	IMT reports
22 April 2010	~02:45 AM	ROV attempted hot stab interventions to close VBRs and blind shear rams (BSRs); ROV attempts were ineffective.	IMT reports
	~07:40 AM	On the third attempt, ROV activated autoshear function. (BSR thought to have closed) Well continued to flow.	IMT reports
25 April – 5 May 2010		Seventeen further attempts by ROVs using subsea accumulators to close various BOP rams and annular preventers. Well continued to flow	IMT reports
23 April 2010		The Coast Guard says it had no indication that oil was leaking from the well 5,000ft below the surface of the Gulf.	BBC
26 April2010		In a reverse, officials reveal the well is leaking an estimated 1,000 barrels of oil per day and warn of environmental disaster. Meanwhile, BP sends undersea robots to the wellhead in an	BBC

Date	Time	Events	Source
		unsuccessful effort to activate the blowout preventer, a piece of heavy kit mounted on top of the well to stem the flow of oil.	
28 April2010		The US Coast Guard warns the oil leak could become the worst oil spill in US history.	BBC
29 April2010		The US Coast Guard sets fire to patches of spilled oil in an effort to prevent the slick from reaching the vulnerable Louisiana coastal wetlands. President Barack Obama pledges "every single available resource", including the military, to help in the response effort.	BBC
30 April 2010		Oil from the leaking well begins washing ashore in Louisiana. Soon fragile coastal wetlands are inundated with thick, brown mud. President Barack Obama's administration bans oil drilling in new areas off the US coast pending investigations into the cause of the BP spill. Before the spill, Mr Obama had said he would allow new offshore drilling.	BBC
2 May 2010		President Obama makes his first trip to the Gulf Coast and says BP is responsible for the leak and for paying for its clean-up. "We're dealing with a massive and potentially unprecedented environmental disaster," he says. "The oil that is still leaking from the well could seriously damage the economy and the environment of our Gulf states. And it could extend for a long time. It could jeopardise the livelihoods of thousands of Americans who call this place home." President Obama said he would 'spare no effort' in responding to the crisis	BBC
8 May 2010		BP's effort to place a giant metal box atop the leaking well to contain the spill fails when ice crystals accumulate inside the box and engineers are forced to remove it. Meanwhile, officials revise the estimate of the leak's rate upward to 5,000 barrels per day.	BBC
10 May 2010		BP officials weigh shoving debris, including golf balls and rubber tyres, into the leaking wellhead, a manoeuvre known as the "junk shot". They also ready a "top hat" - a metal dome - to be placed over the leak. Meanwhile, BP reveals the oil spill has cost the company USD 350m (GBP 233m) so far.	BBC
11 May 2010		At a series of congressional hearings, BP, Transocean and Halliburton, the three companies involved in the Deepwater Horizon drilling operations, all blame each other for the disaster.	BBC
14 May 2010		Pelicans are among the wildlife harmed by the oil Researchers who have analysed underwater video from the leak site estimate as many as 70,000 barrels of oil are leaking into the Gulf per day, with a margin of error of plus or minus 20%, significantly higher than earlier estimates. BP tries to thread a tube into the broken wellhead in an effort to collect some of the leaking oil in surface ships. Meanwhile, President Obama condemns the "ridiculous spectacle" of the companies trading blame while oil spews from the well.	BBC
19 May 2010		Oceanographers say oil from the leak has entered an ocean current - the "loop current" - that could carry it towards Florida and potentially up the US east coast.	BBC
26 May 2010		BP prepares to plug the leaking well with heavy drilling mud, a procedure called a "top kill". The attempt is declared a failure three days later.	BBC
28 May 2010		Obama visits the Gulf Coast again and declares "the buck stops with me".	BBC
30 May 2010		Carol Browner, President Barack Obama's adviser on energy policy, says the spill is the worst environmental disaster in US history, worse even than the 1989 Exxon Valdez spill in Alaska.	BBC
2 June 2010		The US announces a criminal inquiry into the BP oil spill.	BBC
4 June 2010		BP places a cap, called the "lower marine riser package", atop the leaking wellhead. The cap allows the company to pipe much of the oil and gas leaking from the well to ships on the surface. President Obama takes a third trip to the region.	BBC
8 June 2010		Skimmers, including the giant "A Whale", are cleaning oil from the surface Adm Thad Allen, the commander of the US response, says clean-up of the oil-stricken Gulf could take years. Meanwhile, President Obama says he has been consulting with experts so he can learn "whose ass to kick" in the matter. The US government says underwater oil plumes have travelled as far as 40 miles from the site of the leaking well.	BBC
10 June 2010		The US Geological Survey estimates the oil flow at as many as 40,000 barrels per day before a cap was put on the well on 3 June. BP announces it is collecting 15,800 barrels per day from the well.	BBC

Date	Time	Events	Source
12 June 2010		Responding to complaints in the British media of an anti-British tone to his remarks, President Barack Obama tells UK Prime Minister David Cameron that his criticism of BP has nothing to do with national identity.	BBC
14 June 2010		President Obama makes a fourth trip to the gulf	BBC
15 June 2010		President Obama addresses the nation from the Oval Office, vowing, "We will make BP pay for the damage their company has caused."	BBC
17 June 2010		BP announces it will place USD 20bn in a fund to compensate victims of the oil spill and says it will not pay a shareholder dividend this year.	BBC
18 June 2010		BP chief executive Tony Hayward receives a tongue-lashing at a hearing in the US Congress. Henry Waxman, chairman of the House Committee on Energy and Commerce, says BP's "complacency" before the 20 April rig explosion was "astonishing".	BBC
22 June 2010		Many fishermen put out of work by the oil spill have taken jobs in the clean-up effort A federal judge blocks the Obama administration's six-month moratorium on Deepwater oil drilling in the Gulf of Mexico, saying the ban cannot be justified. The administration quickly issues another moratorium with revised terms. Meanwhile, BP hands day-to-day control of the response to Bob Dudley, replacing Chief Executive Tony Hayward, who had been widely criticised for his insensitive remarks on the spill.	BBC
5 July 2010		BP says the oil spill response has cost the company USD 3.12bn (GBP 2bn), including the cost of containing the spill and cleaning up the oil, and the cost of drilling relief wells. The figure also includes USD 147m paid out in compensation to some of those affected by the spill.	BBC
6 July 2010		Oil from the spill reaches Texas, meaning it has affected all five US Gulf Coast states. But officials said it was unclear if the oil had drifted hundreds of kilometres from the leak site to the Texas shore, or had fallen from ships taking part in the clean-up operation.	BBC
10 July 2010		BP begins a bid to place a tighter-fitting cap atop the leaking wellhead. The company warns that oil will flow freely while the caps are being exchanged, but says it has brought in 400 oil-skimming ships to deal with the increased flow. The BBC's Madeleine Morris says it may take days to complete the operation	BBC
14 July 2010		Adm Thad Allen says a relief well, which officials and BP have said is the only way permanently to plug the well, has come within 5ft (1.5m) of the leaking well bore.	BBC
15 July 2010		With the new cap in place, BP says it has temporarily shut off the oil flow in order to test the integrity of the well. President Barack Obama hails "a positive sign".	BBC
19 July 2010		Adm Allen tells BP he is concerned about a "detected seep" on the sea floor near the well and other "undetermined anomalies". He said that if methane was found to be seeping from the sea floor, oil might also be leaking.	BBC
22 July 2010		The rig drilling a relief well was ordered to leave the spill site ahead of Tropical Storm Bonnie Dozens of vessels, including the rig drilling a relief well to permanently block the damaged well, are ordered to leave the site as Tropical Storm Bonnie approaches. BP warns that the final operation to plug the well could be delayed by up to two weeks by the storm. The capped well is to remain unmonitored for several days. Meanwhile, BP says it has been given permission to prepare for a "static kill" - pumping mud into the top of the well through the new cap - a step viewed as an intermediate measure. The firm would need final approval from the US to carry it out.	BBC
25 July 2010		Ships involved in BP's effort to secure the blown-out oil well prepare to resume work after a tropical storm in the Gulf of Mexico weakened. Coast Guard chief Adm Thad Allen says the storm put back efforts to drill a relief well by seven to 10 days.	BBC
		The BBC learns that BP's chief executive Tony Hayward, who has faced widespread criticism over his handling of the spill, is negotiating the terms of his exit from his post.	BBC
26 July 2010		The BBC reveals that 53-year old BP chief executive Tony Hayward will receive a year's salary plus benefits, together worth more than GBP 1m, when he steps down. He will also be entitled to draw an annual pension of GBP 600,000 once he reaches the age of 55.	BBC
27 July 2010		Mr Hayward will leave his post by October	BBC

Date	Time	Events	Source
		BP confirms that chief executive Tony Hayward will leave his post by mutual agreement in October, but he is likely to retain a position in the company. BP plans to nominate him as a non-executive director of its Russian joint venture, TNK-BP. Mr Hayward's American colleague, Bob Dudley, who has taken charge of the clean-up operation, will replace him. Meanwhile, the oil giant's second quarter earnings are published, showing losses of USD 17bn for the three months between April and June - a UK record. The company says it has set aside USD 32.2bn (GBP 20.8bn) to cover the costs linked to the Gulf of Mexico spill.	
28 July 2010		US scientists say the oil from the well has cleared from the sea surface faster than expected, 100 days after the disaster began.	BBC
2 August 2010		The US Environmental Protection Agency says in a study the dispersant used after the spill is no more toxic than oil alone. There had been concerns raised by congressional investigators that dispersant may have been more widely used than the government ordered.	BBC
3 August 2010		The US government says the oil spill is officially the biggest leak ever, with 4.9 million barrels of oil leaked before the well was capped last month. Scientists said only a fifth of the leaking oil - around 800,000 barrels - was captured during the clean-up operation.	BBC
4 August 2010		The US government says three-quarters of the oil spilled in the Gulf has been cleaned up or broken down by natural forces. Meanwhile, BP reports "encouraging" progress with the "static kill" operation to plug the well with mud and seal it with cement.	BBC
9 August 2010		BP announces that the total cost to it of the oil spill so far has reached USD 6.1bn (GBP 3.8bn). The total includes the cost of the spill response, containment, relief well drilling, and cementing up of the damaged well. It also includes grants to the Gulf states hit by the spill and USD 319m paid out in compensation to some of those affected by the spill.	BBC
16 August 2010		The US announces that future applications for Deepwater offshore drilling will require an environmental assessment, ending a practice that allowed BP's Deepwater Horizon rig to drill with little scrutiny. The White House said decision-making must be "fully informed" by knowledge of any potential environmental consequences.	BBC
19 August 2010		A study published in a leading scientific journal confirms the presence of a toxic chemical residue one kilometre below the surface of the Gulf of Mexico, but says it amounts to just 0.1% of the total amount spilled.	BBC
3 September 2010		The blowout preventer that failed to stop the explosion on the Deepwater Horizon rig is removed from the stricken Gulf of Mexico oil well by BP. The 300-ton device will be examined as part of the inquiry into the leak of 206m gallons of oil into the Gulf. Meanwhile, the cost of the oil spill has risen to USD 8bn (GBP 5.2bn), BP says - a rise of some USD 2bn in the past month alone.	BBC
5 September 2010		Thad Allen, the US coastguard official overseeing the clean-up operation, says the BP oil well at the centre of the leak poses "no further risk" to the environment, despite the final stages of an operation to pump concrete into a relief well remaining unfinished.	BBC
8 September 2010		In its own internal report into the Gulf of Mexico oil spill - the first to be published since the disaster - BP spreads the blame for the 11 April explosion and resulting leak. In a 193-page report BP accepts responsibility in part for the disaster, but also blames other companies working on the well.	BBC
17 September 2010		BP pumps cement to seal the damaged well after it was intercepted by a relief well.	BBC
19 September 2010		The ruptured well is finally sealed and "effectively dead", says the top US federal official overseeing the disaster, Coast Guard Adm Thad Allen.	BBC

Table 35: Timeline of BP Deepwater Horizon Oil Spill

Source: *BP (2010c), Deepwater horizon accident investigation report*

Appendix 4: Acronyms BP Texas Case

ACC	American Chemistry Council
AIChE	American Institute of Chemical Engineers
API	American Petroleum Institute
ARPD	Amoco Refining Planning Department
ARU	Aromatics Recovery Unit
AU2	Aromatics Unit #2
BOT	Basic Operator Training
BPSH	BP South Houston
bpd	barrels per day
BUL	Business Unit Leader
CAIB	Columbia Accident Investigation Board
CDP	Compliance Delivery Process
CFHU	Cat Feed Hydrotreating Unit
CCPS	Center for Chemical Process Safety
CMMS	Computerized Maintenance Management Software
CSB	U.S. Chemical Safety and Hazard Investigation Board
CVP	Capital Value Process
DIERS	Design Institute for Emergency Relief Systems
DIH	Deisohexanizer
EHS	Environment, Health and Safety
EPA	Environmental Protection Agency
ERP	Enterprise Resource Planning
GHSER	Getting Health, Safety, and Environment Right
gph	gallons per hour
HAZOP	Hazard and Operability Study
HC1	Hydrogen Chloride
HRO	High Reliability Organization
HSE	Health, Safety & Environment
HSSE	Health, Safety, Security, & Environment
HUF	Heavy Ultraformate Fractionator
IH	Industrial Hygiene
IMAS	Industrial Mutual Aid System
ISBL	Inside Battery Limits
ISOM	Isomerization unit
kPa	kilopascal
KPI	Key Performance Indicators
L&D	Learning and Development
MAR	Major Accident Risk
MAWP	Maximum Allowable Working Pressure
MDL	Manufacturing Delivery Leader
MOA	Memorandum of Agreement
MOC	Management of Change
mscf	million standard cubic feet
NDU	Naptha Desulfurization Unit
NESHAP	National Emissions Standard for Hazardous Air Pollutants
NPRA	National Petrochemical and Refiners Association
NPS	Nominal Pipe Size
NTSB	National Transportation Safety Board
OSBL	Outside Battery Limits
OCAM	Operator Competency Assurance Model
OSHA	Occupational Safety and Health Administration
P&ID	Piping and Instrumentation Diagram
PHA	Process Hazard Analysis
PIP	Piping Integrity Program
pph	pounds per hour
PPS	Amoco Petroleum Products Sector
psi	pounds per square inch
PSM	Process Safety Management
PSS	Process Safety Standard

PSSR	Pre-Startup Safety Review
PT	Process Technician
QA/QC	Quality Assurance/Quality Control
R&M	Refining and Marketing
RCFA	Root Cause Failure Analysis
RHU	ResidHydrotreating Unit
RIF	Recordable Injury Frequency
RMP	Risk Management Program
SAP	Systems Applications and Products
SEP	Special Emphasis Program
SHIFT	South Houston Infrastructure for Tomorrow
SIS	Safety Instrumented System
SOI	Standard Operating Instructions
SOPs	Standard Operating Procedures
TCEQ	Texas Commission on Environmental Quality
TCR	Texas City Refinery
TCS	Texas City Site
TSP	Traffic Safety Policy
UK	United Kingdom
ULC	Ultracracker unit
UOP	Universal Oil Products
USW	United Steelworkers
UU3	Ultraformer Unit # 3
UU4	Ultraformer Unit #4
VOC	Volatile Organic Compounds
VPP	Variable Pay Plan