A Sociotechnical Systems Analysis of the Toronto Sars Outbreak

Andrea Cassano Piché and Kim J. Vicente

Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2005 49: 507
DOI: 10.1177/154193120504900362

A SOCIOTECHNICAL SYSTEMS ANALYSIS OF THE TORONTO SARS OUTBREAK

Andrea Cassano Piché & Kim J. Vicente
Cognitive Engineering Laboratory
University of Toronto
Toronto, Canada

In February 2003, an outbreak of Severe Acute Respiratory Syndrome (SARS) in Toronto, Canada, resulted in 438 probable SARS cases, 44 deaths, and over 25,000 individuals quarantined. The purpose of this study was to investigate whether or not the predictions of Rasmussen's (1997) framework for risk management can explain how and why SARS was transmitted in Toronto. There are two propositions for this case study. First, multiple actions, decisions, and degrees of capability at all levels of the system are needed to explain how SARS was transmitted. Second, a lack of vertical integration between individuals and organizations explains why SARS was widely transmitted. Both propositions of this case study are supported by the data in the National Advisory Committee's report (Health Canada, 2003). Furthermore, almost all of the predictions made by Rasmussen's (1997) framework were confirmed by the events that transpired during SARS.

INTRODUCTION

In February 2003, Severe Acute Respiratory Syndrome (SARS) made its first appearance in Toronto, Canada, marking the beginning of a seven-month public health crisis. Thousands of health care workers and citizens rose to the challenge of providing care and protecting their home and work environments. Despite these efforts, there were 438 probable cases of SARS, 44 deaths, and over 25,000 individuals quarantined between February and August of 2003.

The purpose of this study was to investigate whether the predictions of Rasmussen's (1997) framework for risk management can explain how and why SARS was transmitted in Toronto.

Rasmussen's (1997) framework for risk management in a complex sociotechnical system has two components: a structural hierarchy of the actors and organizations (Figure 1), and the dynamic forces that can cause a complex sociotechnical system to changes its behavior (Figure 2). The exact number of levels in the hierarchy and titles of each level can vary depending on the system being studied. The bottom level of the hierarchy describes events related to the process being controlled. The next level describes activities of front-line staff. The following level describes the activities of the people that manage or supervise the staff, and the level above describes the activities of the entire company or organization. The level second from the top describes the activities of the regulatory bodies, and finally, the top level describes the activities of the government, which determines public policy.

According to Rasmussen's (1997) framework, vertical integration across all levels of a complex sociotechnical system is required for the system to function safely. That is, decisions made at the higher levels of the hierarchy need to be disseminated to the lowest levels of the hierarchy, and information about what is happening at the lower levels of the hierarchy needs to circulate to the higher levels, creating feedback loops. These feedback loops allow decisions made at the higher levels of the system to reflect the goals and capabilities of the lower levels.

Following this theory, safety is an emergent feature of a system and is impacted by the actions and decisions of individuals and organizations at multiple levels. System stability is difficult to achieve because external forces (Figure 1, right side) influence complex systems, especially in today's dynamic society where change is more frequent than ever before.

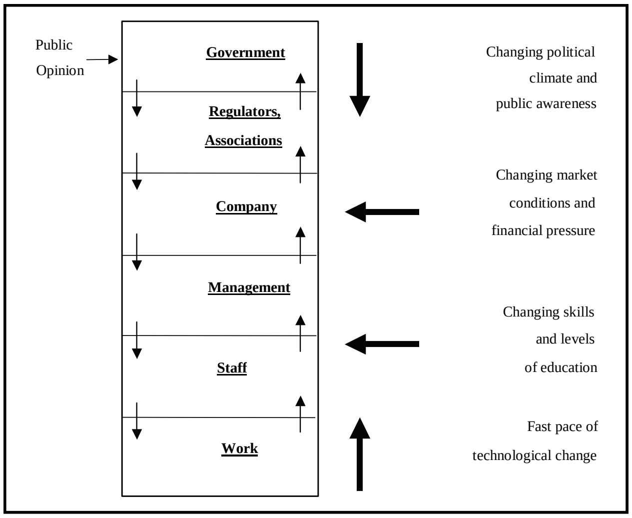

Figure 1: Structural hierarchy of actors in a complex sociotechnical system. Adapted from Rasmussen (1997) and reprinted from Vicente (2002). Quality and Safety in Healthcare, 11, 302-304. With permission from the BMJ Publishing Group.

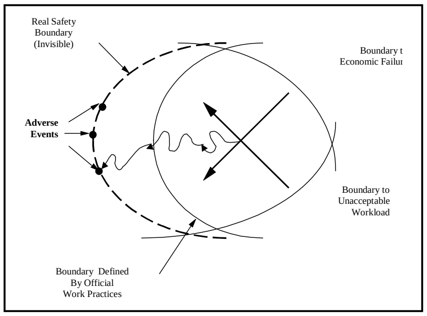

Figure 2: Dynamic forces and behavioral change Adapted from Rasmussen (1997) and reprinted from "The Human Factor: Revolutionizing the Way People Live With Technology", © Kim Vicente, 2003.

Figure 2 illustrates how two dynamic forces, financial and cognitive efficiency pressures, affect the behavior of a complex sociotechnical system over time (Rasmussen, 1997). As these forces interact, people at all levels of the system adapt their work practices to allow operators to work with fewer resources. The changes in work practices may appropriately address the financial and efficiency goals imposed, but they often cause a system to migrate closer to the boundary of safety defined by official work practices. Over time, people migrate beyond this boundary of safety towards the "real" (invisible) boundary of safety where accidents occur. This migration may take years, and so, subsequent to a major disaster, the people involved often do not understand what has happened because their actions did not deviate from those in the recent past.

METHOD

A qualitative case study research method (Yin, 2003) was adopted. According to Yin, a case study has five components: questions, propositions, unit of analysis, logic linking data to the propositions, and criteria for interpreting the findings.

There are two propositions for this case study. The first is that multiple actions, decisions, and degrees of capability at all levels of the system are collectively needed to explain how SARS was transmitted, despite the conscious protective efforts of all actors involved. The second is that a lack of vertical integration across all levels of the system explains why SARS was widely transmitted.

The unit of analysis for this study is the transmission of SARS. The seven theoretical predictions in Rasmussen's (1997) framework (discussed later) provide the logic for linking the data to the propositions of this case study.

Criteria for interpreting the findings are subjective, but efforts were made to enhance construct validity, "establishing correct operational measures for the concepts being studied" (Yin, 2003, p. 34). First, multiple sources of data were used. Second, a key informant reviewed the document. The primary data source was the Report of the National Advisory Committee on SARS and Public Health (Health Canada, 2003). This report was produced in consultation with 46 individuals who are leaders in Ontario's healthcare system and were significant participants in leading the fight against SARS. Additional sources of data included local and national newspaper articles, journal articles, an article in Time magazine, the World Health Organization and Health Canada websites and an interview with Mona Loutfy, a consulting clinician who treated a large number of the SARS patients at the two most affected hospitals in Toronto.

These data were used to construct a timeline of events that occurred in Toronto from November 2002-August 2003 and that contributed to the SARS outbreak. The events in this timeline were then mapped onto a structural hierarchy (Figure 3) and the causal links between events that led to the transmission of SARS were established. Mismatches between organizations and people at, and between, each level of the hierarchy were identified using the events in the structural hierarchy as evidence (Figure 4). Dr. David Naylor, Dean of Medicine at the University of Toronto and Chair of the National Advisory Committee on SARS and Public Health, was the key informant who reviewed this analysis. Finally, the causal links of events and mismatches between organizations were compared with Rasmussen's seven predictions.

RESULTS

The events that led to the transmission of SARS can be seen in the structural hierarchy (Figure 3). The factors that most heavily contributed to the transmission of SARS at each level are discussed in this section.

At the *Equipment and Surroundings* level, there was an insufficient capacity to handle patients with airborne or droplet spread infectious diseases due to a lack of isolation or negative pressure rooms in hospitals.

At the *Physical Processes and Actors* level, the actors had little experience dealing with an unknown infectious disease agent. The process of intubation and use of supplemental oxygen was thought to have exposed healthcare workers to the coughed-up secretions of SARS patients. Additionally, improper removal of protective clothing was thought to have been a source of infection. The Canadian Hospital Epidemiology Committee commented that the high rates of transmission to healthcare workers was a result of systematic problems in the health care system including "insufficient time devoted to learning infection control practices for all healthcare providers" (Health Canada, 2003, p. 39).

One person who unknowingly had SARS broke quarantine regulations imposed under the authority of the *Emergency Measures Act*, which resulted in a co-worker contracting the disease and 200 others being quarantined.

At the *Technical and Operational Management* level, the absence of a centralized database for tracking epidemiological and clinical data across levels of public health was the dominant factor. This infringed on how cases were managed as well as the ability to track clinical and epidemiological data required by researchers to learn how to fight the disease. Provincial budget cutbacks affected the Central Provincial Public Health Laboratory, reducing its ability to process the volume of specimens that were taken during SARS. The lab was forced to offload the overflow to the National Laboratory, causing significant processing delays, while the disease continued to be transmitted during the processing time.

At the *Local Regulators* level, the most significant factor was the economic and social devastation experienced by Toronto following the World Health Organization's (WHO) travel advisory, advising people to refrain from traveling to Toronto. The effects of the advisory put additional pressure on the healthcare system to return to normal as quickly as possible. This economic pressure gradient influenced decisions made by the regulators, and is discussed at the next level.

At the *Regulatory Bodies* level, the Ontario Health Minister, pressured by the social and economic decline in Toronto, convinced the WHO to lift Toronto's travel advisory in return for increased screening of travelers. The Premier of Ontario, also pressured by the social and economic conditions, interpreted this to mean that the province was no longer in a state of emergency, and three days after the travel advisory was removed he lifted the external disaster (Code Orange) status and dismantled the Provincial Operations Committee (POC) that had been put in place to manage the crisis. Tightened infection control practices were relaxed in hospitals. The absence of proper feedback mechanisms between hospitals and the province concealed the new, undiagnosed cases that were appearing as these decisions were being made. The financial pressures to "return to normal" coupled with no new cases of SARS identified in over a month, influenced the work practices of healthcare staff to rule out SARS in these new instances where epidemiological links were not found. This eventually led to what was coined "SARS II".

Another major contributing factor at this level was the existence of multiple regulatory bodies, across all three levels of government (municipal, provincial and federal) as well as international regulators. There was no precedent for groups at all of these levels to work together in a time sensitive and stressful situation, and the jurisdictional boundaries across levels of public health were unclear. Health Canada (federal regulator) was unable to get information from the provincial regulator, the Ontario Ministry of Health and Long Term Care (OMHLTC), because no formal data sharing policy existed between the two. The Province was further constrained by the need to protect patient confidentiality.

Finally, at the *Federal and Provincial Government* level, the most prominent factor was the absence of a national infrastructure for public health with defined goals and strategies. Additionally, funding cutbacks in both the federal and provincial budgets severely constrained resources at the local level. One obvious example of this was the denial of a funding request from the OMHLTC to upgrade disease tracking and outbreak management software over a five-year period. When SARS arrived, the system in use was so obsolete that it could not be adapted to suit immediate needs. As a result, new software had to be developed while trying to manage the disease.

DISCUSSION

Both propositions of this case study are supported. Multiple contributing factors - actions, decisions, and impaired levels of capability - combined with mismatches of vertical integration between levels of the system, collectively explain how and why SARS was transmitted in Toronto. Furthermore, almost all of the predictions made by Rasmussen's (1997) framework were confirmed by the events that transpired during SARS. The seven predictions and their relevance to the Toronto SARS outbreak are discussed here.

1. *Safety is an emergent property of a complex sociotechnical system. It is impacted by the decisions of all the actors.* This was evident by the large number of individuals and organizations, shown in Figure 3, whose interactions ultimately define the level of safety.

2. *Threats to safety are usually caused by multiple contributing factors, not just a single catastrophic decision or action.* No single factor in Figure 3 can be identified as the root cause of SARS transmission in Toronto. Although one single person brought the disease to the city, the chain of transmission that followed is a result of multiple contributing factors. An example is the transmission from patient to healthcare workers that occurred several times when a SARS positive patient was being intubated. Lack of knowledge about the disease, lack of experience dealing with a droplet transmitted virus, and the intubation procedures themselves contributed to transmission in a few particular cases.

3. *Threats to safety or accidents usually result from a lack of vertical integration across all levels of a complex sociotechnical system, not just from deficiencies at any one level alone*. The breakdowns that occurred between levels of the health care system, representing instances of vertical disintegration, can be seen in Figure 4. The National Advisory Committee's report calls for enhanced vertical integration: "A more cohesive, comprehensive approach to public health must form the basis for a sustainable public health system. This means cooperation not only across governments but also within governments, and involves the private sector, non-governmental organizations, and the public."
(Health Canada, 2003, p. 19)

4. *The lack of vertical integration is caused, in part, by a lack of feedback across levels of a complex sociotechnical system. Actors at each level cannot see how their decisions interact with those made by actors at other levels, so the threats to safety are far from obvious before an accident*. "SARS II" emerged primarily because two

important feedback loops were incomplete. The first was a lack of feedback from the front line staff to hospital administrators and hospital administrators to public health officials. Several patients had been fighting what was thought to be post-operative lung infections. Hospital administration was not aware of the condition of these patients, so they did not involve experts in diagnosing these patients. Nurses alleged that administrators ignored their warnings of an impending second SARS outbreak. During this time the hospital was without a Chief Nursing Officer, a nursing representative among administration.

The second poor feedback loop interfered with the ability of clinicians to accurately diagnose SARS patients. The definition of SARS relied heavily on an epidemiological link. Being able to efficiently and effectively track patients and their contacts was required better information technology and integrated databases than were present in the public health system at the time of SARS. Without these resources, information at the lower levels of the system could not be included by decision makers at the Management or Regulatory Body levels, leading to the misdiagnosis of many patients based on poor epidemiological links.

5. *Work practices in a complex sociotechnical system are not static. They will migrate over time under the influence of a cost gradient driven by financial pressures in an aggressive competitive environment and under the influence of an effort gradient driven by the psychological pressure to follow the path of least resistance*. Economic and social decline following the WHO travel advisory sent public health leaders to Geneva to bargain for the removal of the advisory, in return for more intense screening at Toronto's international airport. Leaders in Toronto misunderstood the removal of the travel advisory to mean that the outbreak had come to an end. Trying to restore Toronto's economy, the Premier of Ontario lifted the emergency Code Orange status within three days of the travel advisory removal and dismantled the POC. There were still new developing cases that had not received proper attention or diagnosis that may have been treated differently had the state-of-emergency not been lifted (see prediction four). The result was 57 more probable cases of SARS from May 23 to June 30, 2003.

6. *The migration of work practices can occur at multiple levels of a complex sociotechnical system, not just one level alone*. In this case study, a migration in work practices was seen at all levels of the public health system. Following the removal of the WHO travel advisory, a snowball effect in changes of work practice was seen at all levels. The premature removal of infection control practices at the provincial government level was followed by the absence of syndromic surveillance at the hospital level and the ignored warnings of an impending second outbreak at the hospital level. These actions, paired with the external economic pressure gradient, set the stage for the second wave of SARS to occur.

7. *Migration of work practices causes the system's defenses to degrade and erode gradually over time, not all at once. Accidents are released by a combination of this systematically-induced migration in work practices and a triggering event, not by an unusual action or an entirely new, one-time threat to safety*. It is suspected that a gradual migration in work practices over time did occur, specifically within the Provincial Public Health Laboratory and Toronto Public Health, because of the funding cuts that occurred over time. The National Advisory Committee's report highlights the lab's inability to keep up with testing volumes during two other recent outbreaks of West Nile and Norwalk virus. This claim cannot explicitly be supported using the National Advisory Committee's Report on SARS because it focused on the work practices that occurred during SARS and not on work practices in former years leading up to it.

There are two factors that cannot be accounted for by Rasmussen's (1997) model. First, SARS was a new infectious disease that had no known test or treatment. Even if the warnings that Canada received via federal regulators had been effectively communicated to the lowest levels of the system, treating SARS patients would still have been difficult, and risky, since pathogens and exact modes of transmission were not accurately known until months later. Second, there was an intentional defiance of quarantine by an (unknowingly) infected person who transmitted the disease to at least one co-worker, and sent another 200 into quarantine.

Based on these findings, Rasmussen's (1997) framework may not be sufficient for identifying and explaining every factor that contributes to a complex sociotechnical system failure, but, it does facilitate an understanding of the behavior shaping mechanisms that influence the actions and decisions of actors at each level of the system. By understanding the forces that shape behavior (i.e. levels of funding, availability of resources, the political context, etc.), systems can be (re)designed to influence behavior in a way that creates proper conditions for safety.

REFERENCES

Government of Ontario. (2004). *McGuinty government takes on nursing shortage to improve patient care*. Retrieved March 23, 2004, from http://www.premier.gov.on.ca/english/News/nurses030404_bd1.asp.

Health Canada. (2003). *Learning from SARS: Renewal of public health in Canada*. Ottawa, Ontario: Her Majesty the Queen in Right of Canada.

Rasmussen, J. (1997). Risk management in a dynamic society: a modeling problem. *Safety Science*, 27, 183-213.

US Department of Statistics. (2004). *Overseas Travel Trends.* Retrieved March 22, 2004, from http://www.bts.gov/publications/us_international_travel_and_transportation_trends/overtrends.html.

Yin, R.K. (2003). *Case study research: Design and methods* (3rd ed.). Thousand Oaks: Sage.

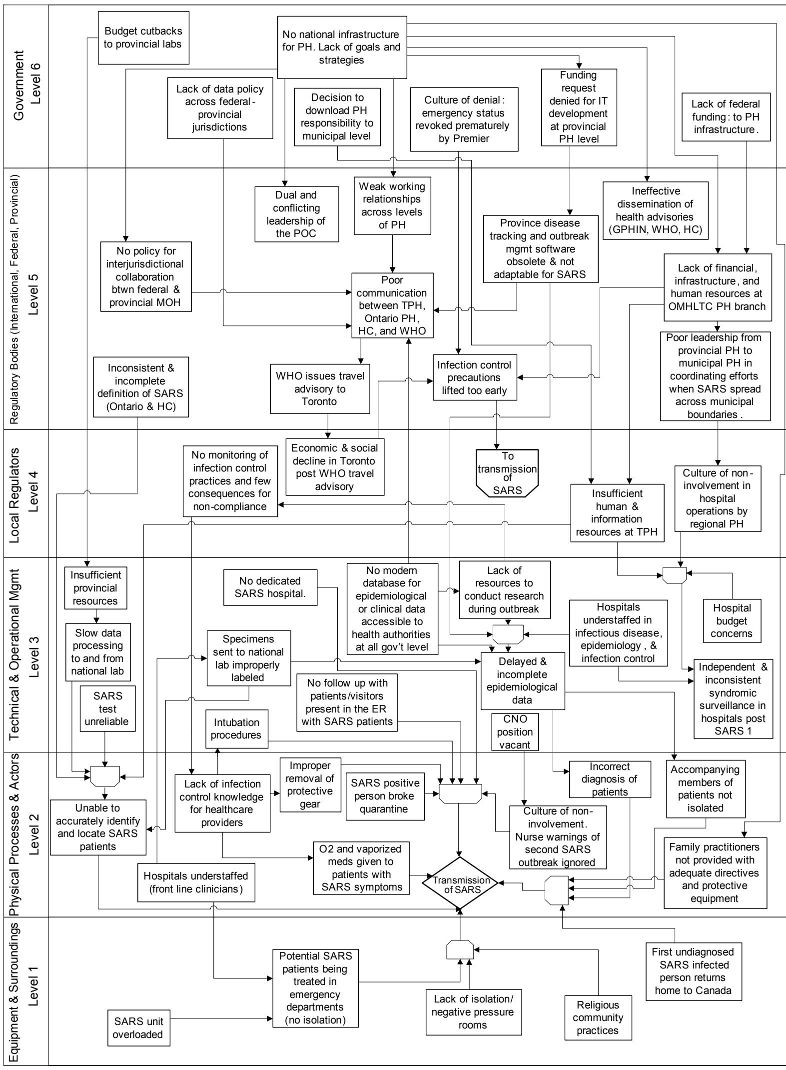

Figure 3: Structural Hierarchy of Contributing Factors

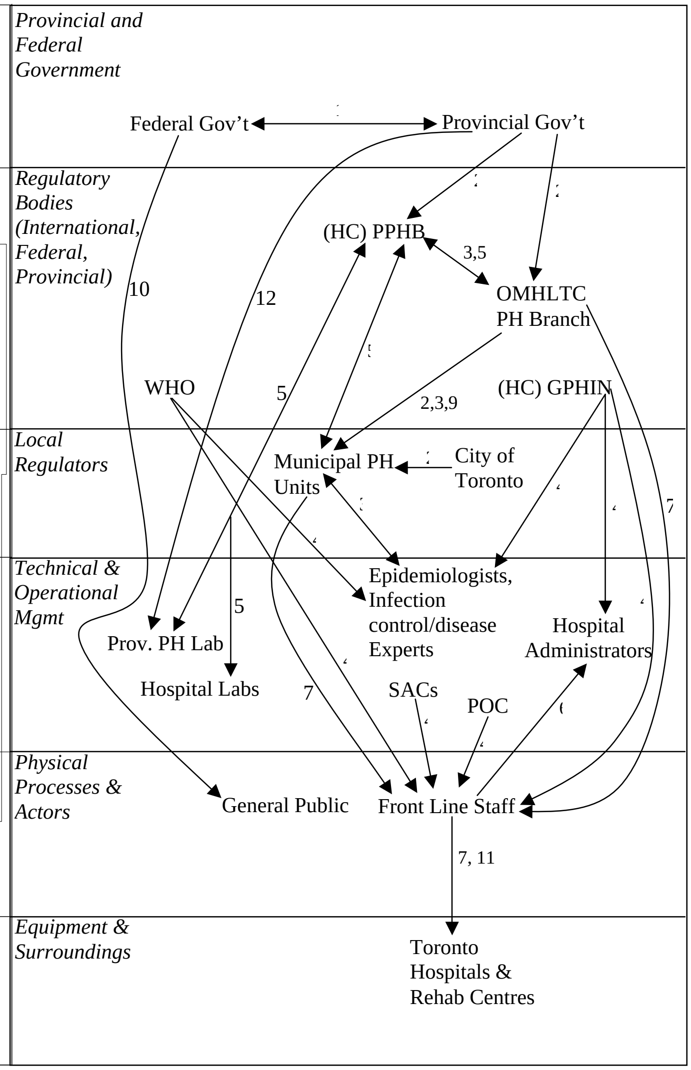

Figure 4: Counter Productive Mismatches

Legend for Figures 3 and 4

PH = public health

WHO = World Health Organization

POC = Provincial Operation Committee

IT = information technology

CNO = Chief Nursing Officer

ER = Emergency Room

HC = Health Canada

TPH = Toronto Public Health

NYGH= North York General Hospital

MOH = Ministry of Health

GPHIN = Global Public Health Intelligence Network

OMHLTC = Ontario Ministry of Health & Long Term Care

PPHB = Population and Public Health Branch

SACs = SARS Advisory Committees

1. Strategies for legislation appear to be inadequate during fast technological change.
2. Lack of funding to Public Health limits ability to provide support during emergency situations.
3. Inadequate coordination; failure to define inter-jurisdictional boundaries and responsibilities between M/P/F health authorities.
4. Lack of reliable mechanisms for disseminating advisories and mandates.
5. Lack of reliable mechanism for tracking epidemiological and clinical data across M/P/F boundaries.
6. Anti-participative culture for nurses. Non-managerial nurse input not valued by hospital management.
7. Lack of emergency preparedness for dealing with highly infectious communicable diseases.
8. Improper operating practices; poor understanding of risks of infectious droplet viruses.
9. Inadequate coordination; Provincial Public Health does not provide leadership for coordinating activities between local PH units.
10. No clear protocol for publicizing and enforcing Quarantine Act measures.
11. Improper operating practices; poor understanding of risks.
12. Budget cutbacks limit ability to process and report lab results efficiently.