Disaster Resilience of the Vancouver Health Care System to Pandemic Influenza

by

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Abstract

By fostering resiliency in the health care sector, disruption to the delivery of health care can be minimized in a pandemic. This study's goal is to evaluate the resilience of the health care system to pandemic influenza by using Greater Vancouver as a case study. The methodological approach is structured around a decision/event tree analysis that computes conditional probabilities of events in an influenza outbreak. Tree branches are partially populated through data procured from semi-structured interviews with ten regional experts. A pandemic influenza scenario was created to provide a specific context to the interview questions. Although the interviews are the primary data source, further information was accumulated through documents such as the British Columbia Pandemic Influenza Preparedness Plan, as well as from a comprehensive review of the existing literature. This event tree allows estimation of the likelihood of certain events occurring in a pandemic, including characteristics such as time, morbidity, and mortality. Additional outcomes include an assessment of the alternative response strategies. This approach is distinctive since prior research on health care has not examined the systems perspective. This perspective allows for a consideration of the entire health care network in a region, including the relationships between each facility and the agencies that govern them. Consequences of the analysis indicate the likelihood of occurrence for four disruption levels, based on the mortality, hospitalizations and stress on the health care system felt in the region. Sensitivity analyses were also conducted to assess the impact of policy decisions. Results suggest that a moderate pandemic event will have a 0.22 – 0.27 probability for causing disruption in the highest two levels, which indicate substantial disruption. Vaccinations were expected to have the greatest impact on reducing virus transmission, if a vaccine is shown to be effective, and made widely available. Three alternative policy options were explored: the All-Mitigations Policy, the Isolation and Social Distancing Policy, and the No Vaccinations Policy. Results indicated a need to further incorporate social distancing and isolation into existing control strategies, and to generate policies and establish agreements to expedite the development and distribution of vaccines in a pandemic's early phases.

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1.0 Introduction

Although it was not the only global infectious disease outbreak in the past century, the Spanish Influenza of 1918-19 is certainly the one that first comes to mind when one thinks of pandemics. Notable for its high infection and case fatality rates, this virus spread to every single continent on the planet, taking the lives of tens of millions of people around the world. Subsequent epidemics have occurred since then, but none have had nearly the same levels of disruption. One hundred years have passed since this large-scale event happened. The world may never see a pandemic of this magnitude again; yet, smaller disease outbreaks still have the potential to cause serious disruption and loss of life to communities around the world. Recent communicable diseases such as Severe Acute Respiratory Syndrome (SARS), Avian Influenza (H5N1), and HIV/AIDS have shown that a vulnerability to these illnesses currently exists.

In the Canadian Province of British Columbia, there has not been a pandemic influenza event in decades, with the exception of seasonal variations of the virus, which are less virulent and easier to manage than pandemic strains would be. Nevertheless, it is critical that communities are prepared to respond to the widespread illness that an event like this would cause. Without advanced planning, the risk for disruption and death increase substantially. In particular, the increased need for medical care demands that the health care sector be especially prepared.

Fortunately, there has been an increased awareness of the potential impacts of pandemic events to this region, which has resulted in the emergence of pandemic planning as an emergency preparedness activity. Among other initiatives, the existence of the British Columbia Influenza Advisory Committee has provided the region with an organization that has a mandate to plan and prepare a coordinated response to a pandemic influenza event in the region. This committee is responsible for developing the B.C. Pandemic Influenza Preparedness Plan, a document that is circulated to facilities throughout the region, and describes the roles and responsibilities of organizations and individuals to ensure readiness for a pandemic event. Additionally, some of the local health authorities have a specialized position within their organization for a communicable disease, or pandemic influenza coordinator. Local facilities have also included pandemic influenza plans in their emergency plans. Finally, the British Columbia Centre for Disease Control has implemented procedures for surveillance and monitoring of infectious disease outbreaks, testing for virus strains, creating a vaccine, and communicating health advisories to the public.

The preparedness activities that have already been implemented are important to reduce the impact caused by a pandemic influenza event; however, these activities need to be supported by research. Common current control strategies that are outlined in pandemic preparedness documents are: surveillance, isolation/quarantines, social distancing, public health communication, and the administering of vaccines and antivirals. Yet the effectiveness of many of these strategies is not agreed upon by the community of health care professionals in many cases. Furthermore, a key gap in the literature that exists is an approach to assess an urban region's vulnerability and resilience to a pandemic outbreak from the perspective of the entire system. This research needs to include variables that are demographic, social, political, economic, and geographical. For example, population settlement patterns, social networks, and prevailing health care policies will all influence the diffusion of an infectious disease across a region. Holistic pandemic research approaches are needed to increase the effectiveness of pandemic mitigations.

The health care sector is composed of many parts, all of which together will be referred to as the "health care system". Together, this system is responsible for managing the needs of all the individual components, and providing adequate quality of medical care to the population in its jurisdiction. Planning for pandemics typically takes place at both the facility level, as well as in the health authorities that govern them. When measuring the levels of preparedness, one cannot look solely at the components; rather, the system needs to be considered as a whole. Unfortunately, no framework currently exists for assessing systems as a whole.

Systemic approaches exist for evaluating complex organizations, but none that are applicable for the health care sector. The scope of the majority of these studies is too broad or too narrow to be used for this type of analysis. As a result, a model needs to be developed that allows for an evaluation of the effectiveness of the health care system to deliver care during, and prior to a pandemic.

This study was framed around the question, "How resilient is the health care system in Vancouver to pandemic influenza?" To address this question, a set of sub-questions were developed:

- How can we characterize the resilience of a regional health care system?
- What types of mitigation strategies are currently being considered? What gaps exist in mitigations that are not being considered?
- How are mitigation decisions made?

This analysis intends to assess the resilience of the Greater Vancouver region in the Province of British Columbia to pandemic influenza. To this end, a framework to measure resilience will first be developed, and then applied to the study region. Data for this research will be primarily obtained from an interview process with several experts from all the relevant organizations within the health care sector. In doing so, this study is able to focus on individual regions, taking into account the unique social, political, economic and geographical variables. However, this framework can also be applied to other communities and regions globally by conducting the research with experts from that locale.

Although the analysis sections of this research paper were rooted in concepts of risk analysis and communication, this study intersects with several fields of research. Background research was conducted on the disaster resilience literature. Additionally, an understanding of the structure and functioning of the health care system required research on literature from this sector. Studies of historical pandemic influenza events and future predictions were also included, as was other epidemiological work on the characteristics of virus transmission and health care response. Finally, this interdisciplinary study looked at policy decisions in the health care context.

To address the key research questions, this paper will begin with a look at the disaster resilience literature, with a focus on health-care related studies that are applicable to a systemic analysis. This will be followed by a discussion on the previous pandemic influenza events locally and globally, and the expected impact of the next pandemic in the Greater Vancouver region. Chapter four will describe the policies that shape the delivery of health care in Canada and British Columbia, and will end with the current preparedness activities and mitigations that have been implemented. Next, this paper will explain the conceptual framework that has been developed to assess the resilience of the health care system to pandemic influenza, including its relevance for the scope of this study. Chapter six will describe in the further detail the methodology for the analysis, including the sources and use of the data. The analysis and results chapter will discuss in detail the outcomes of the study. The final chapter will summarize the key findings of this research, discuss the advantages and drawbacks of structuring a study in this way, and consider some policy implications of the results.

2.0 Disaster Resilience

The delivery of health care is integral to a region's ability to ensure a healthy workforce. If a pandemic strain of a virus spreads through a population, not only will it overwhelm acute care facilities, but there also will be adverse impacts on the local economy because of the reduction in able-bodied workers. Minimizing the virus' spread while also making the delivery of health care services as efficient as possible during a pandemic is critical to allow for minimal disruption to the region. This need for pandemic planning requires a process for estimating the effectiveness of a health care system in this context; however, existing research has not provided a sufficient method for measuring the system's effectiveness, or resilience. Resilience in a disaster context can be defined in many ways; but, generally, it is the ability of an individual, organization or system to withstand a disruption to its regular functioning and/or recover from this shock in a short period of time. Within health care, the system is resilient to pandemics if it has the ability to respond to increased demand for services without a dramatic reduction in functionality, and is able to transition back to normal daily function after the hazardous event has passed. This chapter will provide a review of the disaster resilience literature as it relates to measuring the resilience of health care systems in the context of pandemic influenza. Past research on the resilience of the health care sector falls into three main categories: resilience of individual components within health care, resilience of communities, and the resilience of health care systems. The body of existing disaster resilience literature is significant; so, this chapter will focus only on research in these three areas of resilience studies, while discussing their applicability for this study.

2.1 Resilience of Individual Components

The first set of research looks to establish an approach for assessing the resilience of individual components within health care. Among the most notable of these components are acute care facilities and nursing/residential homes, which receive the bulk of the research attention. This body of work investigates either the ways to measure resilience in facilities, or the impact of a pandemic influenza event on these individual components. The focus of these studies is on disasters caused by regional hazards, with a particular focus on pandemic influenza. Disasters caused by a natural hazard that occurs outside of health care facilities can be called “external disasters”. Some research argues that external disasters of this type are not the only potential source of service disruption. In addition, there is also a possibility that disruptions may occur within facilities themselves, undermining their ability to provide care (Milsten, 2000). Disruptions that originate inside a facility are referred to as “internal disasters”. These internal disasters can be initiated on-site, for example, through a fire, utility failure, hazmat release, or localized terrorist attack. However, internal disasters may also be caused by an event that begins outside the facility but has an internal impact. Natural hazards such as hurricanes, earthquakes, floods, tornadoes, and pandemics are all examples of this. Some of these occurrences may cause an “internal crisis”, which can be defined as an unexpected event that causes disruptions to the normal functioning of a facility. If these types of situations spiral out of control and lead to multiple casualties, or severe destruction, then this can be referred to as an “internal disaster” (Sternberg, 2003).

Regardless of the cause, disasters in health care facilities will cause a reduction in the delivery of health care services. In an attempt to remedy this disruption, resilience needs to be enhanced. The initial sources for disasters in facilities may be numerous; however, there are certain patterns and problems that occur with regularity. As a result, an increase in the resilience of facilities can minimize losses and reduce levels of disruptions. Sternberg (2003) argues that despite all the uncertainties that exist with anticipating the effects of disasters, resilience can be achieved through seven types of mitigations:

1. The first of these is the acquisition and dissemination of intelligence, whereby uncertainties about the events that are occurring and the expected response can be eliminated by ensuring accurate information is made available before and during disasters. This can be accomplished by distributing staff throughout facilities with assigned roles when unexpected events occur.

Accurate information can also be acquired through proper surveillance devices, such as air quality testers, cameras, and sensors.

2. The second mitigation is to address the technological needs of a properly functioning communication system. This is especially critical for the Emergency Operations Centers (EOC's) to ensure that all decision-makers are able to communicate with each other.
3. Resource management is the third mitigation, and demands that protocols exist to reduce the demand for resources in times of excess demand. Some ways to achieve this are through the adjustment of patient loads, staff members, and medical supplies.
4. The fourth mitigation is mobility management, which refers to comprehensive planning to move patients from facility to facility, or within facilities, without exacerbating the demands on the system.
5. The next mitigation is to physically design facilities in a way that facilitates resilience, such as including emergency lighting, and allowing for easy evacuations.
6. The sixth mitigation is to create a decision-making structure with specified roles so that facilities can respond quickly to adverse events.
7. Finally, the last mitigation to increase resilience is staff versatility. Individuals need to be trained so they can competently engage in a variety of courses of actions if the need arises (Sternberg, 2003).

The role of health care workers is considered important for increasing resilience. Certain characteristics have been identified as integral for a health care worker to have to contribute to the resilience of their organization. Individuals need to be able to improvise effective solutions to difficult problems. Additionally, they need to have a critical understanding of their situation, as well as the resources that are available to solve problems. This requires the effective use of information. Individuals should also not be handcuffed by their official role; instead, they should be able to fill in for missing workers, which requires an understanding of the goals they intend to achieve.

Resilient individuals are also able to rely on multiple sources of information to ensure information is accurate and unbiased (Mallak, 1998).

In addition to acute care facilities, preparedness levels have also been gauged for residential and nursing homes to determine how ready they are to cope with the increased demand in a disaster (Fell, 2008). Results from a study out of England showed little had been done in the way of planning, with significant hurdles surrounding areas of responsibility, and what the priorities should be. Preparations that have taken place were typically for seasonal influenza, which would not have the same virulence, or demand on the health care system that a pandemic strain would. Although this research area in not based in our study region it brings up important points about establishing roles and responsibilities for health care workers during a pandemic.

Other work expands the study scope beyond just facilities to look at the interconnections between acute care facilities and other infrastructures. This is done to gain a greater understanding of the complexity of interactions between these systems. Hospitals rely on a number of critical infrastructures to function, such as energy, transportation, telecommunications, food, and water. Any obstacles to receiving these essential services can severely impede the delivery of health services. Most hospitals have backup plans in place in case these services are interrupted; unfortunately, the supplies are typically limited, and only last a matter of days at best (Itzwerth et al., 2006). The public health care system has been compared to a business continuity model, where the overall objective for planning is to ensure that the business is less prone to interruptions, which increases its resilience. In an effort to increase its resilience, research suggests that existing plans need to be updated to include information on the expected impacts that other sectors will have on health care, since the failure of one sector may trigger a cascading effect causing dependent sectors to experience a service breakdown (Itzwerth et al., 2006). Although all of these findings are relevant, they do not provide a framework with which to measure system resilience.

The frameworks that have been identified in this section all relate to facility-level measures of resilience, while the scope of this study is the entire health care system. A concentration on individual components will inevitably overlook some of the resilient capacities held by a complete system. As a result, the frameworks discussed have limited applicability to a study of the health care system; however, some of the resilience considerations that have been studied at this level are important to take into account when assessing system-level resilience. The Sternberg paper (2003) in particular incorporates many types of mitigations that can be useful, such as implementing resilient design elements, designating roles and responsibilities to streamline decision-making, and training staff to increase job versatility.

2.2 Community Resilience

The second set of existing research has a substantially broader scope, looking beyond the health care system itself and focusing instead on community resilience. Community resilience has been extensively researched; so, only the articles with the most applicability to this study will be discussed in this section. A community-based approach to resilience is based on the notion that nothing operates in complete isolation; so, discussions on resilience should be broadened to focus on entire communities. It is argued that disasters occur as a result of local policies and other societal decisions, in conjunction with the occurrence of a natural hazard (Mileti, 1999). In other words, risk is derived from hazard interacting with vulnerability, where “hazard” refers to the natural phenomenon that are occurring, and “vulnerability” refers to the conditions in a region that leave it susceptible to disruption. This reasoning suggests that a naturally occurring hazard alone cannot cause a disaster, nor can a high level of vulnerability. However, if there is an overlap in a region where vulnerability exists, and a hazardous event occurs, this combination can result in a disaster. For certain hazards, some degree of risk will always be inherent, since a region will always be vulnerable to extremely disruptive hazards. Examples include a high magnitude earthquake, or an extremely virulent influenza virus, both of which will cause disruption regardless of implemented mitigations and pre-disaster planning. Based on this concept, the resilience of any subset of a region cannot be established without considering the resilience of the community as a whole.

Existing literature has described in detail the complex interactions between systems in communities. This complexity demands that cities and regions themselves need to be resilient so that they can withstand any potential threats. Cities can become resilient if they are structured based on the knowledge we have gained from past urban disasters. Furthermore, subsystems within communities need to become adaptive, and must increase communication between them. Interventions in communities would result in the ability to cope with an extreme event without causing any long-term physical, social or economic damage. There is a need for unique planning in each community since the local infrastructure and the hazard-specific risk vary from place to place (Petak, 2002). As a result, a thorough understanding of the social, political, economic, and geographic conditions of a locality is necessary to address the mitigation alternatives that are available. Enhanced resilience can be achieved by estimating the level of risk to a community by the hazard, determining how robust the local infrastructure and local population are to this hazard, considering the mitigations that can reduce the risk, and engaging stakeholders and policymakers to implement the appropriate practices (Petak, 2002). When agreeing upon desired resilience levels, it is important to establish tolerable levels of loss based on the characteristics of the community. This will influence policy decision such as the minimum costs to be put towards mitigations (Petak, 2002). Some have called for a comprehensive national plan in the United States that distinguishes urban hazard mitigation from mitigation in general (Godschalk, 2003). In doing so, currently prevailing policy decisions would be challenged by concentrating attention on increasing the resilience of cities.

Building communities that are resilient to disasters is an important concept, but there needs to be a method to quantify resilience. Traditionally, losses have been measured by totaling economic losses; however, the true impact of a disaster is much larger. Measures of resilience need to incorporate technical, organizational, and social dimensions, in addition to economic ones (Bruneau et al., 2003). Technical resilience refers to the ability of physical infrastructure to withstand the effects of a disaster. Bruneau et al. (2003) studied resilience as it pertains to a seismic event, so loss of physical components of a system due to an earthquake is reasonable to expect. For a pandemic, technical resilience is less of a concern. Organizational resilience refers to the ability of organizations to manage systems so that they can be functional. This dimension speaks to the management of resources and people, as well as the nature of policies. Social resilience refers to the ability to minimize the adverse impacts on a society caused by a loss of critical services. Finally, economic resilience refers to the ability to reduce the direct and indirect monetary losses incurred (Chang and Shinozuka, 2004). These four components together will allow for an assessment of community resilience.

Previous research has applied the community-based resilience approach to many hazards. Using a volcano hazard, for example, a study was conducted on community resilience to volcanic eruptions in 1995 and 1996 in New Zealand. Volcanic ash falls were shown to have the largest impact by disrupting air and ground transportation, reducing water quality, and even impacting national power supplies (Paton et al., 2001). The results of this study suggested that resilience can be enhanced by concentrating on mitigation strategies and risk communication oriented towards tangible goals, instead of on uncontrollable natural phenomena (Paton et al., 2001). In applying this concept to pandemic influenza, an example would be to implement policies that would decrease the number of infections to children in schools, instead of trying to reduce the virulence of the virus itself. A longitudinal survey method was used for this study, where the permanent population of the eruption-affected region was chosen as the study group. Three measures of community resilience were identified by researchers, which were: self-efficacy, coping style, and sense of community. Because of the differences in the nature of studying a community versus an infrastructure system, these measures would not be difficult to use for determining the resilience of the health care sector. Additionally, this study benefitted from a recent extreme event from which to gather data. The most recent influenza pandemic was the Hong Kong flu of 1968. Because of the societal changes and the advances made in technology in the last 40 years, data used from this pandemic would not provide an accurate representation of our current state.

Other research has looked into the seismic resilience of communities. One such approach uses three different measures of resilience: reduced failure probabilities, reduced consequences from failures, and reduced time to recovery (Bruneau et al., 2003). This research has established a framework which can measure resilience in various types of systems. The framework takes resilience measures such as robustness, rapidity, resourcefulness, and redundancy, and combines them with the four dimensions of community resilience: technical, organizational, social, and economic (Bruneau et. al., 2003). With this method, the performance of the system is evaluated by using several earthquake scenarios. The expected disruption to the system is evaluated by applying the scenarios, as is the time expected for the system to fully recover. The framework used in this pandemic influenza study utilizes a similar scenario-based concept, where a realistic estimation of an extreme event is used to determine the systemic impact.

The abovementioned research examines disaster resilient communities, and goes about trying to find a method to assess resilience. The approaches that have been described typically used natural hazards such as earthquakes, volcanic eruptions, and floods as their basis. Given the unique nature of a pandemic influenza threat, these methods cannot be directly applied to this particular study. For example, a pandemic hazard will have little to no impact on hard infrastructure such as buildings, pipelines and roads, whereas most other natural hazards will cause damage. Due to global surveillance and communication, there may also be a window of time to implement pandemic plans, in comparison to other natural hazards that can strike without warning. A third key difference is that the greatest disruption caused by pandemics is a reduction in the healthy labour force. While also a consideration for other natural hazards, the diminished number of workers may be larger in a pandemic. For these reasons, mitigations that are oriented towards a single natural hazard, or an all-hazards approach, cannot be directly applied to pandemics. Additionally, the scope of the community resilience body of work is too broad for an analysis of the health care system. Community based resilience deals with the interactions between the systems that make up an urban area. The focus of this study is on the health care system alone; so, community based resilience approaches are too broad to be applied here. However, some of the concepts that have been used will be drawn on for this research. In particular, this analysis will be structured around a region-specific scenario. Also, it will look at the interactions between infrastructure systems when assessing resilience. Finally, this study will focus on mitigation strategies and risk communication, instead of attempting to prevent or control the hazard itself.

2.3 Resilience of Health Care Systems

The final set of research on health care related disaster resilience has the right scope for this study, but the approaches typically are not applicable for this type of analysis. Resilience is a term that has been defined in many ways and for many purposes. Within the health care literature, there is no agreement on a single definition of the word; as a result, some studies have established approaches to study resilience which cannot be adapted to this research. As an example, some portions of the literature view a resilient health care system as one which limits preventable medical errors, such as adverse events involving medical devices and medical errors (Carthey et al., 2001). This body of work does not include concepts such as natural hazard mitigations, preparedness, or risk communication in their definitions of resilience, centering attention instead solely on the prevention of medical errors. Other studies define resilience in more general terms as the ability of an individual or an organization to adapt in a positive fashion to fluctuations in their immediate situation while enduring minimal stress (Malak, 1998). This definition is wide enough to include disaster related concepts, although they are not mentioned outright. It is notable that this type of research stresses the importance of the resilience of individuals in an organization or system by using resilient measures which can be considered to be characteristics of health care workers. An example is, "goal-directed solution-seeking", where an individual enjoys tackling difficult problems and is able to improvise solutions (Malak, 1998). The role of health care workers in contributing to overall resilience is significant; however, resilience for our purposes is comprised of much more than that.

The existing body of literature that discusses the resilience of the health care system and that is adaptable to pandemic influenza is limited to date. Most attempts at quantifying resilience are still at the theoretical level. Frameworks that do exist tend to be in the rudimentary stage, requiring further research so that it can be applied to real-world situations. For example, a framework has been developed by Handler et al. (2001) that aims to provide one standard method for measuring the performance of the public health system. Five components were identified as the root measures of resilience: macro context, mission, structural capacity, processes, and outcomes. Each of these components needs to be measured to assess overall resilience levels. This framework does not describe the methods used to measure each of the components; rather, they are intended as a way to guide further studies in generating their methodology to gauge resilience. Other research evaluates the impact felt by the health care system, if one subsystem is adversely impacted. In one such study, a survey was undertaken of a small number of residential and nursing homes to determine levels of preparedness. It was found that preparations were inadequate, and the repercussions would ripple through the health care system (Fell, 2008). Additionally, it was found that future planning requires coordination across a range of sectors.

This chapter has discussed the research gap that currently exists for studying the delivery of health care from a systems perspective. Measures of resilience exist in detail at the facility and the community level, while the systems level is conspicuously under-researched. Facility-based research provides a basis for the understanding of resilience as it relates to health care, but ultimately falls short by not considering the implications of the relationships between all the health care organizations. Community-level resilience studies are not directly applicable for this type of study because their scope is too broad; however, these frameworks do explore the nature of the interactions between systems within a community. Since the structure of health care is composed of a number of interrelated agencies and facilities, elements of community-level resilience can be utilized for a systems analysis. Finally, the existing literature at the health care systems level has yet to develop a framework to assess the resilience of health care which can be replicated. Any study with this scope would require the development of a framework which is oriented at the systems level.

3.0 Epidemiological Hazard

Throughout history, humanity has had to endure many epidemic hazards. Some, such as the Black Death of the 14^{th} Century and the 1918 Spanish Influenza pandemic were global phenomena where millions were killed. Other recent infectious diseases such as Severe Acute Respiratory Syndrome (SARS), West Nile Virus, and avian influenza have been more localized in nature, but certainly have the potential to diffuse around the world. Each of these diseases has its own variation in terms of characteristics such as their pathogens, their mode of transmission, and their mortality/morbidity rates. This section will look at global influenza outbreaks from the past, and shed light on the elements from those events that may be similar to the current conditions in British Columbia's lower mainland. It will also focus on historical infectious disease outbreaks in British Columbia, and conclude with a discussion on the expected characteristics of a pandemic influenza outbreak in this region based on historical precedence.

3.1 Previous Global Influenza Events

When one thinks of influenza pandemics, the aforementioned Spanish Influenza of 1918-19 is most often cited as an example. This is understandable, given that this pandemic is considered to be the most devastating in recorded history. It certainly has taken the greatest number of lives in the last century. Estimates place the death toll at somewhere between 20 and 50 million people (Cox, Tamblyn and Tam, 2003). These remarkable numbers are explained by the exceptionally high virulence of this outbreak, with case fatality rates as high as 2.5% (Billings, 2005). Putting this into perspective, previous epidemics had substantially lower rates, closer to 0.1%.

Typical signs and symptoms of pandemic or seasonal influenza include fever, chills, headaches, sore throat, and a dry cough. These symptoms are typically resolved within a week, with the exception of serious complications in the respiratory tract which most often occur in the very young, in those over the age of 65, and in those with pre-existing medical conditions (Cox and Fukuda, 1998). With an especially severe influenza infection, such as the one from the 1918-1919 pandemic, primary influenza pneumonia can occur. This illness can progress to severe pneumonia with respiratory failure within 24 hours, and is fatal in 10-20% of the cases (Boyd et al., 2006). Although this type of pneumonia is rare, its prevalence was significantly higher in the 1918-1919 pandemic.

Due to technological advances, it is much easier to determine mortality and other statistics today than it was during this pandemic. As a result, estimates have been made for important statistics decades after the event occurred. The R_o number, or the number of cases an infectious individual infects in a totally susceptible population, is an example of this. Through calculations, rough estimates place the R_o number between 1.2 and 3.0 in community settings, although it has been noted to be substantially higher in confined places such as boats and prisons (Vynnycky, Trindall, and Mangtani, 2007). An R_o value in this range is considered to be extremely high, and explains the efficiency with which the virus was able to spread throughout the human population. Assuming the lowest transmission rate, each infected person would transmit the virus to 1.2 other individuals, who infected a further 1.2 people. In this way, the virus was able to rapidly diffuse across the population. When combined with the high case fatality rate, it becomes clear why this pandemic was so disruptive. An R_o value of less than 1 means it cannot have sustained transmission in a population and will eventually go extinct. If an infection has a value of R_o greater than 1, then the infection can spread in the population because each case is expected to cause more than one additional case. Values significantly higher than 1 will result in a rapid diffusion of the virus; but, values closer to 1 may still die out on their own.

This was a truly global pandemic, impacting many nations of the world, and one-fifth of the population overall (Billings, 2005). Numerous countries in Africa, Europe, Asia, the Americas, and Oceania were all affected. The virus diffused through human carriers along major trade routes, and was also propelled forward via the armed forces engaging in battle during the First World War. Specifically, troops would become infected while abroad, and would continue to transmit the virus within their own camps due to the high concentrations of people. Furthermore, the soldiers who were carrying the virus would bring it to their own shores when they returned from duty, infecting the population at home.

Although it was the largest pandemic of the century, it was not the only one. More recent events include the Asian flu of 1957, and the Hong Kong flu of 1968. Significantly more data is available from these latter two outbreaks, due to advances in laboratory investigations. Both pandemics had considerably lower mortality than the Spanish flu. The Asian flu was the next global epidemic to occur since the one in 1918, and had a global death toll of approximately two million people (Global Security, 2005). The low level of fatalities was a result of a lower case fatality rate of 0.13 to 0.35. In addition to these characteristics, this virus had less of an impact due to the improving ability to detect epidemic threats. As a result, the particular strain of virus was quickly identified, and a vaccine was derived from this information and made available in limited supply by the fall of 1957 (Global Security, 2005). Unfortunately, logistical issues arose over the immunization of vulnerable portions of the population, reducing the effectiveness of the vaccine. Further propagating the virus' spread was the lack of knowledge in prevention concepts such as *social distancing*, which is a set of measures that are taken to limit when and where people can gather to stop or slow infections (Globalsecurity.org, 2005). As a result, the majority of transmission occurred in existing networks of contact, such as classrooms, conferences, and festivals.

The 1968 Hong Kong flu was milder still in comparison to the Asian flu 11 years before. Total deaths were estimated to be around one million worldwide. Since these two pandemics were separated by just over a decade, there is speculation that the survivors of the 1957 flu may have gained immunity to the Hong Kong virus; thus, reducing transmission rates. Also, the time of the Hong Kong virus overlapped with school holidays, reducing the levels of contact amongst children.

3.2 Infectious Disease in British Columbia

Infectious diseases are prevalent in every region around the world, and British Columbia is no different. Although they do not garner the same amount of worldwide attention, perhaps due to the lower mortality rates, local outbreaks are still common and can still be dangerous. The British Columbia Centre for Disease Control (BCCDC) monitors the transmission of certain reportable diseases, to ensure that they do not spread past baseline levels. In doing so, they have compiled statistics on the incidence of these diseases. A quick look at their data reveals how common local cases of infectious disease are in this province. In particular, genital Chlamydia, Giardiasis, Hepatitis B and C, Tuberculosis, and Salmonellosis have shown a high number of case reports in 2006 in comparison to the Canadian rates (BCCDC, 2007).

Events such as the SARS scare of 2003 have indicated that infectious diseases can spread in Canada, and that the specific regional health care interventions are critical to reduce loss of life and social disruption as much as possible. A comparison of the response between Toronto and Vancouver support this claim. Due to the increased risk of pathogens from Asia entering North America through Vancouver's ports, the BCCDC implemented a system to distribute important information to health care facilities across the province. This network was utilized to immediately enhance vigilance for severe influenza-like symptoms for travelers from China and Hong Kong, when a cluster of illness was reported in this region in February 2003 (Skowronski et al., 2007). Additional protocols were enacted at the hospital that ensured barrier precautions were applied to all acute-onset respiratory infections. As a result, the first patient with SARS in Vancouver was immediately identified and managed cautiously to prevent further transmission, thereby containing the all the cases. In Ontario, a centralized communicable disease control body like the BCCDC did not exist; so, the first patient there with SARS was not immediately recognized as a special threat, and further generations of transmission occurred. This example highlighted the need for baseline preparedness locally, and an efficient network of communication (Skowronski et al., 2007). Further to this SARS example, other emerging infectious disease threats such as the West Nile virus and the avian flu are now posing a constant threat. The potential for a bioterrorism attack must be considered as well, especially in the context of the 2010 Olympic Games to be held in Vancouver. These outbreaks have shown that the region is vulnerable to an outbreak of an infectious disease, including influenza.

As was discussed earlier, the 1918 pandemic was the most disruptive that the world has seen, triggering massive amounts of fatalities. Due to a variety of reasons, the influenza pandemics during the mid-20th century resulted in significantly less loss. Mortality and morbidity were both lower in 1957, and dropped again in the subsequent outbreak of 1968. This can be attributed in part to the lower R_o and case fatality rates. Estimates for future influenza pandemics reflect these statistics from previous events. As a result, these measures were set accordingly in the scenario below, with values of 1.8 and 2.0% respectively. It is worth noting here that these numbers are not only derived from an analysis of preceding events, but are also consistent with estimates put forth by researchers.

Applying these estimates to the population of British Columbia, an estimated three million people may become infected in a future influenza pandemic, while 1.8 million would become clinically ill by showing influenza symptoms. Of those people as many as 6,800 will die from influenza and related complications based on the predictions put forth by the British Columbia Centre for Disease Control's Pandemic Plan (2005). This document has been developed by the BCCDC to anticipate, prepare and respond to the next influenza pandemic in this region. It outlines policies and mitigations, as well as the roles and responsibilities of those working in the health care sector, based on estimates of the pandemic's impact. Furthermore, up to 610,000 people are expected to visit a health care provider, placing a substantial burden on this system. All together, the death toll is expected to exceed 6,800 people from influenza and related complications (BCCDC Pandemic Plan, 2005). Given the higher concentrations of people in Vancouver and other urban settlements, the virus will be more likely to spread in these areas. Rural regions will have considerably less interaction with large groups of people, and are less likely to come into contact with infected individuals from abroad. So, fewer infections will occur in rural regions in comparison to urban ones.

Fortunately, these numbers are not as high as they could have been without the reforms to the medical system that are now in place. Because of the advances in microbiology, laboratories have become an integral weapon in the fight to mitigate the effects of a pandemic. Due to the cooperation between local public health officers, physicians and the centre for disease control, a system of communication is in place to identify higher than normal rates of disease incidence. Once an infected individual is identified, laboratory tests can be undertaken to determine the strain of the virus. With this information, a virus-specific vaccine can be created, and programs to administer it can be enacted.

For the purposes of planning, the BCCDC has made a number of assumptions about the expected progression of an influenza pandemic. It is anticipated that the next pandemic virus will arrive in Canada within three months after it first emerges elsewhere in the world, and will be followed by the first peak of illness two to four months later. A subsequent wave may occur anywhere from three to nine months after the initial outbreak, with each wave lasting six to eight weeks. Vaccinations will be the primary method of prevention, although the supply will be limited during the early stages (BCCDC Pandemic Plan, 2005). As a result, protocols for priority immunizations will need to be established. Additionally, the BCCDC expects there to be a substantial reduction in the available workforce due to illness, with health care workers to be the most impacted. Essential community resources are likely to be disrupted, as are non-essential medical procedures. Since pandemics are global events, the BCCDC pandemic plan is consistent with national and international plans. Links have been made to the work done by the World Health Organization, Public Health Agency of Canada, and other Canadian provinces.

Greater Vancouver is especially susceptible to infections because of the geographical and socio-economic characteristics of the region. There are a number of potential points of entry here, including two international airports. Situated on the Pacific coast, Vancouver also has a number of ports that are heavily trafficked for commercial trade and tourism. Finally, the city is located adjacent to the United States border, to which it is connected through major highways. These spatial attributes allow for a considerable amount of human-to-human interaction with people from around the world. Moreover, Greater Vancouver's diverse ethnic population leads to the residents having extensive global ties with family and friends around the world As a result, viruses can easily be carried to the region and diffuse locally through any of these points of entry, and to all cohorts of the population. In the scenario described below, the virus first arrives through Vancouver International Airport; however, it is likely that there will be numerous infections occurring simultaneously through the other regional interfaces. In terms of the virus itself, it is impossible to predict the specific traits it will have. The rate of transmission, case fatality rate, ability to spread from human-to-human, and other defining features will depend on the strain of the virus. Regardless, it is expected that there will be little to no natural immunity since the world has not seen an influenza pandemic since 1968.

3.3 Expected Pandemic Influenza Characteristics

Given the history of infectious diseases in British Columbia, it is clear that an influenza pandemic would certainly impact the population in this region. What remains to be seen is the extent to which an outbreak would cause disruption in terms of mortality, morbidity and social disruption. The answer must be rooted in historical precedence, with due consideration to the changing social factors and scientific advances. To this end, a scenario was created that indicates one of many possible outcomes. For this analysis, it was decided that the virulence of this virus would not be at the extremes of the spectrum; rather, it would reside somewhere in the middle. Specifically, it would mirror the trends from the abovementioned global pandemics.

In generating the scenario, a number of parameters needed to be considered. The location where the virus is introduced to a population is important if interventions can prevent further transmissions from this point source. Regardless, much of the response typically targets increasing the immunity of the vulnerable population. The nature of transmission must also be identified, as well as the capabilities for secondary transmission. The R_o number, and expected case mortality rates should also be considered, which will lead to an estimation of the number of people expected to be infected. Also, a case definition, a description of the symptoms of the disease, must be created. Following this, this scenario can take into account the availability of the vaccine, based on the expected amount of time that is required to produce it and have it widely available after the strain of virus is identified. The last thing to bear in mind is the existing social conditions and medical improvements since the Hong Kong flu. This is important in differentiating the impacts of a disease on a population with similar virulence. Each of these components factored into the scenario (Chapter 3.4).

The case definition has been described in the scenario as similar to seasonal influenza, but more severe. This strain of influenza can cause health complications such as pneumonia, bronchitis and death in healthy cohorts of the population as well as vulnerable ones. Transmission is typically through droplets that have been ejected into the air through a cough or sneeze of an infected person, which are then passed into the system of an uninfected person. Human-to-human spread of the virus is possible, resulting in higher rates of diffusion with increased social contact. Incubation period for this type of influenza ranges from 1-5 days.

In addition to the affected population and virus attributes, the scenario outlines the time of year when the initial introduction of the virus to the population took place. The occurrence is in the early fall, when an infected passenger arrives at Vancouver International Airport and is not detained. A vaccine is not yet available, since this strain of virus was only recently identified in Asia.

Unfortunately, the introduction of the virus to a heavily concentrated area such as Greater Vancouver means that it is likely to travel through the population more rapidly than if it had entered a rural area. There is potential to limit the amount of infections with appropriate interventions from the public health arms of the local health authorities. In comparison to the previous pandemics, strategies exist to limit the amount of transmissions that occur. Also, the high connectivity of the population through telecommunications should aid risk communication, more than it would in a less developed region. As a result, pertinent information such as keeping children home from school and other sanitary measures can be broadcasted with relative ease.

Box 3.1 - Pandemic Influenza Scenario

The World Health Organization has discovered a new strain of influenza that has recently mutated from a previous variation. Unfortunately, the novelty of this strain has resulted in limited global immunity from naturally occurring antibodies. This virus has the ability to spread directly from human to human. Symptoms are similar to those associated with seasonal influenza, but can be much more severe. This particular strain of influenza can cause health complications in healthy people such as pneumonia, bronchitis, and even death. Vulnerable portions of the population, including young children, the elderly and those who are immuno-compromised will be impacted much more severely. Typically, transmission occurs when droplets that have been ejected into the air by a cough or sneeze by an infected person are passed into the system of an uninfected person. Commonly, this happens if droplets land on the surface of one's eyes, or if contaminated hands touch the eyes, nose or mouth.

First discovered in Southeast Asia, the influenza virus has been confirmed to have diffused across the continent and into Europe. The R_o, or rate of transmission, in these countries has been approximated at 1.8, with a case fatality rate of 2.0%. The latter indicates a high virulence, and combined with the high transmissibility, will result in a considerable amount of morbidity and mortality if it diffuses to the general population.

On October 9th, 2009, a flight that originated in Shanghai reached the Vancouver International Airport. Passenger X reported feeling ill prior to boarding, however, was still permitted to travel. Upon arrival, a small minority of passengers were noted to have been sneezing and coughing. Given the time of year, it was assumed to be a minor cold or seasonal influenza, and despite the heightened global pandemic awareness, the passengers were not detained. Unfortunately, Passenger X's illness turned out to be the new strain of pandemic influenza. In the meantime, he has come in contact with a number of people, and in all likelihood spread the virus. The incubation period ranges from 1-5 days, so infected persons may not be showing any symptoms yet, and it is impossible to track down each person he has come in contact with. Regardless, the local public health agencies have not been informed of the threat yet. Within several weeks, local physicians have reported a higher than normal incidence of influenza across the lower mainland that appears to be a different strain from that seen before. No vaccine currently exists for this particular strain, although anti-viral drugs have been shown to have some impact.

3.4 Conclusion

The population in the Greater Vancouver region is undoubtedly at risk for an influenza epidemic, despite the fact that a large-scale infectious disease outbreak has not occurred here in decades. Unfortunately, past events have shown that epidemics are inevitable. Moreover, Vancouver has a number of characteristics that would allow virus transmission to flourish. One of the main contributors to this is the geographical conditions in this region combined with the high interaction between people from around the world, which allows viruses to spread faster than they would otherwise. Additionally, in areas with higher population densities, such as Vancouver, contact between infected and non-infected local residents is impossible to avoid. This is especially true of the city's downtown core, where large numbers of people congregate daily in office towers, shopping districts, and tourist attractions. At the end of the day, a significant portion of the population commutes home to the suburbs, potentially carrying diseases with them. A mobile population with frequent human-to-human interaction, such as the one that exists in this region, is exactly what a virus needs to thrive. In addition, since it has been so long since the last influenza epidemic impacted the region, there is likely to be little natural immunity to the evolved strain of the virus. The outcome of these traits is a region that will undoubtedly be affected by a global pandemic. Pandemic plans and resources need to be oriented towards reducing the virus' progression once it enters a population, instead of preventing the initial infections at the point of entry. This is especially true since screening procedures are not completely effective. Regardless of how rigorous traveler screening may be, people who are carriers of the virus but are not showing symptoms would not be detected. The incubation period for this illness ranges from 1-5 days, so many travelers could potentially be infected but would not be feeling ill. Because there are simply too many potential paths a virus can travel, focusing efforts solely on screening would be futile. Health care's approach to mitigating virus transmission should be rooted primarily in prevention of secondary spread in the community. The situation demands that the response from the health care system is decisive and with a substantial positive impact. So, mitigations and comprehensive plans must be in place before an event actually occurs.

4.0 Health Care Structure

The occurrence of any disaster in an urban area will result in illness or injuries, thereby increasing the demand on the health care system. This is especially true of a pandemic, where the majority of patients will be suffering from a sickness caused by a virus, instead of the physical trauma that is associated with earthquakes, floods, and other hazards. Health care facilities typically are operating at full capacity or even over their capacities in a non-disaster situation; so, for them to maintain functionality during an extreme event there needs to be comprehensive plans in place. This chapter explains the Canadian national policies that shape the delivery of health care in the country, and will outline the structure of the health care system specifically in the province of British Columbia. To conclude, this chapter will discuss the current pandemic plans and mitigations that have been implemented to reduce the adverse impact on the region.

4.1 Canada Health Act

Canada's health care structure is shaped by the Canada Health Act (CHA), which was adopted in 1984. The CHA exists to ensure that all eligible residents of Canada are granted access to insured health care services, without being directly charged at the point of service. A primary goal of the CHA is to provide health services to all Canadian residents without any financial or other impediments, and to make certain that the physical and mental well-being of the population is ensured. This is accomplished by a set of criteria that have been set out by the federal government which must be met by the provinces and territories to receive full federal cash contributions. If the provinces and territories adhere to these conditions, they will be given the financial resources that are earmarked for the delivery of health care in their region (Health Canada, 2005). Included health services under the CHA include all medically necessary hospital, physician and surgical-dental procedures.

Nine requirements have been established under the CHA for the provinces and territories to fulfill for full federal cash contributions. The first is *public administration*, which states that health care insurance plans must be administered and operated on a non-profit basis by a public authority, which is accountable to the provincial or territorial government for decision making (Health Canada, 2002). Additionally, health care records and accounts can be publicly audited. The second criterion is that of *comprehensiveness*, which requires that all of the abovementioned insured health services be covered by the health insurance plan. *Universality,* the third requirement, makes sure that all insured residents are entitled to the insured health services. Under the *portability* criterion, the responsibility of providing health care is assigned to the province or territory where a resident lives. This allows one to travel or to be temporarily absent from his/her home province or territory, while retaining health insurance coverage (Health Canada, 2002). Equal access to health care services without impediments such as discrimination on the basis of age, health status, financial circumstances or ethnicity is the basis for *accessibility*, the fifth criterion. Under the sixth condition, it is required that the governments of the provinces and territories provide information to the Minister of Health. The seventh condition states that provincial and territorial governments must recognize the federal financial contributions towards health care services. The final two requirements pertain to extra-billing and user charges. Extra billing refers to an insured person being billed for an insured health service in addition to what has been paid for by insurance. User charges are any charge for an insured health service, other than extra-billing, where the service is covered by the insurance plan. Both of these are barriers to health care along financial lines, and as a result, both of them are not permitted under the last two requirements of the CHA (Health Canada, 2002).

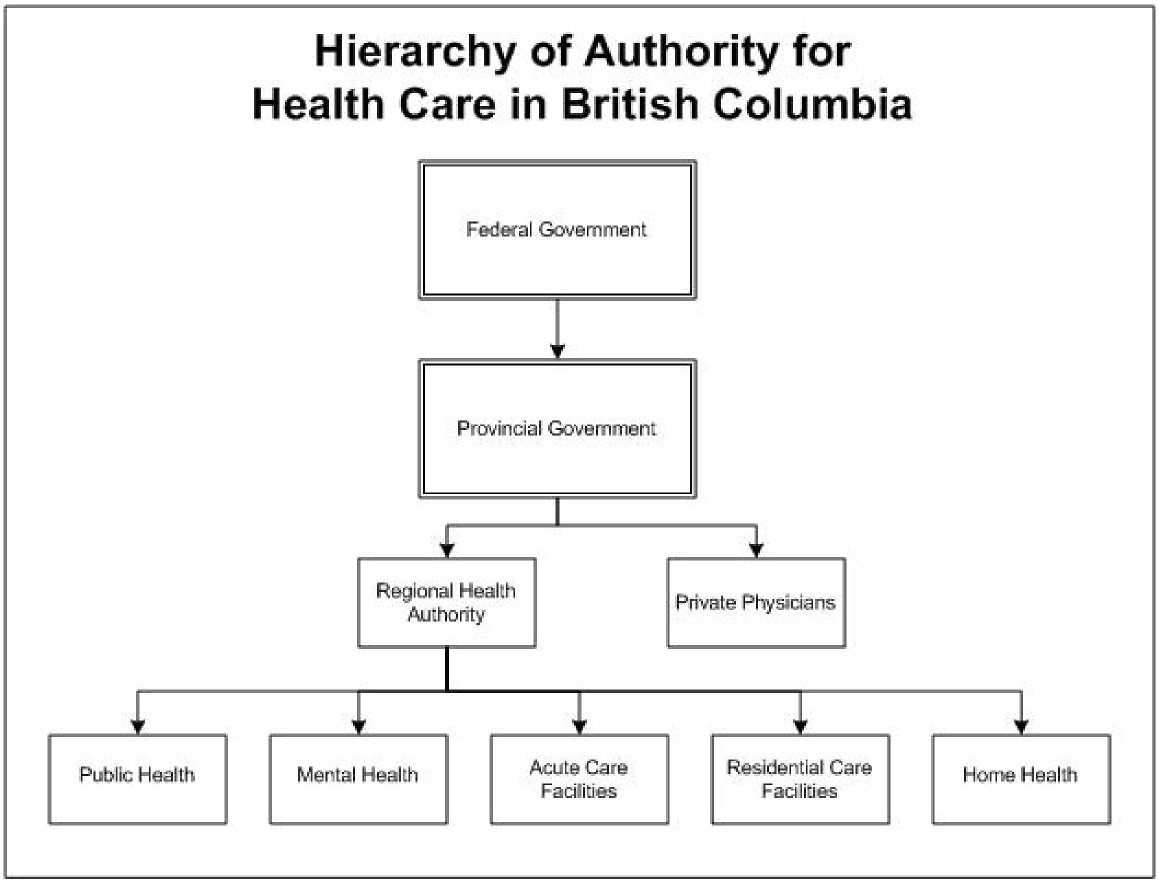
Since health care is the responsibility of provinces and territories, the onus falls on their governments to operate a public medical health insurance system. As described above, the CHA's requirements shape the delivery of insured health services across the country. At its root, the CHA is a means for funding health care across Canada; however, its guidelines also represent the values which underlie the health care system. Working outside these requirements is not a viable option for the provinces and territories, since infractions are penalized with deductions from the federal transfer payments (Madore, 2005). The main role of the provincial and territorial governments in health care includes administering health insurance plans, as well as planning and paying for acute care, physician care, prescription drug programs in hospitals, and public health. Supplementary health services, such as drugs prescribed outside the hospital setting, ambulance costs, hearing/vision/dental care, and physiotherapy, are not covered under the CHA, and must be privately financed (Health Canada, 2005). Under these guidelines, provinces and territories are given the freedom to structure the delivery of health care in the way that they deem appropriate.

4.2 Health Care Components

Across Canada, provincial governments are ultimately responsible for the delivery of health care, but in British Columbia, the province has devolved authority to six regional health authorities. Authority was transferred to the local level in order to contain costs, improve health outcomes, and to better integrate and coordinate services (Lomas et al. 1997). Across the country, no health authority is involved in raising revenues; instead, they are responsible for local planning, setting priorities, allocating funds, and managing services (Lomas et al. 1997). As mentioned above, the federal government's main role in health care is to provide funding by collecting taxes and distributing them amongst the provinces. Three of these regional health authorities fall within the study area of Greater Vancouver. The first is the Vancouver Coastal Health Authority (VCH), which serves residents in the communities of Vancouver, North Vancouver, West Vancouver, and Richmond. Spatially, these communities make up the north and easternmost extremes of the region. All the other municipalities east and south from here are under the jurisdiction of Fraser Health (FH). While the previous two health authorities serve geographic regions, the third health authority's role is to govern specialized health care services across the province. This health authority, the Provincial Health

Services Authority (PHSA), operates agencies such as the B.C. Children's Hospital, and B.C. Transplant Society, and is responsible for specialized health services such as trauma and chest surgery, cancer treatment, complex mental health problems, and cardiac care (PHSA, 2009).

Figure 4.1



Each of these health authorities is tasked with delivering health services to the residents who require it. Every facility and agency within Greater Vancouver falls under the jurisdiction of one of these health authorities. Together, these components make up the health care delivery system for the region. Each of these components will be affected by a pandemic event, but only some play a direct role in the response to such an event. Figure 4.1 shows the hierarchy of agencies within the health care system in British Columbia, each of which will be discussed in more detail below. This section will describe the function of all of these pieces.

When considering the delivery of health care services, acute care facilities often come to mind. Indeed, acute care facilities, or hospitals as they are commonly known, are integral for providing care. Commonly, hospitals provide emergency services, including walk-in patients, and ambulatory care. These services are made available for situations that demand urgent medical attention. Additionally, acute care facilities also provide long-term care, and acute care programs. For example, Eagle Ridge Hospital in Port Moody offers elective surgery for urology, gynecology, plastics and orthopedics. Also offered are public education in areas such as asthma, diabetes, rehab services, youth crisis, and children's grief recovery (Fraser Health, 2008). Vancouver General Hospital also provides many specialized services, including treatment for: Alzheimer disease, arthritis, multiple sclerosis, oncology, organ transplant, psychiatry, spinal cord injury, and sports injuries, in addition to others (VCH, 2009). Each hospital in the region offers a range of specialized services, so that all the needs of the region are met by at least one facility.

For those who are unable to access acute care facilities, or for those who have chronic, palliative, or rehabilitation needs, there exist Residential Care, and Home Health programs. Residential Care is provided to residents who are unable to safely or independently live at home, due to health-related issues. A variety of services are provided, with a focus on personal care around the clock. A living space is also given to patients, which includes meals, and basic laundry services. Some residential facilities offer recreational programs as well. The costs of care are covered under the CHA, and are paid for by the health authority. However, there are living costs for the food, accommodation, and activities that the residents are expected to pay. Health services not considered to be medically necessary under the CHA are not included, and must be paid for by the patient. Home Health exists to fill a similar need, which is to provide health service to those who are unable to seek out care at acute care facilities. Home Health is unique from residential care, in that it allows patients to remain living at home without jeopardizing their health. Typically, people require Home Health services if they are being released from the hospital following surgery, if they have a stroke or other injury, if they are experiencing a worsening of a chronic health condition that demands a greater level of care than they have at home, or if a person with persistent health issues is having increasingly more difficulty taking care of him or herself (Fraser Health, 2007). If an individual is eligible for Home Health, they will be seen within several days of the request, depending on the urgency of the situation. This service does not exist for emergencies; rather, it requires a scheduled appointment. The patient may be seen at home, or a clinic in the community where they reside. Typical Home Health services are nursing care, rehabilitation therapy, hospice palliative care, and respiratory services.

The abovementioned agencies have all concentrated on treating physical afflictions; but, there is also a need for treatment of mental ailments and addiction issues. The health authorities have addressed this with a comprehensive program covering the spectrum of need. Fraser Health's mental health programs and services range from those that are: age-specific (targeting seniors, adults and adolescents separately), emergency after-hour services, short-term treatment, residential care, rehabilitation and recovery, long-term problems, and even for community education (Fraser Health, 2009).

All of the above services can be considered secondary health services. Access to these agencies typically comes through a medical referral from a physician. In conjunction with other practitioners such as nurses, physiotherapists, and pharmacists, physicians are considered to be primary health care professionals since they act as the interface between the health care system and the rest of the population. In this context, physicians can be defined as general practitioners at a walk-in clinic, or as family doctors. Individuals with health concerns will typically seek medical help from a physician or pharmacist initially, unless the condition requires immediate attention. If this is the case, individuals will proceed straight to the emergency room of an acute care facility. Despite the fact that physicians are a central component of a functioning health care system, they fall outside the jurisdiction of the health authorities. It is a commonly believed that physicians in Canada are not privatized, since there is usually no exchange of money for services. However, physicians are actually operating their own private enterprises, and are compensated financially with fees per service, at a rate negotiated with the provincial government. They are not truly autonomous, because of the administrative and financial constraints of the CHA; but, they still do not fall under the health authority umbrella. Private physicians are privy to information from the province, health authorities, and other governing bodies via telephone, fax and email. This way, relevant information can be passed in both directions from the physicians to the rest of the health care system.

Another arm of the health authorities is focused on preventing illnesses from occurring, to minimize illness in the region. A benefit of these preventative measures is the reduction of demand for health services. This agency is called Public Health, and its role is to improve overall levels of health. Core functions for public health have been set out by the province's Ministry of Health, and are followed by the local health authorities in Greater Vancouver. Ultimately, the goal of public health is to prevent disease, injury, and disability. In the past, public health initiatives have resulted in achievements like vaccinations, motor-vehicle safety, workplace safety, promoting healthier diets, family planning, and infectious disease control (Ministry of Health Services, 2005). Current programs try to extend this progress in areas such as reproductive health, mental health promotion, food security, unintentional injury prevention, dental health, water and air quality, and sanitation (Fraser Health, 2009).

The final integral component of health care in the context of a pandemic is the British Columbia Centre for Disease Control (BCCDC). While not directly involved in delivering health care services, the BCCDC is responsible for a number of other essential tasks that allows health care services to function. The BCCDC is an agency of the Provincial Health Services Authority whose chief focus in on the prevention and control of communicable diseases, as well as the promotion of environmental health (BCCDC, 2002). The BCCDC has linkages to many international agencies, which allow for the sharing of epidemiological information as it pertains to any potential diffusion to British Columbia. Among these agencies are the U.S. Centres for Disease Control and Prevention (CDC) and the World Health Organization

(WHO). The BCCDC is tasked with coordinating the prevention, control, and treatment of certain diseases throughout the province, including hepatitis, tuberculosis, HIV, and other STI's. Additionally, the BCCDC also provides environmental health services, and is also a coordinating body for the provincial response to a major emergency such as a large-scale communicable disease outbreak. Laboratory services are also undertaken by the BCCDC, as they provide public health with data on food-borne disease agents, safe drinking water, and the viral characteristics. This component is vital for surveillance purposes and in detecting the causes of outbreaks. Finally, the BCCDC, receives all data on communicable diseases from across the province, and is responsible for developing and implementing control policies to minimize the diffusion of disease (BCCDC, 2008).

When in need of medical care, residents across Canada first contact the primary health care professionals described above. This initial contact, or primary health service, is the health care system at its most basic level. This initial service exists to prevent and treat common or minor diseases and injuries, such as seasonal influenza, and muscle sprains. Through this initial interaction, an individual can also gain access to the other services within the health care system. Referrals to specialists, mental health services, palliative care, and rehabilitation services all can be given by a physician. To ensure continuity of care, relevant medical information is relayed back to the physicians, who communicate it to their patients.

4.3 Existing Pandemic Protocols

When a pandemic influenza outbreak hits Greater Vancouver, each component of the health care system will be impacted. Because of the increased need for medical care, there will be a substantially higher demand on the health care system to provide this service. The situation will be exacerbated by the reduction in trained health care professionals, who are sick, or are tending to sick family members. To avoid a large-scale influenza pandemic the health care sector has implemented a range of protocols. Some are policies aimed at responding to the threat once a proportion of the population has become infected, while others look at reducing the spread of the virus during a pandemic. These policies cut across the entire health care system, and require cooperation between the health authorities, the BCCDC, and all the facilities.

4.3.1 Pre-Pandemic Phase

In the pre-pandemic phase, the British Columbia Pandemic Influenza Preparedness Plan (hereafter referred to as "The Plan") has outlined roles and responsibilities between the provincial government and the health authorities to achieve a state of readiness for subsequent pandemic phases. The Plan was last updated in August of 2005, and was put together by the British Columbia Influenza Advisory Committee, comprised of people from various government agencies, as well representatives from the health authorities and the BCCDC. This committee reports to the Provincial Health Officer through the BCCDC. The mandate of this committee and the plan is to prepare a coordinated response to a pandemic influenza threat in this region (BCCDC, 2005). For the sake of sharing information across global agencies, the plan is consistent with other provincial, national, and international plans for pandemic preparedness and response. This plan is arranged in three separate sections that correspond with the pandemic phases used for planning: pre-pandemic, pandemic, and post-pandemic. Each section considers the six key components of pandemic planning, which are: emergency response, vaccines, antivirals, clinical health services, surveillance, and communication (BCCDC, 2005).

The provincial government is responsible for developing key messages and strategies, and establishing systems for a communication, surveillance, and emergency response. The province also established working guidelines for infection control and triage during a pandemic, and is also responsible for making plans to acquire resources like antivirals and vaccine supplies. The health authorities are also accountable for advanced planning, but their scope is narrower. Instead of acquiring vaccines and antivirals, the health authorities need to plan for mass immunization clinics, and develop protocols for administering antivirals. Health authorities will also assess the capacity of their facilities and compare this to the estimated demand during a pandemic. If need be, they will use this information to identify and secure additional and alternative care locations and resources. Surveillance is a central component of the pre-pandemic phase, so the health authorities will coordinate this function. Finally, the health authorities will define the communication roles for all the local facilities and agencies that they govern, and develop a provincial infrastructure for the dissemination of information from the top down.

4.3.2 Pandemic Phase

As a result of monitoring and surveillance by the public health agencies, there should be some advanced warning of an impending pandemic event occurring in Greater Vancouver. However, in the unlikely event that a pandemic strain of the virus had begun to diffuse across the region without any knowledge from health agencies, redundancies have been built into the system to allow the disease transmission to be noticed. Figure 4.2 outlines the relevant linkages in a disease outbreak. Since each outbreak is different, the steps in this diagram may occur in different orders. For a pandemic influenza event of this magnitude, this is the likeliest response. Box 4.1 has a key which corresponds with Figure 4.2, describing the health care interventions in more detail. Seasonal influenza spreads throughout the population on an annual basis, typically during the winter months. Based on historical precedence and the experience of physicians, there are expectations that include seasonal fluctuations, on the amount of infected people year-round. When physicians notice an increase in these baseline levels, or symptoms that are more severe than the expected norm, they may refer patients to a laboratory for testing. Microbiologists at these laboratories are able to identify the strain of the virus, which they can then compare to known pandemic strains. If it is verified that the pandemic variation of the virus has entered the population, the information is passed forward to public health agencies, and the BCCDC. In doing so, the information is fed back into the system so that health care agencies can make informed decisions.

Figure 4.2

Health Care Linkages in a Disease Outbreak
Disease Outbreak
1a
1b
Physicians
Public Health
2a
2b
Acute Care (Laboratory)
3
Public Health (MHO)
4
Public Health
5
Acute Care (Laboratory)
6
Public Health
7a
7b
7c
7d
7e
Acute Care
Physicians
Home Health
Residential Care
General Public
8
Public Health
Time

Box 4.1 Health Care Linkages in a Disease Outbreak

1a:	Physicians notice a higher prevalence of an ailment
1b:	Public Health notices a higher prevalence of an ailment
2a:	Physicians inform laboratory of higher prevalence
2b:	Public Health informs laboratory of higher prevalence
3:	Laboratory confirms an outbreak of the disease at levels higher than the baseline, and the Medical Health Officer is informed.
4.	The Health Authority broadly, and Public Health issue preliminary control measures to the public to prevent secondary spread
5.	Lab determines specific strain of virus
6.	Public Health uses the strain, and elements of person, place and time to develop a case definition
7a-e.	Acute Care, physicians, workers in Home Health and Residential Care and the public are informed of the nature of the outbreak, and methods to control it
8.	If there is a point source for infection, it will be eliminated by Public Health. This includes vaccinations.

When the laboratory confirms that there are higher than baseline levels of influenza prevalent, the Medical Health Officer (MHO) within the public health agency is informed. Prior to a pandemic strain of the virus being identified, the laboratories can communicate this information to public health so that preliminary control measures can be acted upon. Without specific knowledge on the transmission characteristics of the virus, general strategies are put forth by public health, as well as the health authorities. The public is informed and reminded of sanitary practices that include frequent hand-washing, and the avoidance of large gatherings of people. Given time, the laboratories are able to accurately determine the specific strain of the virus, which public health can use in addition to elements of person, place, and time to develop a case definition for the disease. The case definition is used for subsequent diagnoses, to confirm the virus is of the pandemic strain. Armed with this case definition, public health can now communicate this information to acute care, residential care, and mental health facilities, as well as home health workers, and private physicians. Additionally, all are informed of methods to treat and control the spread of the virus, including vaccinations if they are available. If there is a single point source for the spread of the infection, this can be determined by epidemiologists at the BCCDC, and eliminated. Unfortunately, in the case of influenza, there will likely be many points of entry into the region. Combine this with the fact that pandemic influenza is expected to spread from person-to-person through secondary spread and it becomes highly improbable that a single point source can be found for this type of outbreak. So, control strategies will not focus on eliminating the point source; rather, they will look at preventing transmission in the community.

Every agency within health care has a role to play in a pandemic. Some will be responsible for implementing and enacting protocols for the region, while others are responsible only for maintaining service in their facility. Interventions can range from those that prevent virus transmission, to those that treat infected individuals. Medical care can be provided to individual patients, while other policies are intended to protect larger portions of the population. In the pandemic scenario presented in this analysis, the virus is expected to enter the region via an infected passenger at the Vancouver International Airport (YVR). The Public Health Agency of Canada, or PHAC, is tasked with the duty of screening passengers and airplane crews to prevent the spread of infectious disease. During the times when a known pandemic strain of a virus is prevalent globally, there will be enhanced screening measures. A central component of screening at YVR are questionnaires and passenger surveys that are given to passengers prior to boarding flights, on-flight, and after their arrival. The separate time frames are established in case individuals have contracted the virus, but are asymptomatic when boarding the plane. The surveys intend to assess the level of risk based on the symptoms that are showing, and the contact made with others who may carry the virus, prior to travelling. The symptomatic people are given questionnaires on-flight, as well as when they arrive at YVR. Upon arrival, the symptomatic individuals are triaged, and sent to an acute care facility if need be. All the asymptomatic travelers are assessed by quarantine officers on-site. This group is further divided into those who may have been in contact with disease carriers, and those who have not. The latter group is released, while the former is given information on the symptoms of the infection, and told to self-isolate to prevent secondary spread. The quarantine officers are in regular contact with the BCCDC and the World Health Organization (WHO), and would communicate relevant information about potential transmission risks.

As mentioned earlier, the virus is expected to enter the region through a number of sources, so elimination of the point source will likely only delay the peak of the pandemic. This interval can be used to step up pandemic preparations; but, there is still a need for community based strategies to control the spread. Interventions by public health are intended to minimize transmission in the population at the regional level. The likelihood of control strategies being applied to individuals is dependent on how prevalent the pandemic strain of influenza is perceived to be. There is no direct detection algorithm for the virus once it is spreading through the Canadian population. Sick individuals will likely seek medical help, and are most often sent home after the doctor's diagnosis. Influenza testing by laboratories is very low, even during times of heightened awareness of a potential threat. Furthermore, travel questions are rarely asked by physicians to establish whether or not there has been contact with someone from an infected region. If a physician does recommend laboratory testing, the results take time to process. Because of these hurdles, the policy of public health is to concentrate less on treating individuals who are infected, and more on mitigations that blanket the entire region. Of course, if an infected individual is shown to be carrying the pandemic strain of the influenza virus, he/she will be given full treatment as well.

A key mitigation technique is that of vaccination, where at-risk populations are given a vaccine that will provide some degree of immunity to transmission, depending on the effectiveness of the vaccine. If an effective vaccine has been produced and is readily available to administer broadly, it is expected to have a great influence on reducing transmission. However, it is expected to take at least six months to produce a vaccine, after the strain of the virus has been identified globally. Fortunately, cooperation between international health agencies such as the Centres for Disease Control and the WHO allow for this type of data to be shared. In theory, a large lag time between a global outbreak and a local outbreak could allow for the vaccine to be developed before it reaches British Columbia. In reality, expert predictions claim that the vaccine will almost certainly not be available during the first wave of the pandemic, and even if it is, it will not have been produced in large enough quantities to have a meaningful impact on transmission rates. To date, a vaccine for H5N1 (Avian Influenza) has been difficult to develop because of the agents that are being used themselves. Depending on the nature of the pandemic influenza strain, similar barriers could arise.

The response of public health would then turn to other strategies, including the use of antivirals as both a method of prophylaxis, and treatment. There is a great deal of debate on the effectiveness of antivirals for preventative purposes. The evidence so far has been inconclusive in determining the impact that this type of treatment has. Within health care, the expectation is that there may be a small degree of impact, but it is difficult to predict. Even if effective, the influenza strain could become resistant to the antivirals, limiting its impact. Public education would be a core method of prevention at the community level. Communication would occur through all the popular media outlets, such as radio, television, and newspapers. These updates would consist of symptoms and signs to watch out for, as well as preventative recommendations like frequent hand-washing, self-isolation, avoidance of large groups, and staying home when feeling ill.

The role of most facilities is to treat infected patients, as well as to prevent the virus from being transmitted to other patients or their staff. Sick patients can be funneled through to acute care facilities from YVR, but more commonly are referred through a physician, or by coming to the emergency room themselves. Once at the hospitals, any patient with a respiratory illness is identified when triaged, and would be isolated from other people in pressurized rooms. In a pandemic state, it is estimated to be very likely that the illness is identified as influenza in hospitals, although it may not be the pandemic strain. The infection control people receive a daily report, generated by the BCCDC, with all the current influenza cases, as well as the newly flagged cases. Additionally, this report carries information about the laboratory results on virus strains, as well as the current level of resistance to antivirals. Current conditions across Canada, and even abroad, are also described, for surveillance purposes. This list is passed forward to microbiologists at the BCCDC who can follow up with the patients if need be. However, as long as the patients present with the influenza symptoms, that is all that is needed for them to be admitted to the hospital. For patients that are admitted to the hospital, strict protocols exist to prevent additional spread. Proper hygiene practices such as hand washing and sterilizing of instruments are standard procedures in a non-pandemic state, and are continued during an outbreak. Highly contagious individuals are isolated into pressure controlled rooms. Health care workers are given personal protective equipment (PPE), including personal respirators to make sure their air intake is not contaminated. Additionally, workers are instructed to stay home from work if they are ill, to decrease the likelihood of spread. Antivirals and, if available, vaccinations will be used for prophylaxis. Early recognition in acute care is critical to allow for isolation and other control strategies to be effective.

The three health authorities are responsible for providing resources, and direction to the facilities and agencies that they govern. In anticipation of high competition for medically necessary supplies during an emergency situation, the health authorities have created stockpiles. This is a departure from past practices, where the just-in-time system of acquiring resources used to be the norm. In the event of a disaster, a lack of stored resources could lead to a massive reduction in the delivery of health care. As a result, there has been a shift in policy towards storing supplies in advance. Critical items such as antivirals and clean water are prioritized, and other items are stored if there is space as well. There is centralized purchasing and stockpiling for all the health authorities by the provincial government; however, all of the health authorities are responsible for their own warehousing and stockpiling, although Fraser Health and Vancouver Coastal Health are working on shared logistics. Supplies are divided up amongst the facilities as needed. There is, however, little reserve capacity for food storage, so meals for patients would be severely impacted. Additionally, specialized medical supplies are not stored in large amounts, which would impact care if there was a prolonged disruption. Finally, the health authorities would be required to manage the increased demands by cutting other programs temporarily. The health sector already runs at beyond 100% capacity during a non-pandemic state; so, the surplus demands for medical care would need to be met by reducing other services. Typically, this would include cancelling non-emergency surgeries that have been pre-scheduled, removing health care workers from long-term care facilities and shifting them to acute care facilities, and temporarily suspending specialized care programs such as closing down dialysis clinics.

4.3.3 Post-Pandemic Phase

Once the Provincial Health Officer declares that the influenza pandemic is over, the primary focus of work for the health care sector is to return to normal functioning, while reviewing the effectiveness of the response interventions. This investigation into the pandemic response activities can be broken down into the six components of pandemic planning. Two of these, emergency services and clinical health services, are both demobilized from the pandemic state and their effectiveness is evaluated and documented. Successful mitigations are retained, while recommendations for future pandemics are used to revise the emergency plans as needed. Similar assessments are undertaken of the impact of the efficacy of the vaccine and antivirals, as well as protocols for their distribution, and incorporated into revised emergency plans. Finally, a post-mortem is conducted for the inter-agency communications, and infectious disease surveillance mechanisms. Recommendations for all of these components are integrated into updated versions of pandemic plans.

5.0 Conceptual Framework

Chapter 4 described the structure of health care in the province of British Columbia, and explained the flow of policies, information, and resources. This look at health care illustrated the connections between the various organizations within this sector, and how they each play a role in delivering health care. By taking a holistic view, it becomes apparent that although health care services are delivered by acute care and other facilities, there is a role to be played by the other components of the system as well. So, estimating the efficiency of the delivery of health care requires an understanding of the entire system. In terms of assessing resilience, the same principle applies. To accurately measure the resilience of the health care sector, the entire system needs to be evaluated as a whole. As discussed in Chapter 2, existing resilience research tends to study individual facilities and communities, while systemic approaches are limited. This study has created an approach that models a pandemic influenza outbreak in the region and explores the potential consequences from this extreme event. Section 5.2 will describe in more detail the nature of this framework. Prior to that section, there will be a background discussion on the principles of decision analysis as they apply to this study, as well as the reasons why this approach has been chosen for this type of analysis

5.1 Decision Analysis and the Event Tree

In complex situations with many unknown variables, making decisions can be a difficult task. To make informed decisions, there needs to a be a process to structure decision elements such as potential alternatives, outcomes, uncertain events and consequences in such a way that facilitates a greater understanding of the entire problem. In these situations, decision analysis techniques can be utilized. A general decision analysis tool that is often used as a starting point for analysis is an influence diagram, which provides a visual representation of real world decision problems using shapes and text. In these diagrams, each shape represents a variable in the decision-making process, with descriptive text explaining the relationships between the shapes. Typically, rectangles represent decisions, ovals represent chance events, and diamonds represent the final consequence (Clemen & Reilly, 2004). These shapes are referred to as nodes, and are connected to each other by arrows. Often, influence diagrams are structured around a specific set of objectives. For example, a simple influence diagram could model all of the potential decisions involved with investing in designing a building, with the fundamental objective of minimizing damage from a seismic event. With this goal in mind, all of the potential consequences of an influence diagram can be analyzed to determine the best case available option.

Influence diagrams are valuable for generating visually appealing graphics that outlines decisions which need to be made; but, they are also simplified models that omit many details. To include more of the relevant data, decision trees, also known as event trees, are perhaps a better tool. Event trees have a similar structure to influence diagrams, with squares representing decisions to be made, and circles representing chance events. The branches that emanate from a decision node describe the choices available to the decision makers, while the branches that stem from the chance nodes represent the potential outcomes of a chance event. The result of these diagrams is a tree with several branches that examines all the potential outcomes, and the ultimate consequence. Outcomes can be defined as the direct result of a decision or chance, while a consequence is the ultimate resolution of all the outcomes. In the example above where a building is being designed for seismic safety, an outcome might be the decision to use materials that can withstand shaking, while a consequence would be an overall increase in safety.

Event trees are structured so that a decision maker can only choose one path towards a consequence. For example, the decision can either be made to use the better quality materials, or to not use the materials, but cannot be both. The rationale behind this is that the branches that emanate from a node are mutually exclusive (Clemen & Reilly, 2004). The decision tree represents all the potential paths that a decision-maker may take in chronological order. Typically, event trees are constructed from left to right;

so, the outcomes on the right side of the diagram can only take place if the outcomes prior to them on the same pathway have occurred.

As described in Chapter 2, there is no existing framework in the literature that is able to assess the resilience of a health care system. Decision analysis techniques, as described above, can be manipulated to analyze the health care sector from a systems perspective. Instead of focusing on the structure of health care, this approach can model the progression of a pandemic as it enters a region, and combine that with the interventions from the health care sector. Furthermore, this event tree can be constructed to correspond with the pandemic influenza scenario that was described in Chapter 3 (Box 3.1). The scenario illustrates a pandemic event that is realistic for the Greater Vancouver region, beginning with a few isolated cases of influenza. The event tree is consistent with this information, and models the progression of the influenza virus from this stage and onwards. Once the event tree has been created, the health care organizations and facilities that have expertise in the pandemic response for each of the nodes need to be identified. Health care professionals from these organizations and facilities are then chosen as potential interviewees, to confirm the structure of the event tree is accurate, as well as to provide additional information about the likelihood of the occurrence of each branch.

5.2 Event Tree Structure

Event trees, or probability trees, are used to show all possible outcomes resulting from an initiating event, taking into account a number of variables. By determining and applying probabilities to the consequences of this analysis, event trees can assess the likelihood of all potential outcomes in complex systems. Furthermore, weaknesses or oversights can be identified so further attention may be given to them. Because of these attributes, event trees are generally used to evaluate systems in terms of the impact of decisions that will be made, as well as recognizing potential amendments and improvements.

To build the event tree, there are certain necessary components. The first structure in the diagram, which takes the shape of a circle, is the initiating event. Without this occurrence, the subsequent events would not take place. This incident is often adverse in nature, exposing the functionality of the system. Next, come all the possible outcomes and decisions that are caused by the initiating event, which are represented as text above the connecting lines. These lines lead to decision or chance nodes, symbolized as squares and circles respectively. A decision node indicates where a decision has to be made, and is followed by any number of connecting lines with text that describe the possible outcomes that will occur as a result of the intervention. Similarly, a chance node denotes an uncertain event, from which connecting lines will express the potential outcomes. The end points of the event tree are blocks of text that describe the final consequences of all the decisions and chances. Stemming from each decision or chance node are a number of potential decisions or outcomes. Along with the text, a decision tree branch will show a value, ranging from 0 to 1. This number expresses the probability of that branch occurring, given the preceding decisions and outcomes. The total value of all the branches from any node must equal 1.0. To compute the likelihood of any consequence in the event tree, one must simply multiply together all the probabilities in all the branches that lead from the initiating incident, all the way to the consequence, or end point.

The event tree begins with an initiating event, represented in the diagram with a large circle. For this event tree, the initiating event is the pandemic strain of the virus first entering the region through infected passengers at Vancouver International Airport. A series of nodes and branches separate this starting point with the consequences at the other end of the event tree. Although they appear several times in the event tree, there are only four potential consequences from this analysis. These four consequences correspond with levels of disruption that are caused by the pandemic, where a disruption level of one yields the lowest disruption, and a level of four results in the largest disruption. The pandemic disruption index is described in more detail in Chapter 7.

Throughout the event tree, there are a number of decision and chance nodes that will influence the transmission of the virus throughout the region. Circles represent chance nodes, where variables that are difficult to control are modeled. For example, demographic considerations like population density, employment rates, and transportation patterns will all influence the degree of contact between people that is typical for the region. Greater contact increases the chance of human-to-human transmission, thereby spreading the virus at a faster rate. Since these variables are inherent in the study region, it is nearly impossible to alter them. A key chance variable in the diagram is the likelihood of secondary spread. Some viruses are capable of transmitting directly between people without a vector, or disease-carrying organism. Depending on the strain of the virus, the ability to spread directly from human-to-human will increase the speed with which the illness is spread, and will also shape the response from the health care sector. Another important chance variable is the likelihood of the outbreak progressing from isolated cases to affecting entire communities. Population densities and the movement patterns of residents will impact this variable.

Health care can impact the diffusion of the disease through mitigations and control strategies, which are modeled in the event tree as decision nodes. The branches that flow from these square shaped nodes describe health care interventions that are aimed at reducing the spread of the virus. In the event tree, decision nodes are prevalent at three main junctures. The first of these is at the points of entry for the region. In the case of this scenario, this pertains to the airport. The key intervention modeled here is the decision to isolate potentially infected passengers or not. In the model, this strategy may stop transmission, or the virus may spread anyway. In the latter outcome, the pandemic will progress to isolated cases in the region, and onwards to community outbreaks. Here, is the second major health care intervention, labeled "Strategy A" in the event tree. Strategy A is actually a group of interventions aimed at preventing further spread, while not committing excess resources. Priorities for the health care sector at this time are to ensure plans and resources can be easily implemented if the situation escalates. This includes developing a vaccine, increasing surveillance, securing additional medical supplies, and coordinating response protocols. The public will also be informed of proper hygiene methods in an attempt to reduce virus spread. If the pandemic worsens, the health care sector will ramp up their response with another group of mitigations, called "Strategy B", in the event tree. This approach will exhaust all possible resources in an attempt to end the diffusion of the illness. In addition to all the mitigations from Strategy A, Strategy B will also start administering antivirals and a vaccine, assuming they are available and considered to be effective. Additionally, pandemic response plans will be activated, and may include mobilizing additional health care workers or volunteers, managing increased demand for the delivery of services, and obtaining extra supplies and resources. Interventions at this stage are expected to substantially reduce the diffusion of the virus, leading ultimately to consequences of the event tree. The entire event tree is presented in Appendix B.

The event tree will be completed once a probability value is attached to each branch. Through some calculations, the likelihood of occurrence for each of the four disruption levels can be determined. Furthermore, the probabilities for all the branches can be manipulated to reflect policy changes and the effectiveness of certain strategies. Different probability values that are inputted into the event tree will yield different likelihoods for the four disruption levels. To assess the resilience of the health care system, the likelihood of each of the disruption levels can be compared across the different probability trials.

6.0 Methods

6.1 Data Sources

The event tree described in Chapter 5 is based on concepts taken from decision analysis. This framework relies heavily on the risk analysis literature, most notably through the work of Clemen and Reilly (2004). An analysis of this type requires very specific data to create and populate an event tree. In creating the event tree, there needs to be an understanding of the organization and functioning of the health care system in both pandemic and non-pandemic phases. Additionally, this knowledge must extend to the expected events and outcomes during a pandemic influenza outbreak. This information was acquired by compiling the literature on the components of health care, the structure of health care, the interconnections between all the health care agencies, and the public policy as it pertains to health care in Canada and the province of British Columbia. Epidemiological literature was also accumulated that referred to the expected transmission characteristics, the pandemic responses by health care, and the effectiveness of mitigations. All of this information was used in conjunction with the geography and social characteristics of the region, to map out the initial version of the event tree.

To conduct this analysis, the most significant set of data that is needed is the conditional probabilities which are missing from the initial event tree. The event tree is populated with probabilities of an outcome occurring, based on the assumption that the previous events have already happened. In the diagram, the events are represented by the connecting branches, which describe the nature of the event. The existing literature does not provide a comprehensive assessment of the likelihood of pandemic events happening, especially when considering specific conditional events. To populate this event tree, interviews with regional health care experts were conducted, which provided numerical data for the analysis, as well as anecdotal information that offered insight into the day-to-day functions and protocols of local facilities and agencies. Because of the absence of data on the functioning of a health care system in the context of a pandemic, expert interviews were chosen as the best available data source. However, there is a degree of uncertainty with expert judgments that are not supported by real-world observations. As discussed previously, this gap in the literature is due in large part to the lack of recent pandemic events in this region.

When selecting potential interviewees, a wide enough net was cast to ensure that all the agencies that are relevant for a pandemic influenza event were included. The list covered the entire health care hierarchy, ranging from decision-making bodies like the regional health authorities, down to medical health professionals at local facilities. All of the potential interview subjects were chosen because of their knowledge in the areas of health care structure and functionality, or pandemic influenza and disease outbreaks. In addition, the respondents needed to represent organizations that are directly involved in the delivery of health care, or in ensuring that health care services are provided through policy making. Finally, a potential interviewee needed to hold a position in these organizations which would allow them to speak with confidence about the planned actions of their agency in the context of a pandemic. Once this list of experts was identified, each was contacted via email with a description of the study, and asked if he/she would like to participate. Nearly all of the people contacted chose to be interviewed. In total, ten experts were interviewed. They represented the following roles and organizational affiliations:

- Emergency Management Consultant for the Provincial Health Services Authority (PHSA)
- Director of Business Continuity at the PHSA
- Corporate Manager of Business Continuity at the PHSA
- Pandemic Influenza Coordinator for the Fraser Health Services Authority
- Director of Public Health Laboratory Services at the British Columbia Centre for Disease Control (BCCDC)
- Emergency Planner at the BCCDC

- Microbiologists/Laboratory Technicians at Vancouver General Hospital and the BCCDC
- Director of Pharmacy and Epidemiology Services at the BCCDC
- Chief Medical Health Officer at Vancouver Coastal Health Authority
- Office of Quarantine Services at Vancouver International Airport which is under the jurisdiction of the Public Health Agency of Canada

All of the interviews were conducted in the summer and early autumn of 2008, and had a duration of approximately 90 minutes. To address the key questions of this study, a number of different types of questions were asked. Each interview was broken down into five individual sections with each having a similar theme. They are as follows: Occurrence Probabilities, Structure of Event Tree, Interventions, Capacity to Respond, and Agency-Specific. Each question was carefully crafted so that the answer would address the probabilities for each outcome in the event tree. Questions were worded in general terms, and the answers were then extrapolated to all the relevant branches in the event tree. For example, the answer to a probability question about the effectiveness of vaccinations can be applied to various nodes in the event tree, since vaccination as a control strategy appears several times.

The first set of questions was intended to find out the likelihood of certain outcomes in the event tree. Since it was difficult to ask for a numerical value outright, a scale was created prior to the interview that would facilitate easier responses. To each question in this section, the experts were asked to answer probability questions with one of the following four answers: not at all likely, somewhat likely, very likely, and extremely likely. In doing so, these answers could be translated into numerical values for the purposes of populating the event tree.

In addition to this likelihood scale, respondents were given the opportunity to provide further information. For example, a question in this section asked about the likelihood of detection for a passenger at the airport who is infected with the pandemic strain of the influenza virus. It was followed by an open-ended question about the protocols for detection at the Vancouver International Airport, as well as the roles of various agencies in this process.

The second set of questions pertains to the composition of the event tree and scenario, asking the interviewees to criticize their structure, and all of their elements. A preliminary draft of the event tree and scenario was sent to the interviewees beforehand so they would be familiar with the content. Both of these components had been constructed prior to the interviews with information derived from the pandemic literature. They combined the predictions in the literature with previous historical events to arrive at a likely event for the Greater Vancouver Region. The interviews allowed for the regional experts to comment on these two pieces of research. Respondents were asked to rank the variables in the event tree according to their expectations for the ones which would have the greatest and least impact on virus transmission. Additionally, the interviews gave the experts a chance to provide feedback and suggestions on the structure of the event tree, as well as the content in the scenario. The data from this section was used to revise and refine the event tree and scenario, to reflect the judgments of regional experts.

The next section of questions utilized the likelihood scale again, and asked for an assessment of the effectiveness of certain common control strategies on the reduction of virus transmission, such as vaccinations, public education, and the use of antivirals for prophylaxis.

The fourth section of questions was concerned with the capacity of health care to deliver services during a pandemic. The questions in this section focused on the anticipated loss of service based on the expectation that health care workers and medically necessary supplies will be diminished.

The fifth and final section asked questions that are specific to that particular interview, with a concentration on issues that are prevalent for that agency. Appendix A provides a set of sample interview questions.

6.2 Data Use

6.2.1 Deriving Probabilities

The expert interviews provided considerable insight into the expected progression of a pandemic influenza event in this region; however, the data that came out of the interviews was in a format that was difficult to manipulate for the purposes of this analysis. In particular, all of the questions were answered verbally, but some of the responses needed to be converted to numbers to compute the conditional probabilities. Specifically, the questions that asked for a response about the likelihood of an event occurring would need the answers converted into numerical values. It was for this purpose that the above likelihood scale was given to frame the responses from the interviewees. In addition to the open-ended responses, the interviewees would answer these likelihood questions with one of the following answers: not at all likely, somewhat likely, very likely, and extremely likely. Because there are four potential outcomes from the questions, these responses can be converted to four values in a probability scale that ranges from 0-1. In doing so, each response can be assigned a numerical value. For the response, “not at all likely”, the probability range was set at 0 to 0.24. The remaining range of likelihood responses can be converted to a numerical range accordingly, with “somewhat likely”, “very likely”, and “extremely likely”, each having ranges of 0.25 to 0.50, 0.51 to 0.74, and 0.75 to 1.0 respectively.

Table 6.1 Numerical Interpretation of Likelihood Responses in Initial Three Trials

	Not at all Likely	Somewhat Likely	Very Likely	Extremely Likely
Baseline	0.125	0.375	0.625	0.875
Lower bounds	0.010	0.260	0.510	0.760
Upper bounds	0.250	0.500	0.750	1.000

Full ranges of probabilities cannot be inputted into the event tree diagram in this form, since calculations require one single value; so, it is necessary to select a value from within this probability range to use for the analysis. Single probability values from within this range can be selected in a number of ways. The middle value from the range can be chosen, which would give probability scores of 0.125, 0.375, 0.625, and 0.875. These numbers are henceforth referred to as the baseline values. Other options are to select either the lower bounds, or the upper bounds of the probability range. Trials were run with all three sets of probabilities, to assess the impact this variation would have on the final results. The values for these three trials are summarized in Table 6.1.

Once this was accomplished, further trials were undertaken to test the influence of certain variables on the severity of disruption for a pandemic event of this magnitude. In particular, there was a focus on testing the control strategies that are in the current pandemic protocols, as well as altering these strategies to examine the impact on disruption levels. In doing so, it is possible to assess policy decisions made by health care officials to determine the most effective system. The event tree includes two separate sets of strategies, called Strategy A, and Strategy B. The former is enacted at earlier stages of a pandemic, when localized community outbreaks are occurring in a region, while the latter comes into play typically during and after the peak of the first wave of illness. These two strategies are described in greater detail in Chapter 7. In general terms, Strategy A is concerned with the preventing virus transmission; although, it does so without exhausting all available resources. Public education is important to communicate symptoms and risk factors, while preparations are made within health care if the situation was to escalate. In comparison, Strategy B is a much more comprehensive approach, given that the influenza virus should be widespread by the time it is applied. Most, if not all, available control strategies will be applied at this point, including vaccinations, administering of antivirals, isolation, and the cutting of non-emergency medical procedures

Strategy A and Strategy B in this form are part of the current pandemic response by the health care system; so, the composition of these control strategies was retained in the previous three trials. However, it is still uncertain if these existing protocols are the most effective way to reduce virus transmission. To compare the existing strategies with other alternatives, three hypothetical strategies were created, called the "All Mitigations Policy", the "Isolation and Social Distancing Policy", and the "No Vaccinations Policy".

The All Mitigations Policy assumes that all resources can be utilized from the early stages of the pandemic and onwards, so all mitigations are used in both Strategy A, and Strategy B. This policy should determine the change in effectiveness if all health care interventions were used simultaneously, throughout the entire pandemic. The Isolation and Social Distancing Policy will continue to exhaust all potential options for Strategy B, but will only use isolation and social distancing for Strategy A to find out what impact these two mitigation techniques have on preventing virus transmission. Finally, the No Vaccinations Policy will remove vaccine administration from its approach to see how valuable a vaccine is expected to be in preventing diffusion.

For the baseline and all three policy trials, the probabilities of effectiveness for all the individual control strategies in this study needed to be combined to form a single likelihood value that would be inputted into the event tree. These combined probabilities would populate the event tree at the two major health care interventions: Strategy A, and Strategy B. The interview data assessed the effectiveness of each of the control strategies individually, but did not reveal the likelihood for reducing virus transmission when two or more were used together. The combined probabilities of the effectiveness of Strategies A and B were calculated using standard probability combination rules for independent events; specifically, by determining the inverse of the probability that the interventions were effective, according to the following formulas:

$$P(\textit{Any Strategy Effective}) = 1 - P(\textit{All Strategies Not Effective})$$

where

$$P(\textit{All Strategies Not Effective}) = P(\textit{Strategy 1 Not Effective}) * P(\textit{Strategy 2 Not Effective}) * \ldots * P(\textit{Strategy N not effective})$$

These formulas were applied to each of the trials in this study to compute the effectiveness of various combinations of strategies. For example, the effectiveness of public education alone was expected to be 0.531, and the effectiveness of vaccinations was expected to be 0.092 (after taking into account availability) in the baseline trial. Using the above formulas, the combined probability of the two strategies together can be calculated as follows:

$$P = 1-[(1-0.531) \times (1-0.092)]$$
$$P = 0.574$$

This approach assumes that the effectiveness of the strategies are independent from each other. In addition to the baseline and policy trials, this formula was also applied to the weighted response trial that is described in section 6.2.2. Since the interventions that made up Strategy A and B were different for the baseline and policy trials, each calculation would only include the probability values for the applicable mitigations.

6.2.2 Weighting Responses

To further identify the critical components of the system, additional sensitivity analyses can be performed that test other variables. Inputting the data into the event tree in different forms to examine the changes on the probability result provides an indication of the most important variables for reducing a virus's transmission. Since the event tree covers many facets of health care at various levels, a trial can be run with different weights for different interview respondents. Because standard questions were asked to each interviewee, each person was given the opportunity to respond to each question; however, not everyone has the same expertise in all the areas of health care. For example, the respondent from the Public Health Agency of Canada at YVR would have more relevant knowledge, and a greater confidence in their answers to the questions posed about policies and protocols at the airport, than would a microbiologist from the British Columbia Centre for Disease Control (BCCDC). The reverse would be true for questions that pertain to identifying the strain of the virus, and to the availability of a vaccine. With this information in mind, weights can be applied to certain responses on a question-to-question basis to examine if there is any change in the overall probabilities. Furthermore, this would shed some light on the underlying assumptions made throughout the health care system when implementing policies.

Each interview can be classified into one of three categories for the purpose of grouping similar respondents together when applying weights. The first is the Public Health Agency of Canada (PHAC), whose responsibility is to administer strategies at the point of entry. The second group consists of public health officials, such as emergency planners from the British Columbia Centre for Disease Control, Pandemic Flu Coordinators and planners from the local health authorities, and emergency planners at the acute care facilities. The final group is comprised of laboratory technicians and microbiologists. Depending on the question that is posed, each of these groups is assigned a different weight for their response, based on expected levels of expertise. The event tree itself can be broken down into a number of parts as well, corresponding with the position held by the respondents. The early stages of the pandemic on the far left of the diagram are concerned with the response at the airport. As a result, the answers given by the interviewee from the PHAC at the Vancouver International Airport should be given a greater weight. Questions that pertain to the development and effectiveness of a vaccine, as well as the characteristics of the virus can be answered best by the laboratory technicians/microbiologists. Finally, the remaining responses about public health policies and choices of control strategies fall to the public health officials.

$$p(\theta) = \sum_{i=1}^{m} w_i P_i$$

(Source: Clemen and Winkler, 1997)

The literature on combining probability distributions provides a number of ways to calculate weighted probabilities, with the formula above being the most commonly used. This formula, expressed verbally, is the summation of the product of the weight and the probability for each expert opinion. So, each response will be multiplied by the weight that has been assigned to it based on the respondent's affiliation, with the resulting probability distribution added together (Genest and McConway, 1990). Expressed mathematically for the purposes of this analysis, the formula is defined as: $p(\theta)$ = the combined probability of an outcome occurring including all expert responses, m = the number of expert responses to be used, i = the current expert response being calculated, w_i = the linear coefficient/weight, and P_i = the probability of the ith expert response (Jacobs, 1995).

Table 6.2 Baseline vs. Expert Response Weights

Respondent Category	No. of Respondents	Baseline Weight	Expert Response Weight
PHAC	1	0.125	0.200
Public Health	5	0.125	0.150
Microbiologist/Lab Technician	2	0.125	0.200

The process of generating the weights is subjective, and is settled upon by the decision maker (Clemen and Winkler, 1997). Weights are used to represent the relative quality of the different experts. If the experts are viewed as equivalent, then a simple average of their responses is all that is required to combine the probability distribution. This assumption was made for all of the above trials. For this weighted trial, some experts are believed to have more precise information based on their work experiences, so are not assumed to be equal. Determining which interview categories should be given the greatest weights was determined by subject of the individual interview questions. The sum of all of the weights must be equal to 1.0. For the cases where the PHAC and lab/microbiologists respondents were considered to be more influential, they were given a weight of 0.2. Where the public health was weighted highest, the value was 0.15 across respondents since this group had more interviewees. The remaining weights were divided amongst the other groups. Table 6.2 compares the weights for the baseline trials versus the weighted trials. For the expert response weight column, only the weight associated with the questions that are specific to that response group are listed. As a note, the three interviews with representatives from the PHSA were conducted together. Since all the respondents came to a consensus on their answers, this was considered to be one interview, instead of three separate ones. So, the total number of interviews in Table 6.2 has a sum of eight, instead of ten.

Table 6.3 Expert Response Weights across Interview Groups

Event Tree Elements	PHAC	Public Health	Microbiologist/ Lab Technician
Response at Airport	**0.20**	0.14	0.05
Public Health Choices	0.05	**0.15**	0.10
Vaccine/Virus	0.10	0.10	**0.20**

Table 6.3 compares the weights for the expert responses for all three interview groups. As shown in Table 6.2, in the instances when the subject matter for interview questions was relevant knowledge for PHAC, these responses were weighted with a coefficient of 0.2. In Table 6.3, the corresponding weights for each respondent from the other two groups are also identified. In this case, each of the public health responses will have a coefficient of 0.14 and each of the microbiologist/laboratory technician answers will be multiplied by 0.05. The row sum of all of these weights equal 1.0. In this table, the bolded values represent the weight for the interview groups where the questions pertain to their knowledge base.

6.2.3 Qualitative Responses

The remaining responses to the interview questions that were not converted to probabilities still contained relevant information that was used in this study. This second portion of the questions was largely verbal responses to open ended questions, or was a follow-up response to the probability questions, both of which provided further elaboration on current policies and procedures. This information was utilized in two ways. First, it was used as a source for the literature review chapters that precede this one. In particular, large portions of Chapter 2 (Health Care Structure), and to a lesser extent, Chapter 3 (Epidemiological Hazard) were written with information from the expert interviews. The second use of the data from the open-ended questions was used to update and revise the scenario and the event tree diagram.

For the most part, the structure of the event tree remained largely unchanged. The majority of the comments about the event tree referred to the expected impact of the variables that were represented. This included observations about the efficacy of mitigations, as well as the influence of naturally occurring factors. The only notable change in the diagram's structure was the inclusion of immunity cycles just before the consequences at the end of the transmission. The interviews revealed that there would be an increase in the immunity of the population over time. This immunity would occur either through vaccinations, or by having already contracted influenza, and developing antibodies to prevent any subsequent infections as a result. This increase in immunity has been added throughout the diagram, and explained in an inset box. There were additional minor changes to the terms used in the diagram, to ensure consistency with the language used in a health care setting. For example, when speaking about the likelihood of people being recognized as carriers of the pandemic strain of the virus, the term "noticed" was replaced with "detected". In the context of the event tree diagram, the branches that said "infections *noticed*" would then become "infections *detected*". The details of the scenario were also refined based on the interview responses. Initial understanding of global infectious disease surveillance suggested that the Centers for Disease Control would be responsible for discovering new strains of viruses; however, interview answers revealed that this information would actually be developed and communicated by the World Health Organization (WHO). Additionally, the interviews make it known that infectious disease threats abroad will heighten awareness in Canada, resulting in tighter surveillance and detection protocols locally. Finally, numerous interview respondents stated that in all likelihood, there would not be a single source of entry for a virus to enter a region; rather, there will be numerous pockets of simultaneous disease outbreak. Each of these revisions were noted, and are reflected in the scenario from Chapter 3.

6.3 Event Tree with Pandemic Scenario

As discussed in Chapter 3, the pandemic resilience of Vancouver's health care sector will be assessed in the context of a hypothetical scenario. The structure of the event tree is consistent with this scenario in terms of the progression of the virus through the population. This includes all the nodes and branches of the tree, which are based on the events that are expected to happen in this scenario. So, the initiating event for this tree is the arrival of passengers at Vancouver International Airport who are carrying the pandemic strain of the influenza virus.

Figure 6.1 Initiating Event

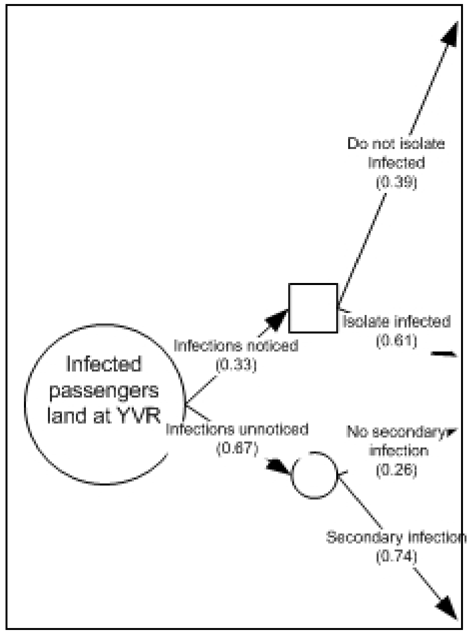
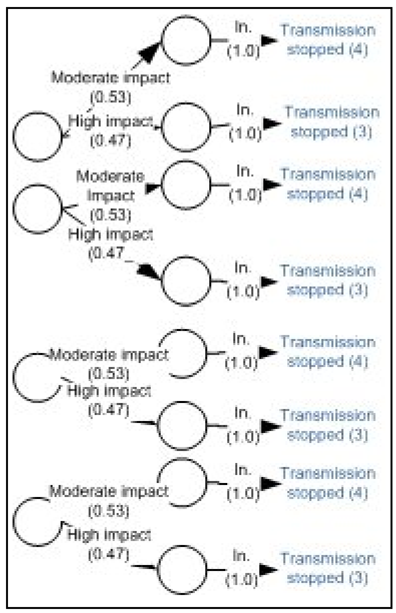


Figure 6.1 shows the introduction of the pandemic influenza virus to the region as the first stage of the event tree. The circle at the left-hand side of the diagram refers to the virus being introduced to the region through infected passengers arriving from Asia. Extending outwards from this event are two branches, indicating the only two possible outcomes. The first is that the infected passengers are detected at the airport, while the second is that the infected passengers are not detected. Airport officials who are involved in the detection process include quarantine officers, customs officers, airplane service staff, and representatives from the Public Health Agency of Canada. Underneath the description of the outcomes on the branches is a numerical value that represents the likelihood of this outcome occurring. In this example, the probability of the infections being detected is 0.33. Since all values that are derived from the branches that flow from a node must add up to 1.0, the likelihood of the infections going undetected is 0.67. Both of these branches lead to separate nodes, from where other outcomes will happen based on the preceding events occurring. After the initiating event, both decision and chance nodes can appear in the tree. Here, the square represents a decision node, and the smaller circles represent chance

nodes. The decision to be made in this part of the event tree is whether or not to isolate infected individuals at the airport. The outcomes that flow from the chance node, which are not within human control, refer to the likelihood that the virus will spread directly from humans to humans, causing secondary infections. To calculate the likelihood of initially infected passengers being undetected and this leading to secondary infections from this abbreviated version of the event tree, all values from the initiating event up until that outcome need to be multiplied together. In this case, the probability is 0.49 (0.66*0.74).

Figure 6.2 Event Tree Consequences



The purpose of the event tree is to measure resilience by establishing measures for the likelihood of various levels of disruption. These disruption levels were incorporated into the event tree as the end points of sets of branches. The disruption scale ranged from 1-4, with lower values indicating less disruption, and higher values meaning a greater disruption. Figure 6.2 demonstrates how this is represented on the event tree. At the end of each set of branches where the transmission of the virus ceases, there is a numerical value in parentheses that is consistent with the disruption scale. The likelihood of disruption level three taking place, for example, is determined by multiplying all the outcomes from the initiating event up until the terminus at disruption level three. This is the exact same process as explained above, except there are many more outcomes to be multiplied together. If there is more than one terminus for this disruption level, then the sum needs to be taken of the product for each terminus. In Figure 6.2, disruption level three shows up four times. Since a different path is taken to arrive at all of these end points, each has to be calculated individually. The resulting values are then added together for the final probability score.

As discussed in Section 6.2, there were a number of different trials run, each with separate probability scores. In total, there were seven separate trials: baseline, upper bounds, lower bounds, All Mitigations Policy, Isolation and Social Distancing Policy, No Mitigations Policy, and the weighted response trial. Calculating these individually would be inefficient, so the computations were conducted in Microsoft Excel spreadsheets. Prior to inputting the values into a spreadsheet, each branch in the event tree was assigned a number. This number corresponds with that row in the main data spreadsheet. The order of the numbers has no other significance. Once these numbers have been inputted into the spreadsheet, each number is compared with the event tree diagram to determine what variable it represents. All the similar branches are grouped together and colour-coded. Once all of the numbers have been classified this way, the probability values can be arranged in the next column accordingly. To simplify this analysis, a second Excel spreadsheet was created which stored all of the verbal answers, as well as all of those answers converted into probability scores for the seven trials, each of which was on their own sheet. A final sheet was created that had linkages to the colour-coded spreadsheet. The final step was to fill up the cells in the colour-coded spreadsheet with formulas that would tie together all the probability answers and convert them into a single value for the event tree. These formulas were generated as described in section 6.2. With the formulas in place, all the probability values from the seven trials simply needed to be copied and pasted into the linked sheet one at a time, with the results computed automatically. The event tree is shown in its entirety in Appendix B.

7.0 Analysis and Results

Event trees, or probability trees, are used to show all possible outcomes resulting from an initiating event, taking into account a number of variables. By determining and applying probabilities to the consequences of this analysis, event trees can assess the likelihood of all potential outcomes in complex systems. Furthermore, weaknesses or oversights can be identified so further attention may be given to them. Because of these attributes, event trees are generally used to evaluate systems in terms of the impact of decisions that will be made, as well as recognizing amendments and improvements that can be made. This chapter will outline the structure of the event tree for the purposes of the analysis, as well as describe all the potential consequences of the pandemic based on the event tree. Finally, this chapter will summarize all the analysis calculations and discuss the results.

7.1 Event Tree Structure for Analysis

This study intends to investigate the resilience of the health care system as it responds to a localized pandemic influenza outbreak. Event trees are particularly useful for this type of research because of the nature of the decision making and response that is required. Temporal variations in actions taken will influence the diffusion of the influenza outbreak as will the nature of those actions. Additionally, the outbreak may unfold in an unpredictable fashion, leading to uncertain consequences. For instance, health care's response to an influenza outbreak will be a series of sequential decisions, each impacting the next. If, for example, the public health agency decides to administer antivirals, they must next establish who is prioritized first, as well as consider implementing protocols, determining locations, and ensuring sufficient manpower is available. The application of this control strategy will impact the transmission of the virus in a variety of ways. Subsequent actions will be decided upon based on the influence of the previous control strategy. Event trees take this into consideration by branching out at all levels to include all possible decisions, as well as the impact of these have on future choices.

In addition to sequential decisions, event trees are well-equipped to deal with unpredictable events. Just as each potential decision is included, all possible outcomes are included in the same way. As the spread of the influenza virus varies, the event tree model will incorporate all the possibilities through different branches. In doing so, no outcome will be overlooked. After the last decision has been made and the uncertain events have played out, what remains is the final consequence of the previous activities. These consequences, and the likelihood of them occurring, are the end points of an event tree diagram. Fortunately, event trees are well-suited to dealing with these characteristics by producing each potential consequence in the diagram.

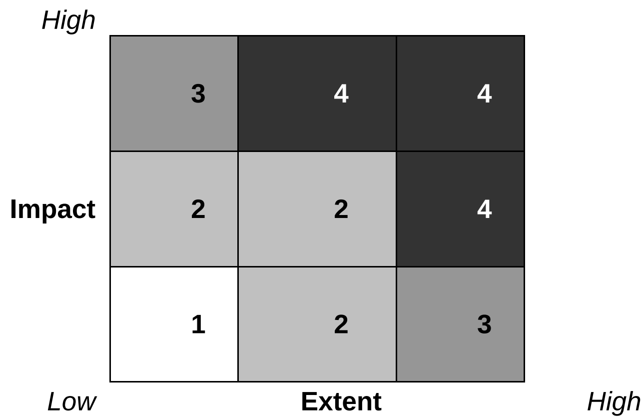
Creation of an event tree requires comprehension of the system that is being evaluated, as well as all the inputs and external events that may influence its behaviour. If the system is mechanical, then an understanding of the mechanics that allow it to function is necessary. In this case it is the health care system that is being evaluated; here, human capital and informed decision making are essential components of the system, as well as facilities and supplies to a lesser extent. Understanding the transportation and availability of resources, the structure of health care delivery, and decision making protocols are paramount to constructing an event tree for responding to pandemic influenza.

As noted in Chapter 6, to build the event tree there are certain necessary components. The first structure in the diagram, which takes the shape of a circle, is the initiating event. Without this occurrence, the following events would not take place. This incident is often adverse in nature, exposing the functionality of the system while under stress. Next, comes all the possible outcomes and decisions that are caused by the initiating event, which are represented as text above the connecting lines. These lines lead to decision or chance nodes, symbolized as squares and circles respectively. A decision node indicates where a decision has to be made, and is followed by any number of connecting lines with text that describe the possible outcomes that will occur as a result of the intervention. Similarly, a chance node denotes an uncertain event, from which connecting lines will express the potential outcomes. The end points of the event tree are blocks of text that describe the final consequences of all the decisions and chances. Stemming from each decision or chance node is a number of potential decisions or outcomes. Along with the text, a decision tree branch will show a value, ranging from 0 to 1. This number expresses the probability of that branch occurring, given the preceding decisions and outcomes. The total value of all the branches from any node must equal 1.0. To compute the likelihood of any consequence in the event tree, one must simply multiply together all the probabilities in all the branches that lead from the initiating incident, all the way to the consequence.

7.2 Pandemic Disruption Index

In this study, the initiating event is the arrival of passengers at Vancouver International Airport (YVR), who are infected with the pandemic strain of the influenza virus. From here, the virus is transmitted throughout the local population. In the earlier stages, there are isolated infections dispersed across the region. This is followed by larger scale community outbreaks, which in turn can lead to a peak of the first wave of the pandemic. From this point, the transmission of the virus will gradually be reduced and will come to a stop eventually. Subsequent waves of the virus may occur down the road; however, this model deals only with the first wave. At the end of the transmission, there are four potential consequences in the event tree, describing the disruption caused by the pandemic. They are numbered from 1-4, with a higher number representing a greater amount of disruption.

Figure 7.1 Pandemic Disruption Index



The four disruption scales, as shown in Figure 7.1, are based on a grid with the regional *impact* on the y-axis and the *extent* on the x-axis. Impact can be considered as the severity of disruption, whether localized or across the entire region. A greater impact means a higher severity of illness, hospitalizations, and deaths. Extent refers to the spatial aspect of the disruption across the region where a larger extent means a greater area is affected by the virus. So, the lowest level on this scale, where both impact and extent are low, will yield the lowest disruption. Each of the four disruption levels can be explained in more detail:

- *Pandemic Disruption Level 1:* The lowest disruption on the scale will result in little to no loss of life, few hospitalizations, and isolated cases of the virus with limited diffusion
- *Pandemic Disruption Level 2:* The second level of disruption, shown as the boxes with the number two in Figure 1, has moderate levels of impact and/or extent. Characteristics of this disruption level include: notably higher than baseline fatalities from influenza; significant, but not overwhelming increase in hospitalizations; and, outbreaks limited to pockets throughout the regions, such as within schools.
- *Pandemic Disruption Level 3:* In the third level of disruption, either the extent is high and the impact is low, or the extent is low and the impact is high. If a pandemic reaches this level of disruption, there will be a very large number of

hospitalizations and deaths in certain areas while others remain unaffected. Or, there will be a low level of hospitalizations and deaths throughout the region, but the impact will be widespread. The overall level of disruption to the region should be equivalent in both situations, because facilities that are operating beyond their capacity can transfer patients to other facilities within the region. So, the areas with high numbers of hospitalizations can move patients to less affected areas. In both situations, there will be an overall increase in the demand on health care throughout the region.

- *Pandemic Disruption Level 4:* The fourth, and most disruptive level, is typified by a very large number of hospitalizations and deaths throughout the entire region, with an overwhelming of acute care facilities, causing a reduction in the quality of the delivery of health care.

The level of disruption that will occur hinges on the variables that shape the disease outbreak. Variables in the event tree range from those that are uncontrollable, to those that can be influenced through health care policies. These are represented in the diagram as circular chance nodes, and square decision nodes respectively. Both types will have an impact on the transmission of the virus; but, decision nodes are the only types that can be altered intentionally by human behaviours. In this diagram decision nodes appear in several places, but can be classified into three separate categories. The first decision to come up in the virus progression is whether or not to quarantine or isolate those who are known to be carriers of the virus. The second, identified as "Strategy A", is actually a series of measures that are intended to decrease transmission. Inclusive in this approach are tactics such as vaccinations and informing the public of risky health behaviours to avoid. The third and final set of decision nodes are labeled "Strategy B", and include antivirals and social distancing in addition to the measures from Strategy A. Additionally, this strategy also takes into account the availability of a vaccine and other necessary medical supplies, as well as staffing levels. Together, these three decision nodes are the locations where policies need to be oriented towards to have an impact on the disease progression.

7.3 Event Tree Probability Computations

7.3.1 Baseline Trials

To complete the event tree, a series of conditional probabilities must be added to each branch. Each one represents the likelihood of that outcome happening, given that the preceding events have already occurred. Since each final consequence, or the last branch on the far right of the diagram, is one of the four disruption levels, calculations need to be made that determine the conditional probabilities at these end points. Because there are numerous end points for each disruption level, the probability of that magnitude of an event happening is the sum of each of the probabilities for that disruption level. Taking a step back, determining the probability of each end point requires multiplying each branch starting from the initiating event, and ending at the consequences.

Data for this analysis has been derived from the answers given in expert interviews. Interviewees were given a series of questions that pertained directly to the various components of the event tree. In addition to open-ended responses, each expert was given a likelihood scale to use for their answers. This scale had four options: "not at all likely", "somewhat likely", "very likely", and "extremely likely." Answers in this form lent themselves well to be converted into numerical values. Breaking up the four answers into a probability scale from 0 - 1, we ended up with ranges from 0–0.25, 0.26-0.50, 0.51-0.75, and 0.76-1.0. Taking the middle value of each of these ranges and we have values of 0.125, 0.375, 0.625 and 0.825. Similar values were derived by taking the upper and lower bounds of the range, to get a series of probabilities which are listed in Table 6.1.

Once the answers had been converted into a numerical value, all the respondent's values were averaged to get one single number for each question asked. Again, this was done for the baseline, as well as the upper and lower bounds. Using these values, the event tree was populated with probabilities. For a large portion of the branches, the interview answers themselves could simply be slotted into the tree with minimal calculation required, keeping in mind that all branches stemming from a node must have a sum of 1.0. However, a significant proportion required additional calculations. In particular, the branches just after the Strategy A and Strategy B decision nodes required more specific information. In the case of Strategy A, there were three branches that followed it. The first had the transmission being reduced as a result of the control measures, the second had no impact and the pandemic escalated to a point where the first wave peaked, and the third branch had some degree of success in mitigating the spread of the virus because there was only partial compliance of the population to control strategies. Since there was a question in the interviews that directly pertained to the likelihood of public compliance, it was straight forward to input this value for that particular branch. To determine the effectiveness of Strategy A, the formula discussed in Chapter 6.2.1 was applied to the applicable measures, with the resulting value then multiplied by the remaining probability after the likelihood of partial compliance was taken out (where the remainder is [1.0 – {probability of partial compliance}]). This value provides the total likelihood for the other two branches.

Table 7.1 Pandemic Disruption for Initial Three Trials

	Pandemic Disruption 1	Pandemic Disruption 2	Pandemic Disruption 3	Pandemic Disruption 4	Total
Baseline	0.656	0.079	0.226	0.039	1.00
Upper	0.396	0.127	0.450	0.027	1.00
Lower	0.825	0.034	0.101	0.040	1.00

With these values calculated and plotted onto the event tree, the probabilities of each level of disruption were straightforward to calculate for each of the three trials. The results are summarized in Table 7.1.

Comparing the three trials, it becomes apparent that there are significant differences in the probability of each level of disruption based on where the line is drawn. As expected, the values taken from the baseline trial fall between the extremes of the lower and upper bounds. What is notable is how much the values change based on which trial is run. The likelihood of a pandemic having a disruption level of one ranges from 40%, to 83%, for a difference of 43%. Pandemic Disruption Levels 2, 3, and 4 each vary 5%, 22%, and 1% respectively. It is interesting to note, that in all three trials, the highest probability was associated with the lowest disruption level, with the exception being the upper trial, where the highest probability was associated with Disruption Level Three. However, there is still cause for concern since the two most disruptive levels still held a large share of the probability, having a likelihood range from 15 – 48% combined.

7.3.2 Weighted Trial

Since each question from the interviews was asked to each respondent, the average of all the responses was used for the probability values in the analysis for all the abovementioned trials. However, some of the interviewees worked for an organization, or held a position, that would suggest a greater knowledge in certain areas when compared to the other respondents. For example, the interviewee from the Public Health Agency of Canada is more likely to have a better sense of the protocols for infectious disease detection at the airport, since they are directly involved with quarantine and surveillance services at Vancouver International.

Table 7.2 Pandemic Disruption for Weighted Trial

	Pandemic Disruption 1	**Pandemic Disruption 2**	**Pandemic Disruption 3**	**Pandemic Disruption 4**	**Total**
Baseline	0.656	0.079	0.226	0.039	1.00
Weighted	0.715	0.062	0.171	0.051	1.00

Table 7.2 compares the baseline probabilities with those calculated by the weighted trial. When the expertise of the respondents is given the appropriate weight, there is a significant change in the resulting probabilities. Notably, the likelihood of a pandemic level one increases substantially from 66% to 72%. Disruption levels two and three have both declined accordingly, with the largest drop occurring in pandemic

disruption level three. The fourth and most disruptive level actually was expected to increase in probability with the weighted results by 1%. These results indicate that there is a greater degree of confidence held by the experts about the positive influence of their own organizations than there is by their colleagues, and also a slightly greater expectation of the worst-case scenario. This can perhaps be explained by the perceptions that the respondents have of their own agency. It is in the interest of the interviewees to present themselves and their organization in a positive light. So, responses may be slightly skewed by the inherent conflict of interest that is prevalent by using interviews. If this is the case, that would explain the higher likelihood for lower disruption levels. Additionally, the greater likelihood for Disruption Level Four may be explained by the lower expectations for an effective vaccine to be developed, mass-produced, and distributed by the microbiologists and lab technicians interviewed.

7.3.3 Policy Change Trials

Another potential trial can examine the worst-case and best-case scenarios, by trying out different combinations of variables. For example, the answers given by the respondents can be altered to further help identify the assumptions that have been made. Similarly, policy choices can be analyzed by changing the probabilities to reflect them. According to the literature, the control strategies that will be implemented depend on the stage that the pandemic has progressed to. Through the interviews, the expected effectiveness of a number of individual measures has been obtained, and forms the basis of the abovementioned probability estimates. Some of these measures were considered for only one of Strategy A and Strategy B, while others were true of both. Trying out different combinations of these measures can help to identify which play the largest role in virus transmission, given their anticipated effectiveness.

Strategy A is applied after community outbreaks are occurring in the region. At this stage of the pandemic, there are localized pockets of outbreaks throughout the city, concentrating in places with a high degree of personal interaction such as a school or workplace. As outlined by the British Columbia Pandemic Plan, typical actions at this time are intended to prevent further spread while trying to avoid overkill. The focus is ensuring there is proper preparation for an efficient response should the situation escalate. At this point, a case definition for the illness should be created, vaccine development should continue, while vulnerable populations will be immunized if a vaccine is available. Additionally, plans for the administration of antivirals will be reviewed, but not yet implemented. Health advisories will go out to the public based on existing information, while surveillance systems will be heightened to monitor the risk. If need be, certain cases will be isolated.

Table 7.3 Strategy Combination Comparison

	Baseline Trial		**AM Policy**		**ISD Policy**		**NV Policy**	
	Strategy A	*Strategy B*	*Strategy A*	*Strategy B*	*Strategy A*	*Strategy B*	*Strategy A*	*Strategy B*
Public Education	**X**	**X**	**X**	**X**		**X**	**X**	**X**
Vaccination	**X**	**X**	**X**	**X**		**X**		
Administration of Antivirals		**X**	**X**	**X**		**X**		**X**
Isolation		**X**	**X**	**X**	**X**	**X**		**X**
Social Distancing			**X**	**X**	**X**			

Strategy B takes place at a later pandemic phase, following the peak of the first wave. This approach is much more comprehensive, since influenza cases should now be widespread. Assuming availability of resources, most control strategies will now be applied, including the following: identifying and interviewing secondary cases, confirming the clinical spectrum of disease is consistent with case definition in a laboratory, immunizing the population if vaccine is available, administering of antivirals if they are deemed to be effective, continuing to communicate health advisories, mobilization of human resources, isolation, use of infection control practices to prevent spread, accessing sources of additional health care workers and volunteers if required, managing increased demand on health care, and acquiring extra supplies and resources. Table 7.3 describes which individual strategies were used for each of the policy trials, including the distinction between Strategy A and Strategy B.

Table 7.4 Pandemic Disruption for Policy Change Trials

	Pandemic Disruption 1	Pandemic Disruption 2	Pandemic Disruption 3	Pandemic Disruption 4	Total
Baseline	0.656	0.079	0.226	0.040	1.00
AM Policy	0.656	0.112	0.214	0.019	1.00
ISD Policy	0.656	0.092	0.231	0.020	1.00
NV Policy	0.656	0.074	0.225	0.046	1.00

These variables were included in the baseline trial of the event tree. Decisions have already been made about which control measures are to be applied at which point in the pandemic. These policies can be evaluated by altering the composition of the strategies by adding and subtracting certain measures and comparing the change on the consequence probabilities. Three separate policy changes will be analyzed. The All Mitigations (AM) Policy will exhaust all potential measures in both Strategy A, and Strategy B. The Isolation and Social Distancing (ISD) Policy will continue to use every option for Strategy B, but only isolation and social distancing for Strategy A. Finally, immunizations will be removed from the baseline to examine the influence of a vaccine in the No Vaccinations (NV) Policy. The results are summarized in Table 7.4.

The first point to note is that there is no change from the baseline to any of the three new policies for the first level of pandemic disruption. This remains the same because both Strategy A and Strategy B appear later in the event tree than do all of the level one disruption branches. Since the probability of the pandemic resulting in the lowest level of disruption is uniformly 67%, only 33% of the variance remains to be changed by the policies. It is interesting to note that each of the three policies results in a difference in the likelihood of the highest disruption level occurring. The change is most disruptive for No Vaccinations Policy, where there is a 0.6% increase in occurrence. Since this policy change eliminated the use of a vaccine for disease prevention, it seems as though immunization is a valuable tool to prevent virus transmission. The change is expected to be greater if there was a higher probability of a vaccine being available in the earlier stages of a pandemic. Both of the other two policies resulted in a declining probability for Disruption Level Four. The ISD Policy decreased the probability of the highest disruption level occurring, while increasing the likelihood of Disruption Level Two, indicating that isolation and social distancing can both be effective methods of preventing virus transmission. Finally, the AM Policy reduced the likelihood of the two most severe disruption levels with the probability shifting in favour of Disruption Level Two. This result indicates that there is a positive relationship between resources used, and the prevention of virus transmission.

7.4 Discussion

7.4.1 Interview Answer Consistencies

The key data source for this analysis was the interviews conducted with regional experts in Greater Vancouver. Questions were kept consistent for all the interviews, with the exception of the final section, where organization-specific questions were asked. Despite working in the same sector and region, there was a large range of answers for many of the questions. In some cases, there was agreement amongst most of the interviewees, while other questions led to varied expectations. Given the different backgrounds of all the interviewees, it is not surprising that there were some inconsistencies in the answers.

Answers to questions about the availability of a vaccine tended to have the greatest consistency. The majority of respondents expected that only in the best-case scenario would an effective vaccine be developed and readily available at a time of six months after the first case was identified globally. More realistically, expectations were that a vaccine would be available in small quantities, if at all, until well after the peak of the first wave of the pandemic. For subsequent waves, there will be a higher probability that a vaccine will be available. This timeframe assumes that there will be no complications in vaccine developments once the strain has been identified; however, a vaccine for the H5N1 (Avian Influenza) virus has proved to be difficult to develop, so there is no guarantee that similar hurdles will not arise. In addition, the effectiveness of the vaccine at preventing transmission is not certain until it has been created and tested, with a real possibility that vaccinations will only provide a limited amount of protection.

There was also a great deal of agreement on questions about the likelihood of secondary spread from a pandemic influenza virus. Citing historical precedence, the regional experts fully expect the virus to have the ability to be transmitted directly from human to human. Finally, the respondents tended to all agree that protocols at the airport would make it extremely likely that symptomatic individuals would be isolated or hospitalized to prevent further spread. Unfortunately, due to the incubation of up to five days for the illness to present, asymptomatic individuals may fall through the surveillance net, and enter the community.

It is widely expected that staffing shortages will be a major concern during a pandemic response. All the experts answered that a reduction in skilled health care workers would be "very likely" or "extremely likely". The reasons are twofold. First, health care professionals are just as susceptible to virus transmission as the remainder of the population, or even have a greater chance of illness due to working in close proximity to infected patients. Second, there will be a portion of health care workers who will choose to stay at home to tend to sick family members, instead of coming into work. Due to both of these reasons, the health care sector will struggle to deliver services. This is especially true since facilities are operating at or near full capacity during non-disaster times. The additional demand during a pandemic only exacerbates the need for medical attention. Suggestions include making provisions for medical help prior to a pandemic, although this type of planning has yet to happen.

7.4.2 Interview Answer Inconsistencies

The remainder of the interview questions had significantly less agreement in the answers. This was sometimes the case where the respondents would answer about an organization that was not their own; yet, at other times, experts within the same organization would differ in their expectations. The Public Health Agency of Canada (PHAC) at Vancouver International Airport considers the initial entry of infected individuals into the region as an important variable for reducing transmission. Surveillance at the airport, as well as the communication of information on symptoms and how to report the disease are considered very significant for reducing the impact of the pandemic by PHAC. Although some of the organizations interviewed agreed with this perspective, many of the other interviewees suggest that the only impact of successful mitigations at the points of entry is to delay the onset of the pandemic, since there are numerous pathways that a virus can follow. Instead of concentrating control strategies at single points, the other respondents believe that the greatest reduction of transmission can take place with mitigations that blanket the entire region. The public health experts in particular expect the greatest efficacy to be achieved at the middle stages of a pandemic, after the phase where there are a few isolated cases, but before it grows to envelop the entire region. Some of the respondents even claim that quarantines and isolations at the airport are amongst the least effective interventions that are available.

When discussing the effectiveness of specific control strategies, some mitigations were widely agreed on, while others would divide opinion. The use of antivirals for prophylaxis is not expected to be a valuable tool for reducing transmission, since the current antivirals are arguably not very effective. Vaccines, if available, are expected by most experts to be the best method for the preventing the diffusion of the virus, but only if vaccination is universal. The timing of vaccinations is also important, with a greater impact if the vaccine is administered at earlier pandemic phases, and not when the virus is already widespread. Social distancing was another strategy with a range of responses. No one expects this approach to have a large impact on reducing virus transmission, although some commented that it would have no impact at all since interaction between the populations in larger urban areas is inevitable.

7.4.3 Interview Bias

As mentioned earlier, the main data source for this analysis was expert interviews. This resource was chosen because expert opinions would provide insight into the pandemic protocols and health care structure that are specific to the study region of Greater Vancouver. To this end, interviews were conducted with representatives from local organizations across the region. These experts are employed by their organizations and have spent countless hours implementing policies to reduce their vulnerability to pandemics and other disasters. As a result, their opinion may differ from what others expect, or from actual events when they do occur. Typically, this bias in expectations is caused by a more optimistic view of what may happen. An optimistic bias is understandable, given the amount of work that these experts put into mitigations. Since they have spent time making assessments of the state of their organization and generating their own policies to increase resilience, experts may overestimate the effectiveness of the work that has been done to date.

A second explanation for this overestimation of pandemic preparedness might be the obligation to present the organization one works for in a positive light. Through written contract or just workplace etiquette, it may be expected to speak about the positive aspects of one's organization, and to not discuss the shortcomings in great detail. This second explanation for the optimistic bias was evident in one of the interviews conducted. In this case, the respondent answered some of the questions with two responses. The first response was similar to the other interviewees, by assessing what the company has done to increase pandemic preparedness. The second response to these questions was that despite the mitigations that had been implemented, the organization still was not sufficiently prepared to handle a pandemic response. Regardless of the reason for this bias, overconfident responses can skew the data so that it does not accurately depict the true resilience. There will be a higher probability of the lower ends of the pandemic disruption scale occurring, and vice versa.

7.4.4 Impact on the Delivery of Health Care

During a pandemic event, there will certainly be a substantial increase in the demand for health care services. In particular, the impact will be felt by private physicians and hospitals, because of the acute nature of pandemic influenza symptoms. As a result of this increased demand, human and physical resources will need to be stockpiled and redistributed according to need. In terms of medical resources such as clean water and antivirals, purchasing and stockpiling is centralized by the health authorities, and then allocated to the facilities to meet requirements. Human resources cannot be stockpiled the way physical resources can; so, the primary method for ensuring enough staff is available during times of increased demand is to focus on critical procedures, while cutting back on all others. This should increase the surge capacity of facilities, albeit at the cost of other types of care and procedures. The long term impact on the health of a region is unclear. Many difficult decisions would need to be made about the procedures and programs that would be temporarily cut to increase service where it is needed. Some of these decisions may result in the aggravation of certain long-term afflictions, or even death. Additionally, the reduction or elimination of non-emergency surgeries and programs may generate a large queue of people who would burden the system once the pandemic event is over and the health care sector returns to non-pandemic functioning.

Increasing staffing contingents from their regular state is nearly impossible given the education and skill required to work in these positions. Since pandemics are not restricted by borders, health care professionals cannot be borrowed from other jurisdictions, since they are likely experiencing a similar increase in demand. Instead of increasing workers, there has been discussion around categorizing existing staff into one of three service provider levels:

- High Level Doctors or Nurses who are able to perform emergency medical procedures
- Moderate Care Workers such as nurse aids who can do some modified clinical care
- Administration Staff, who have no training but can wash, clean, or perform other duties.

A final option for increasing staff would be to contact retired workers to come in on a temporary basis to fill a need. These workers would only be called upon in absolutely dire times, and would only work until the demand was reduced.

8.0 Conclusions

8.1 Summary of Findings

This analysis was structured around an event tree, which modeled a pandemic scenario for the region of Greater Vancouver. The event tree was composed of nodes and branches which described all the potential outcomes and consequences from a pandemic influenza event. Corresponding with the branches was a probability score, indicating the likelihood of that outcome occurring, given the preceding outcomes had already occurred. Using a simple formula with all of the conditional probabilities values, an overall probability could be calculated to indicate the likelihood for each of the four levels of disruption.

For the purposes of this analysis, a Pandemic Disruption Scale was created which outlined the expectations for the levels of disruption in the study region as caused by a pandemic influenza event. The scale has four different categories, ranging from 1-4, where a higher number indicates a greater disruption level. Disruption is measured by the number of illnesses, hospitalizations, and deaths in the region, as well as the increased demand on the health care system. A Disruption Level of one will result in little to no loss of life, few hospitalizations and only isolated cases of infections. Pandemics in Disruption Level Two will have notably higher than baseline influenza mortality and hospitalizations, but outbreaks are not yet widespread. The Third Disruption Level is characterized by either widespread illness but little mortality, or higher proportions of influenza-related deaths and hospitalizations, but only in localized pockets. The most severe Disruption Level has the most adverse impact, with significantly high deaths and hospitalizations across the entire region, and an overwhelming of acute care facilities. The final calculations were able to present the likelihood for each disruption level according to the data and estimates provided by regional experts in an interview.

Table 8.1 Summary of Pandemic Disruption Levels for all Trials

	Pandemic Disruption 1	Pandemic Disruption 2	Pandemic Disruption 3	Pandemic Disruption 4	Total
Baseline	0.656	0.079	0.226	0.039	1.000
Upper	0.396	0.127	0.450	0.027	1.000
Lower	0.825	0.034	0.101	0.040	1.000
Weighted	0.715	0.062	0.172	0.050	1.000
AM Policy	0.656	0.112	0.214	0.019	1.000
ISD Policy	0.656	0.092	0.231	0.020	1.000
NV Policy	0.656	0.074	0.225	0.044	1.000

The resilience of the health care system can be inferred from these disruption level probability scores. Some variables exist which will influence the diffusion of a virus across any region that cannot be controlled through health care interventions. These are modeled as chance nodes in the event tree diagram. The impact of health care planning is felt by the effect their mitigations have on reducing virus transmission, and handling the increased demand for medical care, represented as decision nodes in the event tree. By changing the probability scores to reflect alternate policies or the weighted response of experts, the resulting change in disruption level probabilities will indicate the effectiveness of current procedures. Table 8.1 provides a summary of the disruption level probability results for each of the trials.

The baseline trial provides a point for comparison with all the other trials, since it reflects the current policies and procedures. It is followed in the table by the upper and lower trials, which refer to the upper bounds and the lower bounds of the probability distribution. Predictably, the baseline values lie between the upper and lower extremes. These trials were used to establish the current disruption probabilities if a pandemic were to strike today, and were also used to verify the methodology for the calculations was correct. Notably, the lowest pandemic disruption level was the most likely to occur, although there is still a significant likelihood that one of the two highest pandemic disruption levels will occur.

Additional changes in disruption levels were monitored by changing the probability scores to reflect the expertise of the interviewees. The questions that were asked were consistent across interviews, despite the fact that individuals holding different positions in different organizations were interviewed. Questions were also broken down into categories that would fall under the area of expertise of at least one group of respondents. Previous trials averaged the responses from the each expert. In this trial, more weight was given to the experts who held positions that would indicate they had more relevant knowledge about the specific question being asked. For example, answers to questions about the development of a vaccine from a microbiologist were weighted higher than answers from a public health official. The results of the weighted trial are closer to the lower bounds trial than the baseline trial, where the expected probability distribution is considerably more optimistic, since the majority fall into the lowest disruption category. This is perhaps indicative of the tendency to favorably portray the resiliency of one's own organization when asked questions about the expected functionality in an extreme event.

The final three trials were conducted to compare the current pandemic protocols to other policy decisions. Three variations of the current policy were developed:

- *All-Mitigations (AM) Policy*: Current strategies at the community outbreak phase are intended to prevent virus transmission while not committing full resources. The AM policy assumes that there are ample financial and human resources available, so all the available control strategies can be used
- *Isolation and Social Distancing (ISD) Policy*: There has been debate over the effectiveness of mandatory or self-isolations and social distancing. This policy only uses these two control strategies at the community outbreak phase of the pandemic in an effort to determine how much of an impact they have on transmission.
- *No Vaccinations (NV) Policy*: Vaccinations are widely considered to be the most effective method of reducing/prevent virus transmission. This policy change will remove the use of vaccinations from the control strategies to examine the change on overall disruption levels.

To compute the results of the three policy change trials, the probability values for Strategy A and Strategy B needed to be changed from the baseline trials to reflect the policy decision in each trial. In terms of direct interventions, Strategy A consisted of public education and immunizations for the baseline trials, assuming that a vaccine was available. The probability for these strategies was calculated by using the probability scores from the interview questions that pertained directly to the effectiveness of the interventions in this strategy. For the three policy changes, the values were changed from those of the baseline control strategies, to those of the new policy control strategies. For the AM Policy, the probability of effectiveness for public education and vaccination were retained, and added to them were the probability of effectiveness for antivirals, isolation, and social-distancing. Also included was the probability of availability of antivirals, as well as the likelihood that a vaccine would be produced at this stage and available locally. Since the ISD Policy was concerned only with the impact of isolation and social distancing on reducing transmission, the probability of their effectiveness was substituted into the Strategy A formula in place of the baseline likelihoods. Similarly, for the NV Policy, the vaccination effectiveness probabilities were removed, so only the public education probabilities remained. For the baseline trials, Strategy B consisted of all available mitigations except for social distancing, since the goal at this stage of the pandemic was to stop the transmission of the virus and reduce the levels of disruption at all costs. In the three policy trials, the probability value for the effectiveness of Strategy B was altered in the AM Policy trial by including social distancing in the calculations, and in the NV Policy, where vaccinations were removed from the baseline formula.

The results of these policy changes were somewhat surprising. All three of the new policies had an impact on the overall disruption level probability distributions, but not as great as expected. The AM Policy trial was more effective at reducing disruption from the pandemic than the baseline trial, suggesting that extra expenditures on control strategies at the earlier pandemic phases may reduce virus transmission. Opinions on the effectiveness of isolation and social distancing were varied in the expert interviews; so, the expectations for the ISD Policy were an increase in the highest two disruption levels, since vaccinations and public education were not used as part of Strategy A. Instead, there was a reduction in the overall disruption, with a higher probability of Disruption Level Two, and a lower probability of Disruption Level Four. Only Level Three showed an increase, but it was much less than the decrease of Level Four. These results suggest that the strategies of isolation and social distancing can be expected to have a similar positive effect on reducing the diffusion of the influenza virus as much as more established interventions. The final policy produced changes that were consistent with the expectations from the removal of vaccinations as a strategy. The assumption was that removing vaccinations from the control strategies being used would reduce the effectiveness of the health care interventions. This assumption was verified with the results of the trial, albeit the change was smaller than initially expected. The two most disruptive levels both saw an increase in their likelihood, while Disruption Level Two decreased. The small size of the change in probability for the NV Policy Trial can be explained by the expectations held by the health care experts. The prevailing belief is that a vaccine is not likely to be developed in the early stages of a pandemic. Since Disruption Levels One and Two typically occurred in the earlier portions of the event tree, removing vaccinations from this stage did not influence disruption levels significantly. Moreover, even if a vaccine has been created, it is not expected to be produced in large enough quantities to be distributed as needed. Because both of these probabilities are low, the combined probability of vaccine effectiveness is also low; so, removing this strategy had a minimal impact. Had vaccinations been removed from a pandemic response policy in subsequent waves of a pandemic, the influence would have been much greater. Although this change in probability is a small amount, it still underlines the important of vaccinations as part of the overall control strategies.

A final key result from this study is the likelihood of occurrence of the two higher disruption levels. When a global infectious disease outbreak such as pandemic influenza is spreading, it is widely accepted that it is nearly impossible to prevent any adverse impact in urban areas due to the high global connectivity and human-to-human interaction. Given this assumption, the goal of pandemic preparedness is to prevent a localized infectious disease outbreak to progress to the higher two disruption levels. In this analysis, the AM Policy and the weighted trials proved to be the best-case scenario, since the probability for the higher disruption levels that was associated with these trials was the lower than any other trial. The combined probability for Disruption Levels Three and Four combined was 0.23 for the AM Policy trial, and 0.22 for the weighted trial. In this analysis, a moderate virulence and a single entry point were chosen for the scenario, both of which would reduce the disruption levels in comparison to a virus with higher virulence and multiple entry points. Furthermore, the interview bias discussed in Chapter 7.4.3 might also influence the probability scores to be more optimistic; yet, the analysis suggested that one-fourth of the time there will be disruption in one of the higher two levels, with a probability range of 0.05 – 0.19 for a Level 4 Disruption in the most optimistic expectations. For pandemic disruption levels three and four combined, the probability of occurrence ranges from 0.22 in the weighted trial, to 0.27 in the NV trial.

8.2 Advantages and Drawbacks

This study intended to investigate the resilience of the health care system as it responded to a localized pandemic influenza outbreak. Event trees are particularly useful for this type of research because of the nature of the decision making and response that is required. Temporal variations in actions taken will influence the diffusion of the influenza outbreak as will the nature of those actions. Additionally, the outbreak may unfold in an unpredictable fashion, leading to uncertain consequences. For instance, health care's response to an influenza outbreak will be a series of sequential decisions, each impacting the next. If, for example, the public health agency decides to administer antivirals, they must next establish who is prioritized first, as well as consider implementing protocols, determining locations, and ensuring sufficient manpower is available. Subsequent actions will be decided upon based on what has happened previously. A similar response will be required for vaccinations, and for other mitigation policies. Event trees take this into consideration by branching out at all levels to include all possible decisions, as well as the impact of these have on future choices.

In addition to sequential decisions, event trees are well-equipped to deal with unpredictable events. Just like each potential decision is included, all possible outcomes are included in the same way. As the spread of the influenza virus varies, the event tree model will incorporate all the possibilities through different branches. In doing so, no outcomes will be overlooked. After the last decision has been made and the uncertain events have played out, what remains is the final consequence of the previous activities. These consequences, and the likelihood of them occurring, are the end point of an event tree diagram. Fortunately, event trees are well-suited to dealing with these characteristics by producing each potential outcome in the diagram.

Creation of an event tree requires comprehension of the system that is being evaluated, as well as all the inputs and external events that may influence its behaviour. If the system is mechanical, then an understanding of the mechanics that allow it to function is necessary. In this case it is the health care system that is being evaluated; here, human capital is an essential component of the system, as well as facilities and supplies to a lesser extent. Understanding the transportation and availability of resources, the structure of health care delivery, and decision making protocols are paramount to constructing an event tree for responding to pandemic influenza. Because of the need for a comprehensive understanding of the workings of this sector, this approach is likely to structure the scenario and event tree in a way that is true to the functioning of the system. Perhaps most critically, this approach places less significance on the functioning of individual components of health care; rather, it examines the impact on the entire sector. So, measures of the pandemic such as transmission and mortality rates, as well as the number of fatalities and hospitalizations are considered for the region, without specifying the impacts to single facilities.

The event tree approach is based on the creation of a scenario for the study region. Ideally, the scenario is created with references to up-to-date sources on the state of the health care sector in the region, as well as current research on pandemic modeling. Even in these circumstances, the scenario only presents one potential pandemic influenza event. Because of the unpredictable nature of infectious disease transmission, an influenza outbreak can progress in an infinite number of ways. As a result, specific components from this analysis may not materialize in practice. Despite the fact that the response from health care is largely oriented towards preventing secondary spread in the community, there could be variation in the way that the virus is introduced to the population. These differences can be captured with other scenarios if need be.

Decision analysis and event trees operate under the assumption that events are conditionally independent, where Event A is independent of Event B, conditional on background knowledge and prior events. This event tree is structured in the same way, with occurrence probabilities conditional upon the probabilities of earlier events. For the study of communicable diseases, dependencies between events are prevalent, notably with variables such as transmission risk and immunity. Preventing infections and increasing immunity will diminish downstream virus transmission, resulting in a dependency of events at different stages in the event tree. To model the progression of a pandemic through a region, complex mathematical models are often used because they are able to incorporate these dependencies. The decision analysis framework was chosen to address the main research question of this study, about the resilience of the health care system to pandemic influenza. Because of the focus on the ability of the system to respond instead of precise estimates of disease diffusion, decision analysis was considered to be the preferred method. Subsequent research may choose to combine decision analysis with dynamic mathematical modeling to expand on the scope of this study.

This approach is heavily dependent on expert opinions. For this study, regional experts from within the health care sector were interviewed to learn about the functioning of the system, as well as the mitigations and preparations that are in place. Included in the interview process were representatives from regional health authorities, facilities, laboratory technicians, and epidemiologists. Although insightful, the responses they gave needed to be examined with a critical eye. Respondents can be prone to misrepresenting information when it pertains to themselves, or their organization. In some instances, working within an organization can lead to an overestimation of the expected functionality of one's own infrastructure. Often, this occurs because the experts have implemented the mitigations themselves, and have greater reason to believe they will be effective in preventing service loss. Other times, the results are favorably portrayed by the respondents to ensure that their organization is presented in a positive light. This was evident in the interviews conducted for this study, where one respondent provided two sets of answers for some of the questions. Initially, responses were given that were consistent with what the organization would expect to be divulged. In the interest of full disclosure, a second answer was given for some questions off the record which revealed that certain components of the infrastructure were more vulnerable than initially estimated. Additionally, the length of time since the last pandemic influenza event in this region is longer than the time that practitioners have been working in their positions. As a result, the lack of actual experience responding to such an event may also contribute to the optimistic expectations for a pandemic event. Unfortunately, the need for current data on the operation of the health care system in this region requires research to rely on expert interviews, where this bias is inherent. Further research on health care systems may choose to rely less on expert judgments.

Since expert opinions were intended to form the core of the data compiled for this study, the semi-structured interviews were chosen as the primary method for data collection. For the sake of consistency, the same questions were asked of each interviewee, regardless of the organization they worked for or the position they held. In doing so, the answers were simpler to work with for the calculations required to populate the event tree. The structure of the majority of the questions allowed the experts to respond with a probability value, along with a verbal explanation of their response, and a description of the protocols for their organization. Specific questions focused on the effectiveness of individual health care interventions, such as vaccinations, antivirals, and public education. The interviews did not consist of questions that asked the experts to combine various combinations of strategies, and assess their effectiveness. As a result, the analysis of this study had to combine probabilities using the formula discussed in section 6.2.1. This formula assumes that each of the interventions that are combined to form one strategy, are independent of each other. In other words, the use of one or more together will not impact their individual effectiveness probabilities. Subsequent studies in this area may structure their research to consider the combination of health care interventions at the point of data collection, to determine if this assumption is valid.

8.3 Policy Implications

The potential policy implications of this study can be taken from the results of the final three trials where existing policies were challenged with alternatives. Health care interventions are ongoing before, during and after pandemic events. At certain pandemic phases, the focus of the response and the type of control strategies used can change. As a pandemic event escalates, increasingly more resources are used in an effort to stop the transmission. The AM Policy tested the idea that all available resources should be used in all pandemic phases; and, the results of this trial indicated that the positive impact for the region is tangible. Unfortunately, the cost of utilizing all available resources during all pandemic phases would be much more costly than current practices. To actually implement this type of policy, there would be a need for concrete information that describes the potential risk to the region. Otherwise, there is a potential for massive interventions to occur when they are needed, resulting in unnecessary expenditures.

The ISD Policy's results provided an indication of the effectiveness of isolation and social distancing as methods to reduce virus transmission. Self-isolation is a tactic communicated to the population by public health agencies in an effort to reduce the contact between people. In certain situations, mandatory isolations are enforced by health care officials as well. Social distancing is similar in concept, studying social networks and using this information to alter the frequency of contact of vulnerable groups in a population to contain a pandemic. The effectiveness of both of these control methods has not been agreed on in the literature, or among the experts interviewed for this study. This study does not prove that these strategies are extremely effective; rather, they support the idea that in conjunction with other mitigations, isolation and social distancing can be used to some positive effect.

The NV trial provided more reason to increase vaccine development during a pandemic. Unfortunately, vaccinations can only be a strong tool if the vaccine is proved to be effective at preventing transmission, is developed at an early stage, and is available in large enough quantities to administer to the entire population of a region. Based on literature reviews and expert judgments, a vaccine is not likely to be available during the first six months of a pandemic. Historical precedence has shown that novel strains of influenza viruses often originate in Asia. If a strain is identified early enough, a vaccine can be developed, produced and distributed in Canada before the virus is widespread. Since the effectiveness of vaccinations increase significantly with early administration, the focus of vaccine-related mitigations should be on increasing information sharing and cooperation with other global health agencies. In doing so, vaccines can be developed much quicker than they would otherwise. Since arrangements are already in place with the national organizations that would mass produce a vaccine, additional global health care agreements should be the next priority.

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Appendix A: Sample Interview Questions

Section 1: Occurrence Probabilities: (Please answer questions with one of the following answers: not at all, somewhat likely, very likely, extremely likely)

1. How likely will an infected passenger be detected at the airport? *Follow-up: What are the protocols for detecting infectious disease for incoming passengers at YVR?*
2. When an infection is discovered, what is the likelihood that control strategies (such as isolation, or the administration of antivirals) will be applied? *Follow-up: what types of control strategies are typically used in this scenario?*
3. If influenza was to go untreated, how likely would it spread from human to human (secondary cases) assuming typical levels of contact with other people?
4. How likely will a vaccine be available to administer when the first case is discovered? Two weeks after? One month after? Six months after?
5. What probability is there of non-compliance of the population to health advisories? *Follow-up: What measures are implemented to increase compliance*?

Section 2: Structure of Event Tree

6. Which variables (shown as branches in the event tree) have the greatest impact on the transmission of the influenza virus? Why?
7. Which variables have the least impact on the transmission of the virus? Why?
8. Are there any changes or additions you would make to the event tree?
9. Are there any changes you would make to the scenario?

Section 3: Interventions

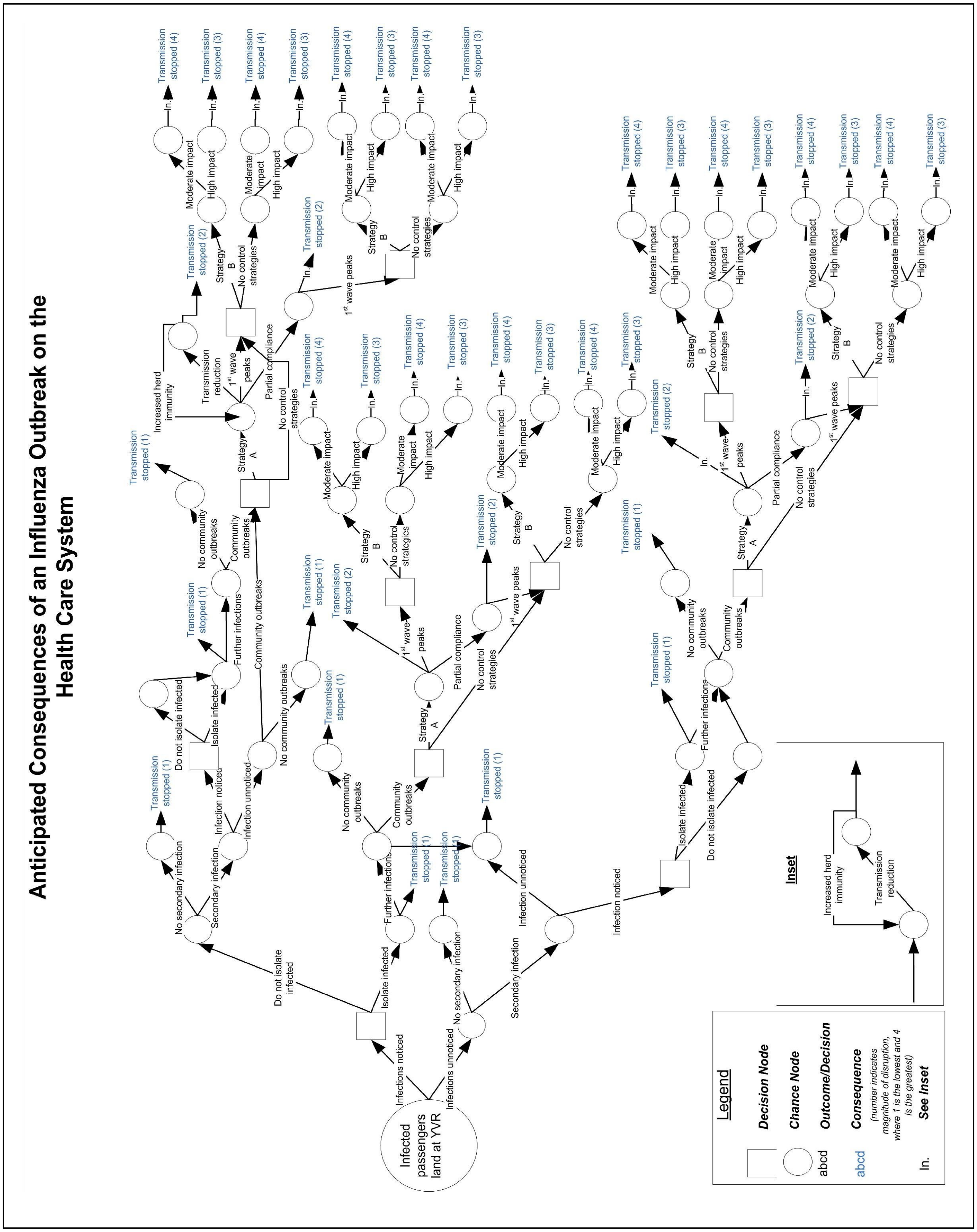
10. What is the likelihood that the following interventions will reduce the transmission of an influenza virus? *(Please answer questions with one of the following answers: not at all, somewhat likely, very likely, extremely likely)*
    a. Administration of antivirals?
    b. Immunization of at-risk populations?
    c. Public education?

d. Isolation of the infected?
e. Social distancing?

Section 4: Capacity to Respond: (Please answer questions with one of the following answers: not at all, somewhat likely, very likely, extremely likely)

11. How likely is it that adequate supplies of a vaccine will be available locally during an outbreak? *Follow-up: What protocols exist for ensuring vaccine supplies are available, as well as security measures while storing and transporting the vaccine?*
12. What is the likelihood that other necessary medical supplies will be readily available (e.g., antivirals, clean water)? *Follow-up: With the just-in-time system that is typically in place, which infrastructures are relied on to ensure timely delivery? What steps have been taken to avoid a shortage of these medical supplies?*
13. How likely is a staffing shortage? *Follow-up: What impact will this shortage have on the delivery of health care? What provisions have been made to increase staffing requirements during a pandemic response?*

Appendix B: Complete Event Tree



Appendix C: UBC Research Ethics Board Certificate

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road,
Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Stephanie Chang	UBC/College for Interdisciplinary Studies/Human Settlements	H08-00195

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
N/A	N/A

Other locations where the research will be conducted:
Interviews will be conducted with employees of the Provincial Health Services Authority, the Fraser Health Authority, the Vancouver Coastal Health Authority, and similar organizations. Locations for the interviews will be in the offices of the interviewees.

CO-INVESTIGATOR(S):
Har-Rajandeep Dhariwal

SPONSORING AGENCIES:
N/A

PROJECT TITLE:
Disaster Resilience of the Vancouver Health Care System to Pandemic

CERTIFICATE EXPIRY DATE: July 15, 2009

DOCUMENTS INCLUDED IN THIS APPROVAL: | **DATE APPROVED: July 15, 2008**

Document Name	Version	Date
Consent Forms:		
Consent form	N/A	June 18, 2008
Questionnaire, Questionnaire Cover Letter, Tests:		
Questionnaire	N/A	June 18, 2008
Letter of Initial Contact:		
Contact letter	N/A	June 18, 2008
Other:		
N/A		

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board and signed electronically by one of the following: