



Emerging coordination and knowledge transfer process during disease outbreak

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Abstract

When multiple agencies respond to a disease outbreak (i.e., H1N1 and SARS), the coordination of actions is complex and evolves over time. There has not been any systematic empirical study of the dynamics of emerging coordination behaviour and knowledge transfer process during a disease outbreak. In this paper, we first introduce our approach for the analysis of multi-agency intervention during a disease outbreak using the study of social networks. Using social networks and its analytic framework, we explore questions such as: How does the multi-agency coordination emerge for supporting the complex knowledge transfer process during different phases of disease outbreak? How effective are these formal and informal coordination mechanisms in achieving a robust outcome in response coordination through effective knowledge transfer process during the outbreak? What are the key lessons learned by studying the emerging coordination and knowledge transfer process during past disease outbreak in improving the multi-agency preparedness for dealing with future outbreaks? The discussion is supported by a qualitative study of the implementation of the results of the analysis. We reveal that profound understanding of social network behaviour and emerging coordination concepts are pivotal to the optimisation of knowledge transfer process which is a prerequisite for successful outbreak intervention. We look qualitatively at how Hunter New England Area Health Services applied these concepts to lead a successful coordination plan during an H1N109 endemic.

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Introduction

Disaster management is inherently complex due to the interdependent nature of the responses from multiple organisations that have responsibility for dealing with the situation collectively (Comfort *et al*, 2001). It has long been advocated that standard hierarchical management structures may not necessarily be the most efficient ones in such situations (Neal & Phillips, 1995). This is due to the demanding requirement for extensive inter-organizational interactions, communication, and collaboration with interwoven dependencies (Chen *et al*, 2008). Disease outbreak can be considered as a particular example of a disaster where the dynamics of the situation is particularly important. It is distinct from earthquakes, bushfire, or floods that can only affect a particular geographical area (that might be large but nevertheless bounded area). Table 1 is a comparison chart highlighting some differences between disease outbreak and bushfire or flood disasters.

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Table 1 Differences between disease outbreak and bushfire/flood disasters

<i>Disease outbreak</i>	<i>bushfire/flood</i>
Wave pattern behaviour determined by the pathogen infectivity; might re-infect the same affected area/population	After burning a certain area, does not return to it
Can arise out of another disaster (flood or earthquake) due to environmental and population behavioural changes	Rarely preceded by other disasters
Outbreaks can cross geographic boundaries to be a global phenomenon (H1N109, SARS)	Bounded by geographical characteristics (bush/ rivers locations)
Population discriminative; usually some population segments (elderly, children) are more vulnerable than others	Population is targeted based on geographical location vulnerability alone
Mutative and adaptive (influenza is the best example). This antigenic-drift adds to the complexity of the spread patterns	N/A
The spread patterns are influenced by different factors including pathogen contagion, demography, and behaviour	Spread is based on simple factor(s) mainly geographical characteristics
Might have a deterministic effect on Health workforce (Health workers will have families to protect; more infection in health work force as result of contact with pathogens more than others in population)	Relief effort worker can relocate family to safe location
Creates hotspots that 'move', 'die', or 'fragment' to hundreds of other locations depending on population movements	Hotspots are population independent. Can be predicted based on geography and meteorology
Can be nature made or man-made (bio-terrorism)	Can be nature made or man-made (arsonists)

Table 2 Confirmed H1N109 infection rates in Australian states and territories at the end of the Contain Phase, 17 June 2009

<i>State</i>	<i>State population^a</i>	<i>Confirmed cases</i>	<i>Rate per 100,000</i>
New South Wales	7,041,400	313	4.4
Victoria	5,364,800	1230	22.9
Queensland	4,349,500	194	4.5
Australian Capital Territory	347,800	75	21.6
South Australia	1,612,000	107	6.6
Western Australia	2,204,000	117	5.3
Northern Territory	221,700	35	15.8
Tasmania	500,300	41	8.2
Australia total ^b	21,644,000	2112	9.8

^aPopulation figures are based on estimated residential population 31 December 2008.

^bThe Australian total includes all territories.

One of the intriguing facts is that outbreaks have different transmission and infection rates not only between countries but also between different states in a single country and within each state of similar demographics and geographic characteristics. An example is the following reported cases of infection in Australia for the H1N1 2009 outbreak (Eastwood *et al*, 2009).

Table 2 shows that within the same country the infection rate can differ by up to fivefold from one state to another (e.g., compare New South Wales (NSW) rates

with those of Victoria and Australian Capital Territory). Table 3 disaggregates information about outbreak within the same state (Eastwood *et al*, 2009).

We can see that Hunter New England (HNE) had the lowest transmission rate (0.9 per 100,000 population), whereas an adjacent health area (North Coast) had a transmission rate more than twice as large (2 per 100,000). Also, HNE had the lowest number of confirmed cases in NSW state (8 only). Table 3 indicates that within the same state there is about an eightfold variation in

Table 3 Confirmed H1N109 infection rates in the eight New South Wales area health services at the end of the Contain Phase, 17 June 2009.

New South Wales area health service	Population ^a	Confirmed cases	Rate per 100,000
<i>Rural</i>			
Hunter New England	862,967	8	0.9
Greater Southern	483,282	42	8.7
Greater Western	301,052	9	3.0
North Coast	495,329	10	2.0
<i>Metropolitan</i>			
North Sydney/Central Coast	1,134,200	33	2.9
South Eastern Sydney/Illawarra	1,209,111	46	3.8
Sydney South West	1,394,652	82	5.9
Sydney West	1,131,294	83	7.3
New South Wales Total ^b	7,011,886	313	4.5

^aPopulation figures are based on estimated residential population 31 December 2008.

^bThe discrepancy with the NSW total in table 3 is due to differences in population projections.

infection rates. Taking into consideration that demographics are similar and pathogen is the same, then management and coordination of the response to the outbreak is one factor affecting the infection rate. This effort is led by the corresponding agencies in each individual state and area health services within the states.

Usually, outbreak detection and intervention plans standardise each type of outbreak according to disease type. Hence, researchers and epidemiologists prepare tuberculosis plans, influenza plans and so on. By contrast, coordination of the multi-agency response is left to public health officials with very little academic research to support their decisions (Comfort *et al*, 2004; Dawes & Government, 2004; Shen & Shaw, 2004; Chen *et al*, 2008). As a result, there are discrepancies in the application of resources, which will impact on infection rates and may partially explain the variation in the rates shown in Tables 1 and 2.

Successful intervention is a direct consequence of successful coordination. It is the coordination effort that brings together different types of resources such as information, expertise, and supplies (Chandler, 1973) for the most efficient intervention plan. Coordination is also based on building a common understanding about the task in hand. In this paper, we use measures from social network theory to better understand the dynamics of inter-organisational coordination during disease outbreaks and how this leads to collective decentralised knowledge sharing. We collect disease outbreak coordination data from Hunter New England Area Health Services (HNEAHS) in NSW, Australia for demonstrating the effectiveness of these network-based measures to accomplish an effective coordination and communication plan that will contribute to the reduction of infected cases and transmission rates. Then we use the theoretical concept of social-based knowledge management sharing to suggest the fundamental principles for modelling knowledge sharing during disease outbreaks.

Background

A considerable amount of research has been undertaken into disease outbreaks from an epidemiological perspective including the role of pathogen transformation, mutation, and infection, and the modelling of disease spread. Some of these approaches represent epidemics of communicable diseases as Markovian or non-Markovian processes and apply stochastic epidemic threshold theory to guide public health measures aimed at preventing major outbreaks. Other approaches identify general properties of emerging infectious agents to determine the success of different public health measures such as isolating symptomatic individuals or tracing and quarantining their contacts. There has also been a promising attempt to develop a disease outbreak event corpus. However, in contrast to the models of disease outbreak, there has been relatively little work been done on modelling the response of the multiple agencies responsible for dealing with the outbreak (Chen *et al*, 2008).

Since there are not many studies that deal with organisational dynamics at play in the disease outbreak context, we use an investigative approach with a qualitative case study to capture rich information from senior health disaster management practitioners in the field. This provides a better insight into the complexity of the problem, a better understanding of the context, and a much needed holistic view of the entire coordination system.

Our case study examines the coordination scenario that took place in 2009 when the H1N109 virus pandemic was declared by World Health Organisation (WHO) (Eastwood *et al*, 2009). Australia had its first confirmed swine flu case in Brisbane on 7 May 2009 on an international flight (Eastwood *et al*, 2009). Worldwide WHO figures reported 4.4-fold case increases during June 2009 in confirmed cases, whereas in Australia there were 13.4-fold case increases for the same period

(Eastwood *et al*, 2009). The higher Australian rate can be partially attributed to the coinciding influenza season in southern winter (Eastwood *et al*, 2009).

In this case study, we explore the multi-agency coordination and communication that took place in HNEAHS during the endemic. HNEAHS is located in northern NSW within a geographical area of over 130,000 km², spans 25 local council areas, and has a population of about 870,000. HNEAHS is unique in that it is the only health service in NSW with a major metropolitan centre (Newcastle/Lake Macquarie), as well as a mix of several large regional centres and many smaller rural centres, as well as remote communities within its borders. HNEAHS activates the Health Service Functional Area Coordination (HSFAC) centre during major health crises. HSFAC is responsible for activating the Emergency Operations Centre (EOC) located in the John Hunters Hospital, leading management response, providing intelligence and guidance, and monitoring the cases reported by the 'Front Line' (i.e., Emergency Department (ED), general practitioners (GPs), and other relevant health professionals). HSFAC objectives are as follows:

- Send a unified message to the community.
- Have standardised information distributed to the front line (i.e., EDs, GPs).
- Apply robust case definition communication policy to reduce the time between receiving it from the state level until deployed in the front line, as well as getting a confirmation about its deployment.
- Providing intelligence and relevant information to the front line in as short as one page, rather than long irrelevant policies.
- Pre-empting any industrial dispute due to changing work conditions like long work hours.
- Keep the different sectors of the industry informed about the outbreak development.

As reported in Table 3, the HNEAHS has achieved the lowest transmission rate in NSW. This can be at least partially credited to their successful management and coordination effort. Using network theory to investigate their organisational coordination and communication model presents a unique opportunity to discover the characteristics of this model.

The interview data used here were collected in October 2010. In order to capture a holistic view of the complexity and dynamics of the coordination process, we conducted semi-structured interviews with the senior HSFAC leaders in HNE. The interviews focused on recalling the communication and coordination processes that took place during the H1N109 endemic. These exploratory interviews were structured in to five sections where each section focused on one aspect of the coordination process. These sections were designed to be used for a follow-up using qualitative data capturing techniques. They were also designed to build a meta-data network structure for the coordination that will be

used for further analysis. The sections and their relative primary questions are presented in Table 4 and the complete questionnaire is given in the appendix.

In this paper, we discuss sections B and C (actors and processes) compiled in the form of inbound and outbound communication protocols.

Theory of networks and coordination

In this section, we introduce the necessary theoretical background relating to coordination, coordination complexity in disasters, and social network analysis.

Coordination is increasingly seen to be important as organisations become more reliant on interdisciplinary teams of specialties and distributed operations for addressing complicated situations demanding a multi organisational response. The Oxford English Dictionary defines coordination as a 'harmonious combination of agents or functions toward the production of a result'. Malone & Crowston (1990) defined coordination as 'the act of managing interdependencies between activities performed to achieve a goal'. In its simplest conceptualisation, coordination brings the activities of many disciplines or organisations together to achieve desired goals. It describes both processes and the goals (Chisholm, 1992) and is particularly challenging where the chains of interaction are complex and long. Research in coordination is therefore an interdisciplinary study that assists in building useful cooperative work tools for supporting activities, actor relations, and their interdependencies for achieving goals collectively.

Complexity of coordination

Complexity of coordination in multi-agency dynamic environments during disasters has been studied by Kapucu (2005) and Hossain & Kuti (2010) using a framework primarily drawn from dynamic network theory and complex adaptive systems theory. Kapucu observed that coordination in extreme events is guided by a group of interconnected actors who necessarily rely on each other to achieve the goals collectively. He further highlighted the difficulty of building effective networks of action, which is particularly difficult in dynamic environments.

Coordination and communication in disasters

A major facet of coordination is communication, which has been studied by Feczak and Hossain (2009) within the context of temporal team dynamics for bug fixing behaviour during open source software lifecycle management. A study by Miller & Moser (2004) suggests that 'Communication can play a key role in the ability of agents to reach, and maintain, superior coordination'. The two concepts are linked because communication can be regarded as a necessary and sufficient precedent associated with coordination. Disease outbreak represents a dynamic environment in which coordination mechanisms must be dynamic in order to adapt to the consequences of disease spread. Therefore, the

Table 4 Summary of the main investigation categories and questions discussed during interviews

Section:	Example questions
A. Situational information	<ul style="list-style-type: none"> • How is outbreak detected? • How is information routed? • What are the outbreak criteria? • What are the containment criteria?
B. Actors	<ul style="list-style-type: none"> • Identifying the organisations involved. • Identifying organisational characteristics (jurisdiction/domain/location ...) • Organisational role: How and when do they get involved in the outbreak? • What is their communication plan and protocols? • Types of the information exchanged.
C. Processes	<ul style="list-style-type: none"> • Information production, filtering and distribution. • Identifying parties involved in each part of information routing phases. • The inputs, feeds and outcome of the decision support system.
D. Determinants	<ul style="list-style-type: none"> • How to measure coordination gaps? • What are the criteria to determine that coordination is successful? • Can we use epidemiological measures as performance indicators? Historical data? Peer data?
E. Resource management	<ul style="list-style-type: none"> • How are resources deployed? • Centralized vs distributed resource storage and distribution? • How to measure resource allocation efficiency?

coordination structure for disease outbreaks cannot be modelled or analysed using current standard and static coordination methods that focus on market theory proposed by Malone & Crowston. The concept of dynamic emerging coordination (Comfort *et al*, 2001) is seen to be better suited to model the inter-organisational communication where agencies have a tendency to establish, drop, and enhance communication links over time in order to achieve the optimal coordination scheme. We propose that emerging coordination can be best modelled as a complex adaptive system where the components are interacting dynamically with each other within the environment. Some of the characteristics of such coordination are:

Robust information flow

Information sharing can be regarded as the backbone of any successful coordination (Iannella & Henricksen, 2007). Information flow can be unidirectional or bidirectional. Therefore, rapid information flow is essential for dynamic coordination because it provides the essential situational data necessary for quick adaptation.

Environment dependency

The coordination context is a direct result of the environment motivating the coordination. Besides dictating the resources sought after, the environment also influences the nature of the organisations that coordinate with each other.

Self-organising behaviour

Self-organisation is a dynamic and adaptive process where systems acquire and maintain structure without external control (De Wolf & Holvoet, 2005). Under these circumstances, operations will autonomously organise themselves within the whole coordination structure. This can further suggest that the system is adaptive to any external perturbations and change, in which case it will always be attracted to the self-organised state rather than to chaos. This is the main reason for referring to such coordination systems as 'dynamic' since self-organising is inherited from adaptability, resilience, and flexibility.

Visualising inter-organisational coordination as a network structure is not uncommon. Hossain (2009) has shown the viability of using network modelling for inter-organisational coordination and collaboration. Using this modelling approach, a node represents an entity (organisation, agent), and the links represent communication channels. These channels can be unidirectional (one-way communication – push or feed communication) or bidirectional (two-way communication). Modelling emergent coordination as a network structure can be beneficial as it can incorporate the dynamism of the process of emergence. This is represented by re-configuring the nodes based on their new contexts, which are determined by updated communication links. Hence, it is possible to add new agencies to the structure, move the important ones to the action centre of the network structure and the unimportant ones to the periphery. Also, this structure can be analysed across time. Below are

some of the measures that can be applied in such a coordination structure.

Degree centrality

Centrality is the number of links to and from an organisation measured within the locality of the specific node (Freeman, 1978). In a directed, asymmetric network, there can be in-degree centrality, number of ties received, and out-degree as the numbers of ties sent. In-degree is an indication of the importance of the node for its connected neighbours. It can be one that requires resources or a decision-making authority. Out-degree will be an organisation actively establishing links to acquire resources.

Betweenness

Betweenness is a measure of the nodes that lie on the shortest path that connects everyone else in the network, hence it measures the degree to which a node occupies a strategic position within the network (Freeman, 1978). This means that these nodes have quick access to new information and share this information with others. These nodes act as information relays since they will be used to pass information quickly to others.

Weak ties

Weak ties are efficient in knowledge sharing (Granovetter, 1973). They provide access to new information since they bridge otherwise disconnected nodes or groups (or what are known as structural holes) (Hansen, 1999). A bridge is a link in a network that provides the only path between structural holes. Linking nodes across the structural hole bridges two networks together (Harary *et al*, 1965). These weak ties, or bridges, are instrumental for learning new information because they provide access to novel information which would otherwise be absent within the standard contacts' reach (Valente, 1996).

One other facet of coordination and networks is the *informal coordination*. It can be defined as when individuals or organisations establish communication networks (CNs) outside the standard coordination structure to 'get things done' (Baker, 1981; Han, 1983). Informal networks can fill the lines that formal channels ignore, or capitalise existing ones to circumvent their complications, inefficiencies, or even their inaccuracies. Informal networks are an integral part of any coordination process. Indeed Cross *et al* (2002) even stated that, 'work increasingly occurs through informal networks of relationships rather through channels tightly prescribed by formal reporting structure of detailed work processes' (Cross *et al*, 2002). Devons supports that 'informal relationships are deliberately and consciously established and developed with the intent of exploiting them for the purpose of coordination' (cited in Chisholm, 1992).

In a multi-organisational coordination, it is expected that organisations will efficiently utilise their existing links to maximise their fit and access to required resources. Otherwise, if their existing links do not provide

access to the needed resource, they will actively branch new ones. The challenge remains in not falling into the temptation of burdening themselves with too many links, which will generate information redundancy and communication overhead.

H1N109 case study results

We discuss outbound and inbound communication related to the H1N1 coordination dynamics separately. Inbound communication represents a node receiving communication, and outbound represents a node establishing the communication channel. Such a link indicates the presence of a coordination relationship between both organisations. This coordination might be in the form of information sharing or resources exchange.

Outbound communication

Outbound communication is discussed in two parts: formal and informal outbound communication. Formal outbound communication started with the Contain Phase when HSFAC activated the EOC that should function as the main coordinator during such situations. In order to achieve the objectives discussed previously, HSFAC team elicited the existing communication channels rather than trying to establish new ones from scratch. It examined them, strengthened those that needs further support, and worked to bridge any structural holes.

The communication plan displayed in Figure 1 is named the *Pheromone communication*, and followed one-to-many, short, rapid, and two-way communication approaches. It represents the communication links starting from the state public health and ending at the 37 EDs in all the HNE hospitals. These links are primarily used to distribute quick and intelligent information rather than standard operating manuals and policies which in turn were posted on the HNE website for further reference. The case definition is a one-page communication that is essential for having unified cases admitted to the patients tracking system. Also, the same structure is used to receive feedback acknowledgment of case definition deployment into the system.

The Health Service Functional Area Coordinator (HSFAC) has strategically positioned itself on the path of communication that bridges the state public health and the director of clinical operations (DCO). By covering this structural hole, they are able to control and filter the information flow between the two nodes to the benefit of the ED nodes that are linked to the DCO. Hence, the dissemination of the case definition is reduced from 4 h to 30 min including the acknowledgment from the EDs that the new case definition has been imported into the system. It can be noticed that HSFAC is not positioned in a high degree centrality so that it is not overburdened with a communication overhead. They actually elicited the DCO's high degree centrality and its existing communication channels to pass the intended communication.

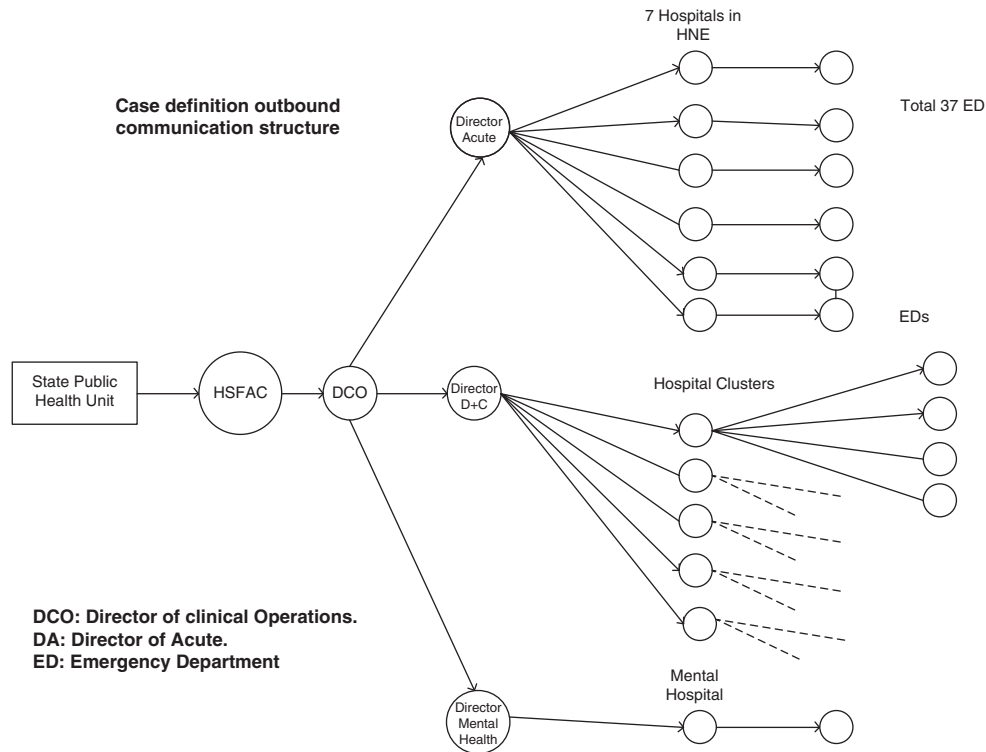


Figure 1 Outbound communication.

Furthermore, the HSFAC team consciously used informal CNs when it was essential to do so. This form of communication was found effective especially when they had to communicate with other bodies (medical and non-medical) outside their own jurisdiction. So, they extended to establish informal communication with the following parties:

- (a) GPs: HNE has five divisions of GPs divided into five executive divisions that work under different jurisdiction and have a direct link to state health services. Being the first point of contact for many potential cases and being geographically dispersed, the GPs represent an excellent network of information collection nodes and an effective medium for message dissemination. Hence, the importance of establishing coordination bridges with them. Once this informal link was established, the GPs network became so efficient that it was possible to set up an urgent meeting with the executive managers of the five divisions within 30 min notice. This relationship was also used to train the GPs to build up their surge capacity to receive more patients rather than directing them to the hospitals and risking over-stretching of the respective EDs.
- (b) Industrial Response Grid: HSFAC wanted to avoid industrial disputes that might arise from changing working conditions, and so updated the local business

network about the outbreak and disseminated information on how to protect their workforce. In order not be overwhelmed by the need for thousands of messages, the HSFAC communicated with the main bodies representing the different industries who then passed the communication to their members.

- (c) Consultancy Grid: In order to get advice from the required disciplines, the HSFAC co-opted expertise personnel from different domains: respiratory, clinical care, infection control, pharmacy, and secondary workforce liaison officer.
- (d) Ambulance Grid: During the outbreak, it was discovered that the Area Ambulance Services New South Wales (ASNSW) was not being updated with the latest outbreak information. Hence, an informal link was established to them to provide the latest outbreak and case definition information.

Figure 2 shows these four informal communication lines between the HSFAC and the four networks discussed above.

One can deduce from the above information that some of the important features of the emerging coordination were successfully implemented by the HSFAC team:

- Active discovery of the structural holes and bridge building. The HSFAC acted as the information broker and passed essential information, while at the same time not overloading themselves with high

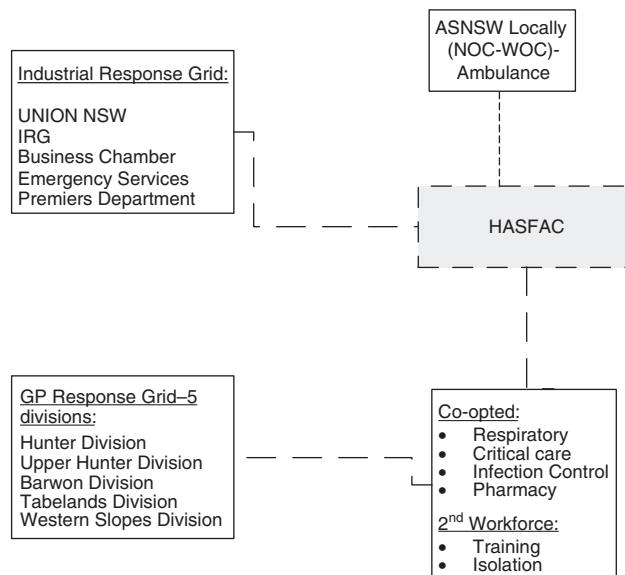


Figure 2 Informal outbound communication.

information demands. One successful method was to sustain a one-way (outbound) informal information feed such as in the example with the industrial response grid and ASNSW.

- Active development of the informal networks when needed in two-way relationships (e.g., GPs) and use their surge capacity to protect valuable resources, such as EDs, from high demand since these have limited surge capacity.

From the discussion above, the HSFAC has utilised network measures efficiently in deciding their relative position in the network and in bridging structural holes when needed.

Inbound communication

Results relating to inbound communication will be presented in two parts:

The global and federal inbound case definition communication

Figure 3 shows inbound communication starting from the WHO to the HNE HSFAC that passes the latest information about H1N109, most importantly the revised and updated 'case definitions' that define which individuals fall under the pandemic follow-up, and management criteria based on symptoms and medical tests. Such communication was through the standard hierarchical communication channels that ensured standardised case definitions nationwide.

Local inbound case definition communication

An important part of disaster management is the collation of data relating to damage impact. In dynamic environments such as a disease outbreak, the need for

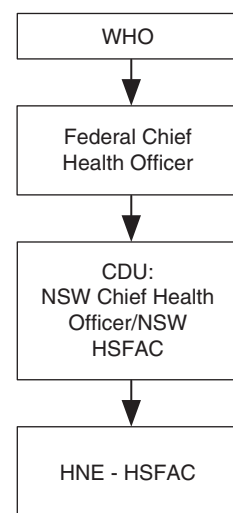


Figure 3 High level inbound communication.

continual live and accurate data cannot be overstated. This is not only required for effective management, but rather for the whole coordination process and successful resource distribution. However, it is practically impossible for a single agency to collect all the data. There will be many agencies gathering information, each following its own protocols under its own jurisdiction. The coordination of the information collection effort and the assessment and optimal investment of this information complete the data collection circle. Disease monitoring systems must be adaptive according to different criteria:

- Case accuracy: Aims at minimising false positives which lead to an unnecessarily high case load, or false

negatives which results in cases slipping the net. Accuracy of case definitions is important for resource management, allocation, and projecting epidemic trends.

- Early reporting of cases: Adding the cases to the case monitoring system, like Netepi, as soon as they are diagnosed for instant follow-up and monitoring.
- Protecting resources which have limited capacities: Intensive care units (ICUs) for example usually have a limited number of beds and nurses, as well as a strict nurse to bed ratio. Also the ICUs' surge capacity is limited and can only add a small number of beds or personnel. Resources such as these need a 'lead monitor' that will quickly flag the number of cases that are using, or will use, this resource. This will enable the organisation to operate within their capacity or coordinate with other organisations to receive overflow cases.
- The monitoring system needs to be distributed geographically and functionally in order to capture cases at early signs of development. This has to be achieved without over-extending resources but rather by using existing ones, such as GPs, whose network extends over a wide area of communities and in many scenarios are the first referral point for patients.

On the basis of these criteria, HNE HSFAC established an inbound monitoring system to capture case details as they are identified with lead indicators on specifically critical resources.

Figure 4 shows the network positions and functionality of each monitor. Again, the HSFAC did not position itself as the central node in the network. They aggregated the lag monitors, which require less attention than the lead

ones, to the Public Health Emergency Operation Centre. On the other hand lead monitors, which have high urgency, were directly connected to the HSFAC in order to communicate their existence to relevant parties quickly and to predict resource requirements, as well as planning their required surge capacities. In this scenario, the HSFAC sacrificed the higher degree of centrality and betweenness, which would have meant a connection to every single node (star network). This would have meant maintaining a link to every single organisation along with the burden of processing all inbound information.

Characteristics of knowledge management system for disease outbreaks

Analysing the CN is a necessary prerequisite to build a knowledge sharing system since the latter uses these channels to transfer the knowledge among individuals, organisations, communities, or groups (Argyris, 1999). Not only knowledge building and sharing is an essential ingredient in productivity, competitiveness, and maintaining institutional memory (Leonard-Barton, 1998; Laycock, 2005), but also a key component for coordinating disaster management and relief efforts (Zhang *et al*, 2002). Sharing knowledge during disasters needs to be further researched by academics.

Types of knowledge

There are two broad categories of knowledge (Polanyi, 1958; Nonaka & Takeuchi, 1995):

1. Explicit knowledge: This knowledge is usually created by systematic methods through structured and managed methods and is usually the product of formal approaches. It is usually stored in the form of

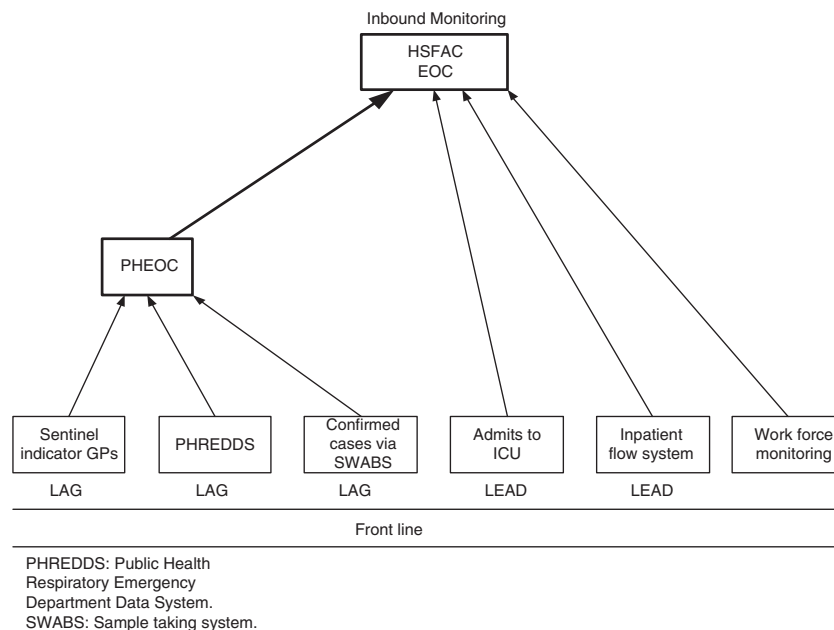


Figure 4 Lower level inbound communication.

documents, formulae, manuals, that can be easily disseminated to others (Brannback, 2003). Case definitions that were discussed previously that are created and transmitted by WHO and to HSFAC team and then disseminated to EDs, JPs and front line public health sectors are a form of changing explicit knowledge that need to be quickly distributed through the network channels.

2. Tacit knowledge: Simply refers to the knowledge in 'people's heads'. They build it through experience, personal learning, and interaction (Brannback, 2003; Gourlay, 2006). This form of knowledge is hard to transfer and requires certain procedures like transferring people through different departments in the organisation or creating an interaction medium through which they can share the knowledge with others (Nonaka & Toyama, 2003). In our case, an example of tacit knowledge is the disease-specific knowledge such as respiratory and infection control knowledge deeply known to subject matter experts.

The 'Shared knowledge base' (SKB) is fundamental in reaching common perception during disease outbreaks. It is the building block for the common understanding of the situational information, events development, and agreement on the approach to the situation in hand. Building this SKB will require a medium that will diffuse *domain-specific knowledge* from those *who know* to those *who need*. In disasters, this also has to happen in a timely manner.

Yet this does not necessarily mean that the SKB should be located in a central location accessible to all parties: the reason being that during the outbreak coordination, a coalition of different agencies is formed (Gerberding, 2003). As discussed above, each one of those agencies has different knowledge requirements, ranging from specific expertise (ED, ICU) to general knowledge (GPs) and to others with no domain knowledge at all (Industrial Response Grid).

Practical SKB characteristics

In analysing the SKB we will use the process view that is explained by Hossain *et al* as, 'the exchange of tacit knowledge among individuals, teams, groups, and communities is critical to the development and sustainability of a knowledge-creating organisation' (Hossain *et al*, 2004). This process-centric approach enables the utilisation of social networks and CNs to create distributed SKB among the community of interest or coalition of organisations (Argyris, 1999; Watson, 2008). We will look at how these networks can be used to create the SKB for both tacit and explicit knowledge.

1. Tacit to explicit knowledge SKB: One example of interpreting tacit knowledge to explicit in the H1N109 coordination discussed above is the informal communication with the industrial response grid, GP

grid, and the Ambulance grid. These groups did not need an in-depth knowledge of the technicalities of the disease characteristics; their knowledge requirement was more of updating their broad understanding of the symptoms, risks, and protection procedures. Hence co-opting domain matter experts (respiratory, infection control ...) to create the information needed and channel it through the information communication structure. As discussed in the communication section, this information was pushed to each group rather than creating a central knowledge base (KB) and relying on their willingness to access and use it. This also enabled tailoring the pushed information to these groups based on their general needs, as well as scheduling the information updates periodically according to each group requirement rather than tying them all to a *one-bit-one-time* scenario. Using the domain matter experts to create the explicit knowledge from their tacit knowledge can be represented in Figure 5, which is adapted from Hossain *et al* (2004). The filled geometric shapes represent tacit knowledge and the letters are the explicit knowledge generated from the tacit.

The generated transferable explicit knowledge will then be 'pushed' along the informal newly established channels to create a shared pool of knowledge within each group of this network, without the overhead of a centralised one for the whole groups. Projecting this process on the communication channels represented in Figure 5 will produce Figure 6. The letters represent the explicit knowledge created from the tacit and then pushed to each group to create the SKB within each group.

2. Explicit SKB: The most vivid representation of explicit knowledge is the Case definition. This is produced by WHO, then passed to Federal level, followed by State then to local ending with departmental level. One of the important aspects about this knowledge is it is field operational and actionable information that has an impact on which patients are to be categorised as 'cases' and therefore admitted to the system and followed up accordingly. Yet one of the challenges in creating a distributed operational SKB is synchronising it between all parties (EDs in this case); otherwise, cases will be incoherent and hence inaccurate. This requires a strong and efficient CN. Theoretically this mandates analysing the network using social network techniques, and then developing the weak ties to strong ones (Granovetter, 1973). This distributed yet synchronised shared knowledge will create a coherent understanding across the distributed nodes of the CN. Figure 6 shows pushing the distributed explicit case definition knowledge to the departments yet without creating a single cognitive entity across the organisation.

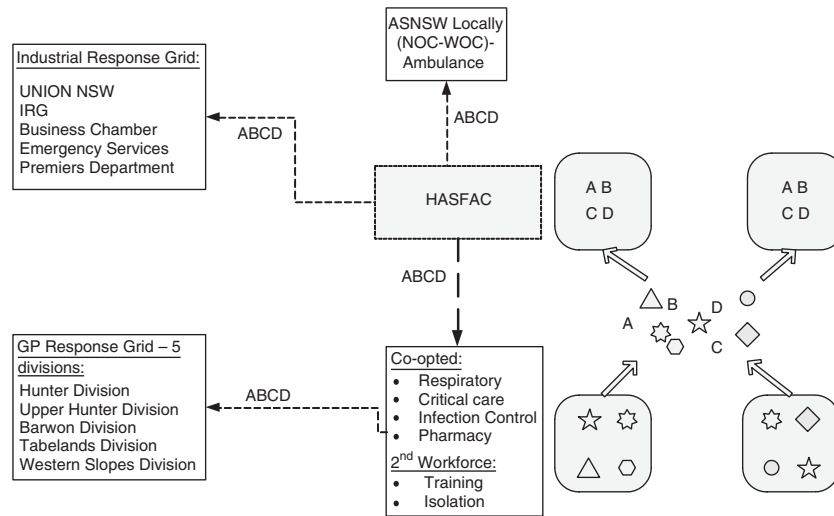


Figure 5 Building explicit knowledge from tacit one and distributing one.

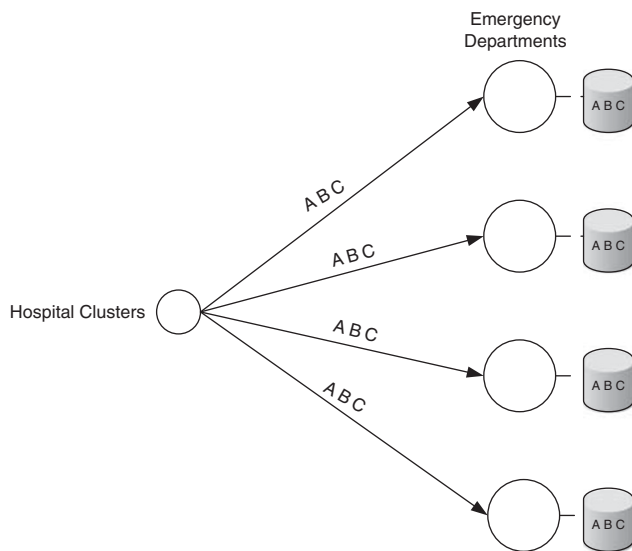


Figure 6 Building distributed SKB across EDs.

Another type of tacit knowledge is the inbound cases – patients confirmed to be infected with the virus. Here for statistics and high-level follow-up the data are being collected from front line departments to central location. This suits the decision makers on area or state level and acts as a central feed channel for follow-up authorities. In disasters, even situational and operational knowledge is essential for local teams, however, there will always be the need to aggregate inbound data for analysis and high level resource management.

SKB IT design criteria

Ensuring a SKB is up to date and correctly distributed and implemented across all parties should be the fruit of such research. Information and Communication Technology

systems (ICT) are a typical medium to build efficient SKB systems and spread network. Below, we will highlight some characteristics of such systems for both case definition and informal outbound communication.

Informal knowledge transfer

These are mostly intended for one-way communication with no or minimal feedback. The ICT system design should take into consideration that it will need to communicate with many different technology systems that are not compatible among each other and will surely contain legacy systems. One can only rightly expect to interact with different corporate systems; some are standard off the shelf and others are built bottom up as per need, while others will be developed on *ad-hoc* basis. The main features of such ICT systems are elaborated in Table 5.

Case definition outbound transfer

These will need to be very reliable and robust. Also, rather than feedback, we will adopt the ‘acknowledgment’ terminology where the EDs will need to acknowledge to the distributing party (HSFAC) receipt and deployment of these data into their systems. Main features of such ICT systems will be as per Table 6.

Inbound cases information

This tacit knowledge will be required by higher authority. Hence, it has to be arranged and formatted in a way that suits their needs. Some of the features of such ICT systems are discussed in Table 7.

Conclusions

The coordination of interventions for disease outbreaks is a complex task and, at the same time, is under-researched resulting in even less understood knowledge

Table 5 Characteristics of the ICT system for informal communication

<i>Feature</i>	<i>Explanation</i>
Redistributable:	Informal information will be expected – and sometimes required – to be redistributed and disseminated down the other party's hierarchy or chain
Push:	After being built, data will be 'pushed' to other parties
Limited feedback:	The SKB should be built with broad audience in mind, however, feedback from such a large audience is expected to be huge and often unnecessary. Hence, limited feedback functionality is provided
Open ability:	The ability to communicate with a wide spectrum of ICT systems correctly and easily
One to many:	Single entity sending to many

Table 6 Characteristics of Case definition communication to EDs

<i>Feature</i>	<i>Explanation</i>
Robustness:	Communications should be both fast and highly reliable
Push:	HSFAC will push the communication across after formatting it in compatible formats with recipients' ICT systems
Compatibility:	Communication will be with limited predetermined recipients (EDs). Since there are limited ICT systems for EDs, then communication format will need to be compatible with these systems to streamline case definition deployment into the ED's systems
Acknowledgment:	After the case definition is deployed into ED's system, an automatic acknowledgment is received by the sender
One to multi:	Limited per-estimated number of recipients

Table 7 ICT features of inbound confirmed cases

<i>Feature</i>	<i>Explanation</i>
Robustness:	Communications should be both fast and highly reliable
Push and Pull:	Being able to get information on request or pushed periodically
Highly compatible:	Data format should be easily, if not automatically, integrated to the data repository system (Data warehouse)
Multi to one:	Information gathered from different locations to end up in a central one

management systems. A good coordination structure is expected to lower infection rates. In this exploratory study, we show the potential use of social network theory to analyse the communication channels implicated in the management of outbreaks. We illustrate this potential by using a particular example of the management of an outbreak of H1N1 by the HNEAHS. A qualitative analysis using network methods to address the complexity of the task, suggests design elements that optimise the level of resource use. In particular, sacrificing the inbound and outbound high degree of centrality by using link aggregations might be

a feasible approach for demanding information dissemination organisations. We also discuss the shared knowledge management characteristics and outline the main ICT system features design considerations.

Limitations and future direction

It is also important to reflect on the data collection approach that we followed for this study. The investigative approach provided us with the first 'insight' into this domain. This approach is useful since no reliable academic data has been collected in this context before.

Further insight is required into the complexity that involves players, characteristics, communication, and the dynamics that affect the processes. This includes the following aspects:

1. When does the initiation point of disease outbreak start and which parties are involved at this stage?
2. What type of agencies are involved at different stages of the outbreak phases?
3. How do the formal and informal relationships evolve during the coordination lifetime?
4. What are the dynamics that affect nodes' (organisations) and links' performance during the outbreak?

Therefore, more qualitative and quantitative data are needed. In a future case, we are planning to arrange follow-up interviews with the players at key positions

during the outbreak management and intervention period. This would assist in capturing rich qualitative data that will then be utilised as the basis for further analysis.

We also aim to collect quantitative data for statistical validation leading to generalisations of the hypotheses generated by this study. Such data will provide a good foundation for structural and statistical analysis of the network. In this phase, we will capture the dynamic behaviour of the network expressed by the creation and loss of links and nodes. Combining qualitative and quantitative data with network analysis techniques, will provide a more powerful understanding of the coordination in outbreaks and creates an opportunity to propose an efficient disease outbreak coordination model based on network theory.

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Appendix

(A) Situation

- Outbreak: How is the outbreak detected?
- What is the information route from the time an infection is detected until containment is successful?
- What are the criteria to categorise a disease spread as being DO. (Cases threshold/are there different thresholds for different disease types?)
- What are the criteria that a certain disease has been contained/'back to normal' situation is declared?

(B) Actors Coordination

- *Inter-organisational*:
 - *Organisations* that coordinate together whenever a DO is declared
 - Name/role (intervention, communication)
 - Jurisdiction (community/local/state/Federal/private/WHO)
 - Contact details
 - Phase of mobilisation (is it called to join)
 - Area of work
 - *Where*: Area/jurisdiction/service covered by each organisation (some organisations might cover geographical area/some might cover professional service/some other might cover information or communication services)
 - *Workflow*: how does involvement start, progress and finish for each organisation?
- *Intra-organisational*: In order to research informal networks: What are specific departments within these

organisations that get involved? Same questions as above.

- *Individuals*: Individuals playing pivotal role in intervention and outbreak management and coordination. Name/contact/position/role before DO/role during DO/communication procedures or protocols
- *Action*: an overview of how the coordination process (communication and intervention) takes place.
- *Is there communication plan/protocol/standards?*
 - Is it predefined?
 - Does it change and how?
 - Are historical data available?
 - How does involvement start, progress and finish for each organisation?

(C) Processes for real-time decision support

- How does the DSS work, inputs/feeds/real-time data/situational information
- How information is added, processed and distributed to relevant parties (who, where, when and how)

(D) Determinants for success coordination/intervention

- How do you measure coordination gaps? (e.g., Are there WHO standards?)
- What are the criteria to determine a successful intervention? (Do you use epidemiological measures, e.g., comparing against historical data, etc. ...)
- Any performance indicators?
- How to measure intervention efficiency (if it is different from success)
- Has any reflective analysis been done to check past and present efficiency of response?

(E) Resource management: Resource optimisation is the direct outcome of the coordination process.

- Generally, what are the resources needed or exchanged during DO?
- How are resources ordered?
- How are they received?
- Do you consider information exchange as a resource?
- Resource deployment: Is it centralised or decentralised?
- How to measure resource efficiency?
- How to measure resource gaps?