Uptake of sensor data in emergency management

by

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Candidate's declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author’s knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

David Hudson Date:

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Abstract

While disasters are becoming larger, more complex and more frequent, traditional emergency management response capacities are not increasing at the same rate. Sensor capabilities could fill this gap by providing improved situational awareness, or intelligence, for emergency managers. Data from sensors is increasing exponentially in quality and quantity while the cost of capturing and processing these data is decreasing. This creates immense opportunities to bring sensor data into emergency management practices.

Unfortunately, not all sensors are created equal. The accuracy, precision, presentation and timeliness of data varies depending on the source, the way the product is structured and who produces it. It is therefore difficult for emergency managers to incorporate sensor data into decision making, particularly when they have not seen the data type before, and do not know where it originated, or how to use.

This thesis researches how data product creators can tailor products to increase the likelihood of their product being incorporated in emergency management decision making. It focuses on the issue of data product uptake, which is inclusion of data products in decision making processes. This issue has been poorly covered in the existing literature.

This thesis synthesises literature from a range of disciplines then designs and conducts three targeted studies to build upon this knowledge. The first study compares four international data systems which use the same data source but make different choices in the design of their products, this then provides examples of the impacts of these design choices. The second study looks at disaster inquiries in Australia to consider how sensor data has been used in decision making in the past, and what lessons have been learnt from these experiences. The third study surveys Australian emergency managers to collect their views on what products they use, trust and what factors lead to that trust.

The results from these studies combine to create a comprehensive collection of design choices available to data product creators. This collection covers not just technical choices like accuracy, but also presentational and data policy choices, to create a more holistic picture of how creators can influence their products. The collection is then presented in a framework which, if applied throughout product development, would be expected to increase uptake of sensor data in emergency management decision making. Design choices and user-oriented design processes are emphasised as a crucially important yet poorly-examined aspect of data uptake in emergency management.

This thesis finds that trust is key to whether emergency managers use a product or not, and that trust is created through a series of design choices which can be grouped into quality, reputation, maturity and data policy.

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List of acronyms and abbreviations

Acronym or abbreviation	Term
24/7	24 hours a day, 7 days a week
AAS	Australian Academy of Science
AATSE	Australian Academy of Technological Sciences and Engineering
ACCA	Automatic Cloud Cover Assessment
ACT	Australian Capital Territory
AFAC	Australasian Fire and Emergency Service Authorities Council
AGDC	Australian Geoscience Data Cube
AIIMS	Australian Inter-Service Incident Management System
ANU	Australian National University
ANZ	Australian/New Zealand
BNHCRC	Bushfire and Natural Hazards Cooperative Research Centre
BoM	Bureau of Meteorology
BPR	Business Process Reengineering
BRDF	Bidirectional Reflectance Distribution Function
BRMM	Bushfire Risk Management Model
CAP	Common Alert Protocol
CAP-AU	Common Alert Protocol – Australia
C-ATBD	Climate Algorithm Theoretical Basis Document
CEM	Comprehensive Emergency Management
CEO	Chief Executive Officer
CEOS	Committee on Earth Observation Satellites
CFA	Country Fire Authority
Ch.	Chapter
Charter	International Charter for Space and Major Disasters
COAG	Council of Australian Governments
CRC	Cooperative Research Centre
CRC-SI	Cooperative Research Centre for Spatial Information
CRED	Centre for Research on the Epidemiology of Disasters
CRESDA	Centre for Resources Satellite Data and Application
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIKW	Data-Information-Knowledge-Wisdom
DLR	German Aerospace Center
EC-JRC	European Commission Joint Research Centre
ECMWF	European Centre for Medium-Range Weather Forecasts
EE	Earth Explorer
EMA	Emergency Management Australia
EM-DAT	Emergency Events Database
EMS-M	Emergency Management Service Mapping
EO	Earth Observation
EOS	Earth Observations from Space
EROS	Earth Resources Observation and Science
ESA	European Space Agency
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FLIR	Forward Looking Infrared Cameras
FOC	Full Operating Capability
GA	Geoscience Australia
GCP	Ground Control Point
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GIS	Geographic Information System
GLIDE	GLobal IDEntifier
GloVis	Global Visualization Viewer
GLS	Global Land Survey
Govt	Government

GPS	Global Positioning System
HPC	High Performance Computing
HTTP	Hyper Text Transfer Protocol
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
ICIMOD	International Centre for Integrated Mountain Development
IOC	Initial Operating Capability
IoT	Internet of Things
IP	Intellectual Property
IPCC	Intergovernmental Panel on Climate Change
IR	Infra-Red
ISO	International Standards Organisation
JPEG	Joint Photographic Expert Group
LBISIS	Location-Based Instant Satellite Image Service
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LPGS	Landsat Product Generation System
N	Number
NASA	National Aeronautics and Space Adminsitration
NBAR	Nadir BRDF Adjusted Reflectance
NCI	National Computational Infrastructure
NDRCC	National Disaster Reduction Centre of China
netCDF	Net Climate Data Format
NGO	Non-Government Organisation
NOAA	National Oceanic and Atmospheric Administration
NSW	New South Wales
NT	Northern Territory
NWS	National Weather Service
OAD	Operational Algorithm Description
OESC	Office of the Emergency Services Commissioner
OGC	Open Geospatial Consortium
OSCAR	Observing Systems Capability Analysis and Review Tool
PAGER	Prompt Assessment of Global Earthquakes for Response system
PDF	Portable Document Format
PPE	Personal Protective Equipment
PPRR	Prevention, Preparedness, Response, Recovery
QA4EO	Quality Assurance Framework for Earth Observation
QLD	Queensland
RADAR	Radio Detection And Ranging
RADI-CAS	Institute of Remote Sensing and Digital Earth in the Chinese Academy of Science
RDF	Resource Description Framework
ROI	Region of Interest
RS	Remote Sensing
SA	South Australia
SD	Standard Deviation
SERTIT	SErvice Régional de Traitement d'Image et de Télédétection Global, International Charter for Space and Major Disasters
SOPs	Standard Operating Procedures
Std Dev.	Standard Deviation
STEREO	Solar TErrestrial RElations Observatory
Tas	Tasmania
TBA	To Be Advised
UK	United Kingdom
UNOSAT	United Nations Operational Satellite Applications Programme
URI	Uniform Resource Identifier
USGS	United States Geological Survey
VGI	Volunteer Geographic Information
VIC	Victoria
WA	Western Australia

WCAG	Web Content Accessibility Guidelines
WELD	Web Enabled Landsat Data
WGS	World Geographic System
WHO	World Health Organisation
WMO	World Meteorological Organisation
XML	eXtensible Markup Language
ZKI	Center for Satellite Based Crisis Information

Glossary

Accuracy—*degree to which information on a map or in a digital database [or remotely sensed image] matches true or accepted values. Accuracy pertains to the quality of data and the number of errors contained in a dataset or map (Open Geospatial Consortium 2013).*

Acquisition—*process of observing an object or feature using a remote sensor (B. A. Harrison and Jupp 1989).*

Adoption— *total amount of usage inclusive of uptake.*

Awareness—*familiarity with a given product or item.*

Crisis—*a serious threat to the basic structures or the fundamental values and norms of a system, which under time pressure and highly uncertain circumstances necessitates making vital decisions (Rosenthal, Charles, and Hart 1989).*

Data—*symbols; discrete, unorganised and unprocessed objective facts or observations that represent properties of objects, events and environments. Data do not convey any specific meaning and are of no use until they are processed into a form relevant to a particular application (Ackoff 1989).*

Dataset—*a collection of data.*

Data Adoption Framework—*a set of tools and or advice on how to target a given data type to a specific audience.*

Data product—*a dataset which has been packaged to maximise the likelihood that it will be useful to a given audience.*

Design choice—*a decision taken by a product creator which influences how a product is received or used.*

Disaster management—*social processes for designing, implementing, and evaluating strategies, policies, and measures that promote and improve disaster preparedness, response, and recovery practices at different organizational and societal levels (Intergovernmental Panel on Climate Change 2012).*

Disaster—*situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance; An unforeseen and often sudden event that causes great damage, destruction and human suffering (Centre for Research on the Epidemiology of Disasters 2012b).*

Earth Observation—*Gathering information about the Earth using Remote Sensing technologies (B. A. Harrison and Jupp 1989).*

Emergency management—*a range of measures to manage risks to communities and the environment. The organisation and management of resources for dealing with all aspects of emergencies. Emergency management involves the plans, structures and arrangements which are established to bring together the normal endeavours of government, voluntary and private agencies in a comprehensive and coordinated way to*

deal with the whole spectrum of emergency needs including prevention, response and recovery (Emergency Management Australia 1998).

***Emergency**—sudden and usually unforeseen event that calls for immediate measures to minimise its adverse consequences (Centre for Research on the Epidemiology of Disasters 2012b).*

***Hazard**— The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (Intergovernmental Panel on Climate Change 2012).*

***Image**—collection of continuous coverage data, usually from sampling at regular, discrete locations (Open Geospatial Consortium 2013).*

***Information**—data that are processed to be useful; contained in descriptions, and answers to questions that begin with such words as who, what, when and how many. The difference between data and information relates to function rather than structure. Information is inferred from data and frequently includes metadata (Ackoff 1989).*

***Interpretation**—process of interpreting the measurable properties of an observed object (that is the converted Remote Sensing observation) in terms of a specific application using a pre-defined structure model (B. A. Harrison and Jupp 1989).*

***Knowledge**—application of data and information; answers how style questions (Ackoff 1989).*

***Map**—two-dimensional visual portrayal of geospatial data, as opposed to the data itself (Open Geospatial Consortium 2013).*

***Measurement**—an observation that results in a numeric quantity. For example, height is both a measurement and observation whereas smell is an observation but not a measurement (Fowler 1997). A measurement usually refers to the measuring device and procedure used to determine the value, such as a sensor or observer, analytical procedure, simulation or other numerical process (B. A. Harrison and Jupp 1989).*

***Metadata**—data that describes other data, such as the co-ordinate framework in space and time for measurement dimensions; documentation of data to enable managers or users to understand, compare and interchange the content of a dataset (Open Geospatial Consortium 2013).*

***Observation**—a self-describing act associated with a discrete time instant or period through which a number, term or other symbol is assigned to a phenomenon. It involves application of a specified 'procedure', such as a sensor, instrument, algorithm or process chain. An observation enables the value of a property of some feature to be estimated (Cox et al. 2010).*

***Precision**—level of measurement and exactness of description of dataset. Measurements may be precise, but not accurate, due to errors in data acquisition or handling (Open Geospatial Consortium 2013).*

Processing—*process of converting Remote Sensing observations to a measurable property of the observed object using a pre-defined measurement model (B. A. Harrison and Jupp 1989).*

Remote sensing—*making measurements of an object using a device that is physically remote from it, such as a camera (B. A. Harrison and Jupp 1989).*

Risk—*Expected losses (of lives, persons injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is likelihood of the hazard plus the consequence of the hazard plus the assets which are exposed (Centre for Research on the Epidemiology of Disasters 2012b; Intergovernmental Panel on Climate Change 2012).*

Sensor—*a device which captures data. Inclusive of Remote Sensing and Earth Observation but not necessarily Earth related (B. A. Harrison and Jupp 1989).*

Sensor Web—*networked collection of sensors that can be remotely read and/or controlled (Open Geospatial Consortium 2013).*

Trust—*the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party (Mayer, Davis, and Schoorman 1995).*

Uptake—*inclusion of a product as evidence within a decision. In the context of this thesis the inclusion of a sensor data product as evidence contributing to emergency management decision making.*

Usage—*the number of times a product or item has been accessed for any purpose. For the purpose of clarity in this thesis usage is not inclusive of uptake.*

Variable—*attribute or physical characteristic of object being observed that is required for end use of the remotely sensed data (B. A. Harrison and Jupp 1989).*

Wisdom—*evaluated understanding (Ackoff 1989).*

Chapter 1: Introduction

1.1 Contextual prologue

On the 7th of February 2009 Australia suffered its worst natural disaster in modern history. With the loss of 173 lives from bushfires across Victoria, this day became known as Black Saturday. Of the many fires which burnt that day the most catastrophic was the Kilmore East fire which resulted in 119 deaths, 1,242 homes destroyed and 125,383 hectares burnt (Country Fire Authority 2012).

Despite the severity of the fires, little data from sensors, such as satellites, planes or smartphones was provided to, or used by, frontline personnel. The testimony in the royal commission which followed highlighted this concern. The Kinglake West Fire Brigade were at the centre of the response to the fire. The Brigade's second lieutenant, Ms Karen Barrow described:

> *"We had no more intelligence than the average resident… I was making uninformed decisions that could have led to further loss of life—both members of the public and crew." (Teague, McLeod, and Pascoe 2010, 84)*

Further, what information was available, from the Country Fire Authority's own surveillance flights and reports, proved inaccessible:

> *"…a liaison officer appointed to the Yarra Ranges MECC was unable to log on to an 'overloaded' CFA computer system. The liaison officer was thus unable to provide information to allow the MECC to 'track the fires and forward plan'." (Teague, McLeod, and Pascoe 2010, 85)*

The result was that *"Between 12:40 and 14:25 no information about the Kilmore East fire was posted to the CFA website"* (Teague, McLeod, and Pascoe 2010, 85). The fire began at 11:45 with the first casualty reported at 17:00 (Teague, McLeod, and Pascoe 2010, 73).

Between the beginning of the fire and the first report of a casualty, three satellites capable of fire mapping passed over the fire ground: Kompsat-2 at 11:54:30, RapidEye-4 at 12:03:30 and Aqua at 15:51:30 (CEOS 2015). The Aqua pass was collected by Geoscience Australia who processed the data into fire hotspots, shown in Figure 1 (Geoscience Australia 2015). The Kompsat-2 data was acquired by the Korean government who provided it to Geoscience Australia after the event (Hudson and Mueller 2009), and the RapidEye-4 satellite did not turn on the camera to image the disaster (Rapideye 2015).

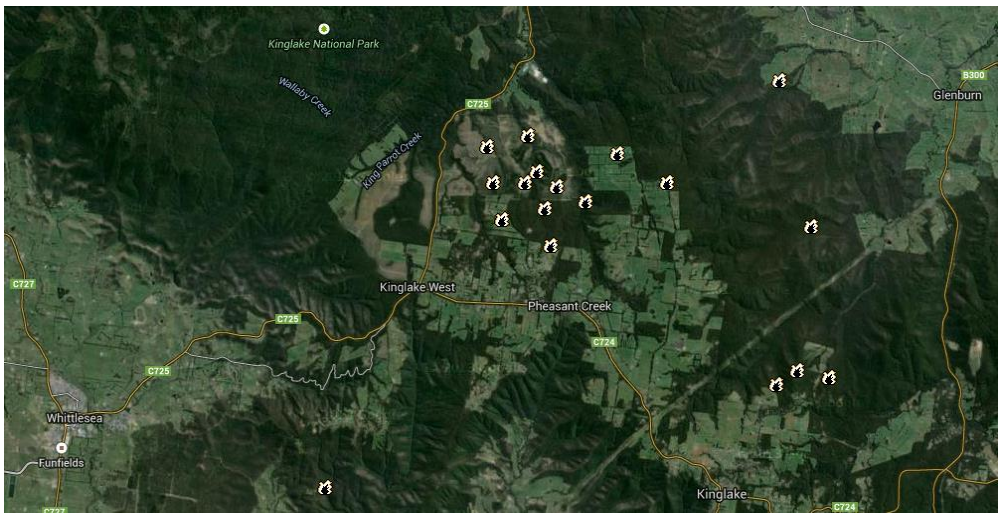


Figure 1: Satellite derived hotspots on the Sentinel hotspots system from the Aqua pass at 15:51:30 on 7 February 2009 in the Kinglake area with Google imagery background (Geoscience Australia 2015).

The data that was captured and published was in high demand. Figure 2 shows a dramatic usage spike from an average usage of around 300,000 hits per day on Geoscience Australia's Sentinel hotspots system, to 5.2 million hits on Black Saturday.

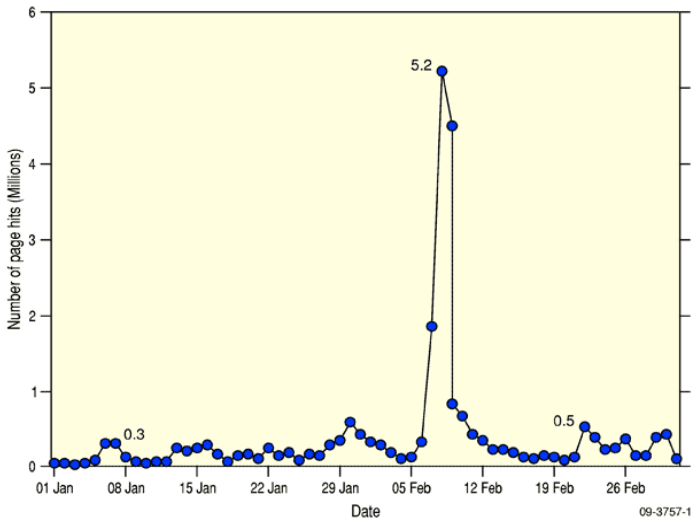


Figure 2: Levels of usage of the Sentinel hotspots website during January and February 2009 (Hudson and Mueller 2009).

Despite these statistics, it remains unclear whether this sensor data had any effect on emergency management decision making. This prologue serves to illustrate the relevance and topicality of this research and raises several questions which set the context for this thesis. Could more have been done to capture and process timely sensor data? Why was the data available not incorporated into emergency management decision making? How can sensor data be retrieved, processed, packaged and distributed to maximise its utility in emergency management decision making?

1.2 The problem statement

In 2010, 385 natural disasters killed more than 297,000 people, affected over 217 million people and caused over $120 billion in economic damage worldwide (Guha-Sapir et al. 2011). With increasing population, urbanisation and climate change the frequency, intensity, spatial extent, duration and complexity of natural and human induced disasters is only set to increase during the 21st century (Intergovernmental Panel on Climate Change 2012; Handmer and Dovers 2013). These increases will have dramatic political, social and economic effects. This makes emergency management capabilities central to global security, prosperity and well-being.

Since the invention of the microprocessor, sensors monitor all aspects of our environment. Sensors, devices designed to capture data, are becoming cheaper and more numerous, at the same time as their capabilities are rapidly growing, enabling more frequent measurements, finer resolution and faster processing. For example, in 2015 the World Meteorological Organisation (WMO) monitors, through sensors, 260 processes on the Earth purely related to the weather and climate (WMO 2015). Separately, it is argued that by 2020 over 50 billion sensing devices are expected to be connected to the Internet (Swan 2012). Due to the number of satellites being launched, the satellite imaging sector alone is expected to more than double within a decade growing from $2.1 billion in 2013 to $5.1 billion by 2023 (North Sky Research 2014). Climate sensor data is projected to grow from less than five petabytes in size in 2010 to over 350 petabytes in 2030 (Overpeck et al. 2011). In 2014, the 10 day weather forecast was as accurate as the 5 day weather forecast was in 1980 in large part due to the addition of satellite measurements (ECMWF 2014). We are arguably witnessing the coming of age of sensor data as the quality, quantity and speed of sensor data increase faster than ever before.

Yet, disasters are becoming more difficult to manage with a frequency and complexity that often overwhelms local and international responses. This thesis contends that using sensor data to map, model and monitor disasters in detail and in real time, can vastly increase the information available about the disaster. This could produce a step-change improvement in emergency management capabilities. Boin et al. (2005) support this contention, arguing that sensor data is one of the few means of reducing complexity of modern disasters. The International Federation of Red Cross and Red Crescent Societies (2005) in their World Disaster Report have gone as far as to say, *"when disaster strikes, access to information is equally important as access to food and water".* Sensor data can provide information on: the detection of hazards; monitoring of hazards or disasters; monitoring of the response; monitoring of the recovery; and modelling the potential impacts of each of these areas. All of these types of information can inform emergency management decision making, reducing complexity and increasing situational awareness.

The challenge is how to channel these large quantities of data into useful products. As it stands, much of the sensor data created about the world is not used. Every second, millions of observations are captured from sensors measuring a range of processes occurring on, above or below the Earth's surface (WMO 2009). Yet much of this data is not requested, never processed or not analysed for use in decision making processes. For example in 2008, Chinese satellite ground reception stations downlinked 369,100 satellite images, however only 13,600 images or 3.7% were ordered by users, with even less reaching the desired decision makers (Zhang 2011). Although these statistics vary across sensor, location and application, it is fair to say that sensor data is not being used to its full potential.

While there is a significant body of research on the technical aspects of processing sensor data, this thesis focuses on a more fundamental puzzle: how can sensor data creator's process and package sensor data so that it will be most useful in decision making, in this case, emergency management decision making.

Like all products, data products can vary greatly and there are innumerable options for how to design a product for a given audience. These 'design choices' are particularly difficult to understand and prioritise for data products, given the relatively new and virtual nature of these products. Every day, new sensors are designed and launched which provide society more information about the world than ever before. Every day, new algorithms are created which allow the calculation of phenomenon in the world to increasingly higher accuracies. Every day, new standards are created to help improve the speed, security, interoperability and consistency of these sensors. When designing a new data product or updating an old product, these multitude of potential improvements or design choices make it difficult to prioritise what to implement first.

While many have claimed that the vast quantities of sensor data at our disposal will improve emergency management decision making (Lorincz et al. 2004; F. Wang and Yuan 2010; Alamdar, Kalantari, and Rajabifard 2014), no literature to date has stepped outside the technical domain and fleshed out how products can be best tailored to improve decision making.

This thesis explores the research question, "How can sensor data products be designed to maximise their uptake in emergency management decision making processes in Australia?" In the context of this thesis, uptake is the active consideration of a sensor data product within decision making. Uptake is a step beyond just usage or awareness, which ensures a focus on the end result – supporting improved decision making during disasters.

1.3 Research aim and questions

The aim of this research is to answer the core research question, "How can sensor data products be designed to maximise their uptake in emergency management decision making processes in Australia?"

To answer the core research question of the thesis the following sub questions are posed:

1. How is sensor data being used in the Australian emergency management sector?
2. What do emergency managers believe are the impediments and opportunities to greater inclusion of sensor data products in emergency management decision making processes?
3. What choices can sensor data product creators make to change how a product is received by emergency managers?
4. What recommendations can be made to sensor data product creators targeting emergency management uptake?

1.4 Key terms used in this thesis

This thesis's scope is limited to *sensor data*. *Sensor data*, for the purpose of this thesis, are raw observations from a device designed to capture data. This includes satellite images, thermal data from planes, depth soundings from a boat, seismic waves from a seismometer and location information from a tweet.

This research maintains a clear distinction between the following key terms *adoption*, *awareness*, *usage* and *uptake*. *Awareness* is the familiarity with a given product or item. *Usage* is the number of times a product or item has been accessed or used. *Uptake* is the inclusion of a product as evidence within a decision. For the purpose of clarity, *usage* is not inclusive of *uptake*. Finally, *adoption* is the total amount of usage inclusive of uptake.

In addition to these key definitions, the Glossary and Terms section in the preliminaries of this thesis lists a collection of definitions. Chapter two further explores terms used in the emergency management and sensor data fields as relevant to this thesis.

1.5 Audience, scope and limitations

The primary audience of this thesis is sensor data acquisition and value adding researchers and practitioners, otherwise known as sensor data product creators. This research is relevant to policy makers, emergency managers and researchers, but its findings really are targeted at people who develop sensor data products.

Government, the private sector, Non-Government Organisations (NGOs) and the public are all affected by and involved in emergency management. The primary audience of this thesis is public sector data acquisition, processing and delivery agencies who aim to assist emergency

management organisations. This is both to manage the scope of the thesis but also because the majority of emergency management practitioners work in the public sector.

This thesis does not focus on technical developments such as new algorithms to increase data accuracy or standards to improve data accessibility because they are well served within the literature. This thesis focuses instead on how to prioritise these developments in order to improve uptake.

This thesis is applicable to all phases of emergency management including prevention, preparedness, response and recovery. Response is explicitly included to ensure timeliness of data delivery is covered by the scope. Furthermore, examples in this thesis are focused on natural disasters but much of the contents is also relevant to man-made disasters but this is not the focus.

A limitation of this research is the limited time and resources related to a PhD program. This thesis is targeted at Australia: a global study would have been relevant but not possible in the timeframe. In addition, trialling the framework created by this research during the development of a sensor data product, and tracking its uptake during a disaster would have been ideal but was not practical given the time and resource limitations.

This thesis assumes that better information makes for better decision making, whether it is instrumental, direct, indirect or in subsequent ways. It is also assumed that sensor data will continue to be captured. The thesis does not consider broader implications of data capture such as civil liberties or satellites failing due to major space weather events.

This thesis takes an integrated and applied perspective and not a pure public policy, administrative, information systems, Earth Observation or emergency management perspective. This research could have engaged more with emergency management doctrine or sensor data interoperability standards but the scope needed to be limited in order to create a manageable project. The research questions require a breadth of coverage across a number of fields, which would be sacrificed by focusing studies more narrowly.

The balance between specificity to an audience and the breadth of fields covered is challenging. This thesis can be viewed as too specific for many audiences, such as public policy and trust academics, but it could just as easily by viewed as too generic by technical experts.

This thesis has a pragmatic, multi-method and data source approach. The thesis does not sit within or follow a singular theoretical or methodological tradition or direction.

1.6 Structure of the thesis

This thesis has eight chapters. The first two chapters are introductory, followed by three chapters which present independent studies. The studies are followed by a discussion which brings together findings from the literature and the three studies. Throughout the thesis findings are highlighted through the use of call out boxes, these findings vary in type and scale but are all relevant to the central argument presented within the thesis. The key findings are then summarised in an uptake framework for practitioners. The final chapter is the conclusion.

The findings of this thesis are highlighted in the section in which they are made using call out boxes. The call out boxes are then summarised at the end of each chapter and in the conclusion. The findings are recorded in this manner to make explicit the conclusions arising during the research, and the sequence in which these conclusions are reached. Even though they are termed 'findings', they include distillations of key points drawn from the literature, including synthesised points, as well as substantive new findings arising from the research undertaken. In Chapter eight, a set of higher level key findings are presented.

Chapter two outlines the key terms, concepts and literature of emergency management, sensor data and the management of a data product as relevant to this thesis. Chapter two then explores the current usage of sensor data within emergency management as described in the literature. This thesis argues that although the existing research is well established there is a gap in identifying whether sensor data is used or has any impact on decision-making and how uptake can be increased.

Chapter three establishes a key term for this thesis: design choices, which refers to the collection of decisions made to create a sensor data product. These creator's choices cover the quality, reputation, data policy and maturity of a sensor data product. Chapter three then uses a comparative case study of one specific and representative type of sensor data system: moderate resolution optical imagery processing systems. This comparison highlights the breadth of design choices available to sensor data product creators and their impact on the usefulness of the products.

The fourth Chapter presents a study on the large body of formal post disaster inquiries in Australia. Chapter four uses word frequency analysis to identify those inquiries which have a significant data focus, then analyses this subset in detail. The analysis looks for examples of sensor data uptake during a disaster, or data concerns raised within the inquiry. This information is synthesised to identify data products used in Australia and common concerns raised by post disaster inquiries.

The fifth Chapter presents a survey which examines how emergency managers choose to use, or not use, a data product. The survey canvases different stakeholder's views across the

data supply chain to identify major concerns with sensor data in disasters, barriers to sensor data in decision making and how sensor data can be optimised to maximise uptake.

Chapter six establishes a common lexicon to describe the design choices available to sensor data product creators and brings together all the evidence collected on each design choice to date.

Chapter seven summarises the findings of the research into a brief, framework for practitioners. This framework aims to help sensor data product creators increase the likelihood of a sensor data product being incorporated in emergency management decision making in Australia.

The final Chapter concludes the thesis, identifying how the thesis research questions have been addressed and identifies the implications of this research. Several future research directions are described.

1.7 Datasets generated for this thesis

This research generated two significant and unique datasets. This research consolidated three lists of Australian disaster inquiries and created the first Australian disaster inquiry database currently used by the Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC). The second dataset was created through a survey titled “Data from sensors in disaster decision making survey”.

The Australian disaster inquiry database developed in this thesis contains 257 inquiries from 1886 to 2013. These inquiries include seven inquiry types: Agency, audit, coronial, governments, independent, parliamentary and royal commission. This database originates from the fusion of three existing lists (Casus Calamitas Consulting 2013; Casus Calamitas Consulting 2012; Eburn and Dovers 2015). Following the addition of more recent inquiries and discussions with experts in the sector the inquiries are processed into a structured, searchable database. Of the 257 inquiries, 183 were acquired digitally, totalling 303 PDF documents. See Chapter four Section 4.3.1 and Appendix A for further details on this dataset.

The ‘data from sensors in disaster decision making’ survey opened on 17 March 2014 for a brief period of testing by key informants, before being distributed throughout the emergency management community. Official invitation emails were sent out during in the first week of May. The survey closed after 84 days on 9 June 2014. In total the survey received 230 responses of which over 90% were Australian. The dataset is a mix of quantitative and qualitative responses, with the core of the results rating the importance of various design choices to emergency managers. See Appendix F for the survey, Appendix G for the raw results and Chapter five for further explanation and analysis of this dataset.

1.8 Publication and validation

During this research, content has been published in various forums. The following Table outlines the publications and presentations created during this thesis and how they relate to the structure of this thesis:

Table 1: Peer reviewed abstracts generated by this thesis mapped to Chapters.

Publication	Ch. 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7	Ch. 8
Hudson, D., 2013. Crowdsourcing, satellites and seismometers: A framework for trusting data in disaster, abstract presented at the World Conference on Disaster Management. Toronto, Canada, 23-26 June 2013	✓	✓	✓					
Eburn. M., Hudson, D. , Cha, I., Dovers, S., Learning from Adversity: What has 75 years of Bushfire Inquiries (1939-2013) Taught Us? Proceedings of the Research Forum at the Bushfire and Natural Hazards CRC & AFAC conference, Wellington, 2 September 2014				✓		✓	✓	

Table 2: Book contributions as part of this thesis mapped to Chapters.

Publication	Ch. 1	Ch. 2	Ch. 3	Ch. 4	Ch. 5	Ch. 6	Ch. 7	Ch. 8
Harrison, B., Jupp, D., Phinn, S., Lewis, M., Hudson, D. Earth Observation Various volumes. In Press	✓	✓	✓					

Chapter 2: Sensor data in emergency management

2.1 Aim and overview of this chapter

This thesis sits at the intersection of three academic fields: emergency management, sensor data and the management of digital products. It brings sensor data into an emergency management application and in doing so, brings theories related to the management of digital products into sensor data.

This Chapter has two objectives. The first is to establish the basics of each of these fields, including by defining key terms and concepts used. The goal is to allow non-disaster or non-sensor data professionals to understand the content presented in this thesis. While a synthesis, this chapter fills a need not covered by existing literature, it provides an explanation and definition of multidisciplinary terms which apply to emergency management, sensor data and the management of digital products. The second objective is to explore the existing literature that engages with these overlapping fields. It concludes that almost no detailed work has been done to date on how to tailor sensor data product for emergency managers, particularly within Australia.

The Chapter is structured as follows:

2.2 Emergency management

Natural and man-made disasters are unexpected shocks which disrupt or overwhelm a system. Understanding and responding to these shocks is the role of disaster managers. In 2010, 385 natural disasters killed more than 297,000 people, affected over 217 million people, and caused over $120 billion in economic damages worldwide (Guha-Sapir et al. 2011). With increasing population, urbanisation and climate change the frequency, intensity, spatial extent, duration and complexity of natural and human induced disasters are set to increase during the 21st century (Handmer and Dovers 2013; Intergovernmental Panel on Climate Change 2012). This increase will have dramatic effects politically, socially and economically. For example, the economic losses from local flooding in Australia in 2040 relative to 2000, are set to increase by 67-514% (Bouwer 2010).

Finding 1: Impacts of natural disasters are a rapidly growing problem (Section 2.2)

Over the last 50 years, the emergency management field has developed to cover all levels of government, the private sector, the non-government sector and the community. This thesis focuses on the use of data which may be acquired by any sector, but is primarily processed and used by emergency managers within Federal, State and Territory government agencies. This section outlines the differences between the terms *hazard, risk, emergency, disaster and crisis*. It then examines the types of disasters commonly considered in emergency management and outlines the main processes through which a disaster is managed.

The modern emergency management field stems from a thesis published in 1942 by Gilbert F. White on the human adjustment of floods. White (1942) argued that various adjustments could be made to limit the impact of a *disaster*, adjustments such as changing the land elevation or land-use. As he explains, *"Floods are 'acts of god,' but flood losses are largely acts of man"* (White 1942, p. 2). This is the foundation upon which modern disaster management is based in that it establishes that disasters are unavoidable events, but their effects are influenced by the way humans respond to them.

Hazard, emergency, disaster and crisis are common terms used every day within society. These terms are often used interchangeably, but in fact they all have specific definitions which allow them to describe various facets of an unexpected event.

> ***Hazard***— *The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources (Intergovernmental Panel on Climate Change 2012);*
>
> ***Emergency***—*Sudden and usually unforeseen event that calls for immediate measures to minimise its adverse consequences*
> *(Centre for Research on the Epidemiology of Disasters 2012a); and*
>
> ***Disaster***—*Situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance; or an unforeseen and often sudden event that causes great damage, destruction and human suffering*
> *(Centre for Research on the Epidemiology of Disasters 2012a).*

A *hazard*, according to the Intergovernmental Panel on Climate Change (IPCC), has potential to harm but may not actually cause any impact at all. An *emergency* is an event which requires immediate action and has caused harm. A *disaster,* on the other hand, is a situation with the ability to *"overwhelm local capacity"*. This means that the difference between an *emergency* and a *disaster* is one of scale. Put another way, a *disaster* only describes events which cause serious disruption (Emergency Management Australia 1998). Finally a *crisis* can be defined as an event where any system has been threatened, such as a financial or personal *crisis*.

According to title 42 of the United States Code Section 5122 a major *disaster* is *"any natural catastrophe ... regardless of cause ... which in the determination of the President causes damage of sufficient severity and magnitude to warrant major disaster assistance" (42 U.S.C. § 5122(2)).* Due to the subjective nature of whether the President determines a *disaster* to be major (or President determines to have overwhelmed local capacity), the physical magnitude or scale of the event is not necessarily the key determinant in defining a *disaster*. A *disaster* can be a minor event in terms of scale or impact, which receives large quantities of media attention causing the minor *emergency* to be treated as a *disaster* (Perry and Quarantelli 2005).

The International Federation of Red Cross and Red Crescent Societies (2013) present an alternative definition whereby a *disaster* is *"(Vulnerability + Hazard) / Capacity"*. This suggests that an *emergency* is when *Vulnerability + Hazard* are less than the capacity to respond. When *Vulnerability + Hazard* are more than the capacity to respond it can be considered a *disaster*.

One aspect of a *hazard* is risk. Risk is commonly defined as likelihood of the *hazard,* plus the consequence of the *hazard,* plus the assets which are exposed (Intergovernmental Panel on Climate Change 2012). Risk can often be the cause of great anxiety due to its conflicting

definitions. This issue was first raised in 1738 when the original ‘Exposition of a new theory on the measurement of risk’ was published. This paper was later republished by Bernoulli in 1954. Risk is often communicated through risk maps which are models which incorporate various datasets to produce a probabilistic map for a given *hazard* type. In this thesis many different styles of disaster related maps are considered including observed maps, risk maps, historical observation maps, risk maps created from historical observations and risk maps created from hazard models.

The management of emergencies, disasters and crises involves the *"social processes for designing, implementing, and evaluating strategies, policies, and measures that promote and improve…preparedness, response, and recovery practices at different organizational and societal levels"* (Intergovernmental Panel on Climate Change 2012, 35).

As an operational field, emergency management has developed frameworks to understand and articulate all areas of operation. The Prevention, Preparedness, Response, Recovery (PPRR) emergency management framework, otherwise known as Comprehensive Emergency Management (CEM), has been the framework for emergency management in Australia for at least the last 20 years (Attorney-General’s Department 2009; Emergency Management Australia 2004; Cronstedt 2002). PPRR was created by the Emergency Preparedness Project of the National Governors' Association in the United States in 1979. Its objective was to create a comprehensive framework to allow all emergency management stakeholders to communicate in a more *"structured approach"* (National Governors’ Association. Emergency Preparedness Project 1979). The PPRR framework articulates all aspects of the emergency management operational lifecycle.

According to the *Emergency Management in Australia Concepts and Principles* manual *(2004, p. 4)* PPRR can be defined as:

- *“prevention/mitigation activities, which seek to eliminate or reduce the impact of hazards themselves and/or to reduce the susceptibility and increase the resilience of the community subject to the impact of those hazards;*
- *preparedness activities, which establish arrangements and plans and provide education and information to prepare the community to deal effectively with such emergencies and disasters as may eventuate;*
- *response activities, which activate preparedness arrangements and plans to put in place effective measures to deal with emergencies and disasters if and when they do occur; and*
- *recovery activities, which assist a community affected by an emergency or disaster in reconstruction of the physical infrastructure and restoration of emotional, social, economic and physical well-being.”*

Figure 3 depicts the four phases and the relative involvement of the main stakeholders in each of these phases.

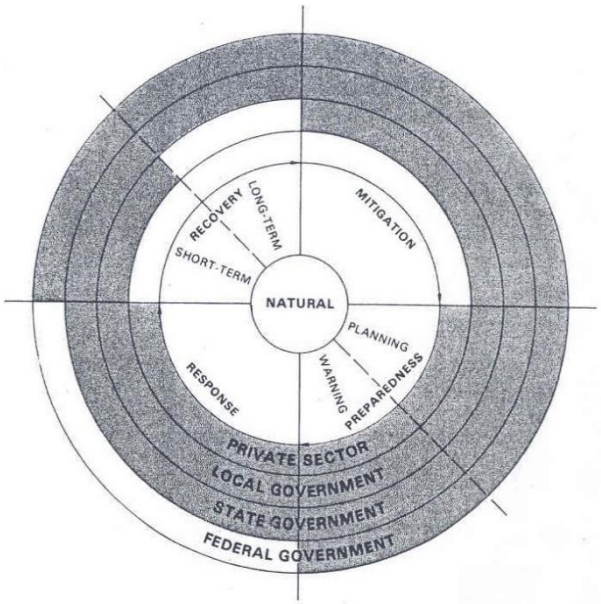


Figure 3: Original Prevention, Preparedness, Response, Recovery emergency management framework. Organisational involvement in natural disaster (National Governors' Association. Emergency Preparedness Project 1979).

Since 1979 the PPRR framework has become the standard emergency management framework in the western world (Cronstedt 2002; Handmer and Dovers 2013). Although PPRR is still the most dominant emergency management framework, particularly in the western world, some aspects have changed overtime. Since 1979, accountability and transparency have become increasingly important in a public policy setting, disasters have become more common and many disasters have overlapped or caused other disasters, hence becoming more complex (Handmer and Dovers 2013). These changes have led to greater involvement throughout the phases of the framework from existing stakeholders, such as government and the private sector, but also new stakeholders such as community organisations and the survivors themselves participating in emergency management using tools such as social media (Goodchild and Glennon 2010).

This greater involvement of stakeholders in all aspects of the framework has led to calls for a more integrated approach to emergency planning and management (Trim 2004; Waugh and Streib 2006). PPRR has also been criticised for its rigid phases which give a sense that one phase must be completed for another to begin (Cronstedt 2002). The US Federal Emergency Management Agency (FEMA) provides a recent and highly relevant example of the evolution of PPRR. FEMA transitioned from having a rigid PPRR, government-centric, approach during Hurricane Katrina in 2005, to a more inclusive survivor-centric model following Hurricane Sandy in 2012 (Jensen 2013). This transition can also be described as *"shared responsibility"*, highlighting the increasing role of the public (Jensen 2013; Waugh and Streib 2006).

Defining the type of disaster is also a challenging exercise. Consider the 2011 Tōhoku earthquake in Japan which generated a tsunami which in turn caused a nuclear accident. Depending on the definition, this event is one complex disaster, two disasters (tsunami and industrial accident) or three disasters (earthquake, tsunami and industrial accident).

Initially established by the World Health Organisation (WHO) and the Belgian Government in 1988, the Centre for Research on the Epidemiology of Disasters (CRED) has built and maintained the world's most well-known database of disasters, the Emergency Events Database or EM-DAT. The database has over 30 types of disasters (Centre for Research on the Epidemiology of Disasters 2012a; Below, Wirtz, and Guha-Sapir 2009). While the database is well respected, it should be noted that there are some differences between the stated classification structure and what is actually stored within the database. These differences are mostly related to disasters without groups, or over usage of the disaster type "Other" which does not appear in the stated classification structure. Furthermore there are still some gaps in the classification such as hail and space weather disasters.

Many countries, including Australia, have developed their own country specific disaster classification structures and databases. These databases have quite different classification structures. The Australian database has only 18 types of disasters, compared with the 30 of EM-DAT. A GLobal IDEntifier or GLIDE number, maintained by the Asian Disaster Reduction Center (ADRC) is now used as a globally common unique number assigned to disaster events to allow comparison between databases.

In order to demonstrate how much sensor data is used in disasters, it is important to develop a comprehensive list of disaster types. This research has fused together several existing disaster type classification structures. The fused classification uses EMDAT as the core, then hail is added to the Sub-sub type Freezing Rain from the Australian EMA classifications and the NOAA classifications of space weather. This list divides disasters into either natural or technological disasters, then into 11 sub-groups ending up with 64 unique disaster types. Table 3 shows this list.

Table 3: EMDAT based disaster classification structure. Adapted using (Centre for Research on the Epidemiology of Disasters 2012a; Below, Wirtz, and Guha-Sapir 2009; Attorney-General's Department 2012; NOAA / NWS Space Weather Prediction Center 2012).

Disaster Generic Group	Disaster Sub-Group	Disaster Main Type	Disaster Sub-Type	Disaster Sub-sub Type
Natural Disaster	Geophysical	Earthquake	Ground Shaking	
			Tsunami	
		Volcano	Volcanic eruption	
		Mass Movement (dry)	Rockfall	
			Avalanche	Snow avalanche
				Debris avalanche
			Landslide	Mudslide
				Lahar
				Debris flow
			Subsidence	Sudden subsidence
				Long-lasting subsidence
	Meteorological	Storm	Tropical Storm	
			Extra-Tropical cyclone (winter storm)	
			Local / Convective Storm	Thunderstorm/Lightening
				Snowstorm/Blizzard
				Sandstorm/Dust storm
				Generic (severe) storm
				Tornado
				Orographic storm (Strong winds)
	Hydrological	Flood	General river flood	
			Flash flood	
			Storm surge/coastal flood	
		Mass Movement (wet)	Rockfall	
		Landslide	Debris flow	
			Debris avalanche	
		Avalanche	Snow avalanche	
			Debris avalanche	
		Subsidence	Sudden subsidence	
			Long-lasting subsidence	
	Climatological	Extreme Temperature	Heat Wave	
			Cold Wave	Frost
			Extreme Winter Conditions	Snow Pressure
				Icing
				Freezing Rain/Hail
				Debris avalanche
		Drought	Drought	
		Wild fire	Forest Fire	

			Land fires (grass, scrub, bush, etc.)	
	Biological	Epidemic	Viral Infectious Diseases	
			Bacterial Infectious Diseases	
			Parasitic Infectious Diseases	
			Fungal Infectious Diseases	
			Prion Infectious Diseases	
		Insect infestation	Grasshopper/Locust/Worms	
		Animal Stampede		
	Extra-terrestrial	Meteorite/asteroid		
		Geomagnetic Storms		
		Solar Radiation Storms		
		Radio Blackouts		
Technological	Complex Disasters			
	Famine			
	Displaced populations			
	Industrial Accident	Chemical Spill		
		Collapse		
		Explosion		
		Fire		
		Poisoning		
		Radiation		
		Oil spill		
		Gas leak		
	Transport Accident	Air		
		Road		
		Rail		
		Water		

This list provides a useful set of definitions for this thesis but it should be noted that alternate definitions do exist. For example, the distinction between natural and technological disasters is not universally recognised. Emergency Response Law of the People's Republic of China states that there are four kinds of disasters: natural disasters; technological disasters; public health disasters; and social safety disasters (China 2007; F. Wang and Yuan 2010).

Multiple official classification structures can also exist within the same country. In an effort to standardise disaster classifications in Australia the Common Alert Protocol or CAP standard was adopted in 2008. This standard was developed to create a national standard for handling of the essential content of alert warning messages. The Australian profile of this standard is referred to as CAP-AU with 176 unique disaster types (Australian Government 2012). The purpose of such a list should be considered. To many stakeholders, 176 categories could be considered overly exhaustive and only useful for scientific or research purposes, but to a specialist, such as a volcanologist, this list does not classify disaster types comprehensively enough.

An example of a simpler data-centric disaster classification structure is the structure used by the German Aerospace Center (DLR); specifically their Center for Satellite Based Crisis Information (ZKI) whose mission is to use satellite data to map emergencies. The DLR-ZKI categorises disasters into: Flood, Earthquake, Wild Fire/Burn Scars, Landslide, Severe Storm/Hurricane, Tsunami, Volcanic Eruption, Technical Accident, Humanitarian Crisis, Exercise and Other. The distinguishing factor to create this twelve type classification is that these disasters require different types of datasets to aid in their emergency response, or put another way they create a different and distinctive spatial disruption. The most common disasters are shown in the DLR-ZKI list but less common disasters are also included. For example, due to a satellite's strength in mapping large areas, volcanic eruptions are included on the list despite being quite rare.

This thesis considers the use of sensors in disasters. As such, a disaster classification structure need only be as specific as will change the type of data required for the management of that disaster. For example, if the same data products are produced for a mudslide compared with a landslide then this difference is not relevant to a data product audience.

Finding 2: Types of disasters are grouped differently depending on the purpose of the classification, the agency, or the author's background (Section 2.2)

2.3 Data and sensor data

This section is based upon Harrison and Jupp (1989), and all unreferenced definitions in this section are from this book. This is because the author of this thesis is a co-author on the new edition of the book Harrison et al. (In Press).

Data is *"discrete, unorganised and unprocessed objective facts or observations that represent properties of objects, events and environments"* (Ackoff 1989). This could be raw telemetry from a satellite's camera, or hand written notes counting the number of cars at an intersection. Many terms are used to describe different groups of data, these groups generally differ by data purpose or collection platform type.

A collection of *data* is generally referred to as a *dataset* or a *data product.* These two terms are used interchangeably by many. While a *dataset* is the core of a *data product* the term product implies considerations such as packaging, marketing and a business model. For this reason these terms are both used in this thesis but with specific meanings – a *dataset* is a collection of data and a *data product* is a dataset which has been packaged to maximise the likelihood that it will be useful to a given audience. This packaging and processing is undertaken by some form of automated, semi-automated or manual system.

Massourian (2005) establishes a method of defining different types of data according to their rate of update, or how often specific data within the dataset is updated from new data. Under this definition there are two major categories: *static* datasets and *dynamic* datasets. *Static datasets* have a slow and steady rate of collection with some being kept up to date, but most are left as static datasets once published. Examples include the road network, contours and general base map information. *Dynamic datasets* are datasets which have high and often continuous data collection rates, where the processing and updating of the dataset can occur in real-time or near real-time. Examples include time series satellite imagery, seismographs, Global Positioning System (GPS) feeds and the weather forecast.

Remote sensing refers to making measurements of an object using a device that is physically remote from it, such as a camera taking a photo. Gathering information about the Earth using *Remote Sensing* technologies is called *Earth Observation* (EO). Inclusive of *Remote Sensing* and *Earth Observation* is sensor data which is data captured using a device or sensor but not necessarily about the Earth (Harrison and Jupp 1989).

Sensor data is collected by a device called a *sensor* which is carried on board a *platform*. There are three general types of platforms which carry sensors:

- space borne—satellites, shuttles, or space stations;
- air borne—manned aircraft, unmanned aerial vehicles, balloons or blimps; and
- ground based—in-situ (seismometers or sonars), mobile devices, or animals (including humans).

For example, the worldwide weather community uses over 65 space borne sensors or satellites, 4000 airborne sensors (3000 aircraft and 1000 upper air stations) and 11000 in-situ sensors (10000 land stations and 1000 ships with sensors) to collect data that informs weather prediction (WMO 2009).

According to Harrison and Jupp (1989), r*esolution* refers to level of detail, *density* refers to the intensity or rate of sampling, and *extent* refers to the overall coverage or area of a dataset. *Extent* relates to the largest object or feature, or range of features, which can be observed, while *resolution* relates to the smallest. *Density* indicates the continuity and frequency of sampling. For a feature to be distinguishable in the data, the *resolution*, *density*, and *extent* of the measurement dimensions of the data set need to be appropriate to the measurable properties of the feature. For a feature to be separable from other features, the *resolution, density* and *extent* must be appropriate to pick up the differences between given features.

Resolutions can also be referred to as sampling dimensions and can include spatial and temporal dimensions for all sensors and spectral and radiometric dimensions for remotely sensed sensors. Each of these resolutions have a specific definition which aligns with resolution, density and extent. Each definition is shown in Table 4.

Table 4: Sampling Dimension in Remote Sensing adapted from Emelyanova et al. (2012).

Scope	Dimension	Characteristic		
		Resolution	**Density**	**Extent**
All sensors	Spatial	Ground area imaged per optical pixel	Number of pixels and lines in image	Area covered by image
	Temporal	Time period over which each image is acquired	Frequency of successive image acquisitions	Total time period for which this imagery is available
Remotely sensed data	Spectral	Width of each wavelength channel	Number of channels detected by sensor	Range of wavelengths covered by all channels
	Radiometric	Smallest change in detected energy that would be represented as a different image brightness level	Number of gradations (grey levels) used to represent full range of radiances that could be detected by sensor	Actual range of radiances detected in each channel

In the past, sensor data products were often static, but with technological advances they are becoming ever more dynamic. Sensors are becoming cheaper and more numerous, at the same time as sensor capabilities are increasing with more frequent measurements, finer resolution and faster processing. One subset of the sensor community is the Internet of Things community which looks at devices connected to the internet, such as smart watches containing sensors like GPS, cameras and microphones, or Wi-Fi (WIreless FIdelity) enabled scales which measure and record our weight. In 2008 the number of devices connected to the internet exceeded the number of people on Earth, and by 2020 there are expected to be over 50 billion devices connected to the Internet (Swan 2012). As one example, figure 4 outlines the projected growth in climate sensor data from less than five petabytes in 2010 to over 350 petabytes in 2030. This increase is due to satellite data and new models for using these data (Overpeck et al. 2011). A more

specific example is the increased accuracy of the weather forecast. In 2014 the 10 day weather forecast was as accurate as the five day weather forecast was in 1980, due in large part to the addition of satellite data to the weather model (ECMWF 2014).

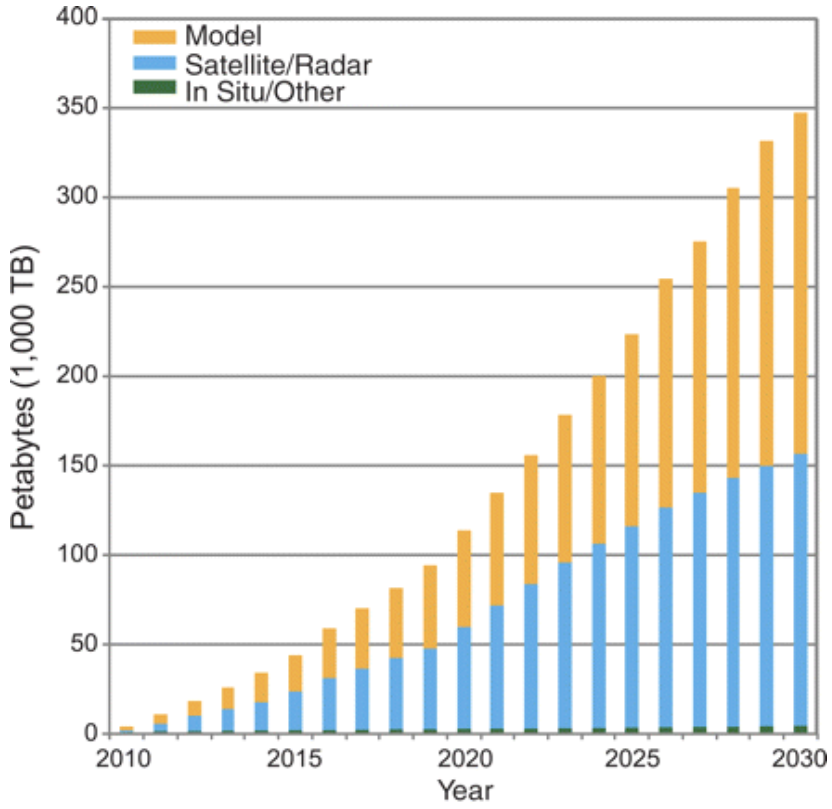


Figure 4: Projected increase in global climate data holdings for climate models, remotely sensed data, and in situ instrumental/proxy data (Overpeck et al. 2011).

Finding 3: Sensor numbers, quality and delivery speed are exponentially growing (Section 2.3)

Different sensors measure different processes for a wide variety of applications. One characterisation of the different applications of sensors is the International Group on Earth Observation's Societal Benefit Areas, which divides different applications of EO sensors into nine key groups: Agriculture, Biodiversity, Climate, Disasters, Ecosystems, Energy, Health, Water, and Weather (GEO 2007). This means that sensor data products have a large variety of users which they must satisfy.

The objective of such applications was best described by Al Gore's 1992 'Digital Earth' vision of a ubiquitous global environmental in which a *"multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced data"* was foretold (Gore 1998). 'Digital Earth' envisioned *"a dynamic framework to share*

information globally and improve our collective understanding of the complex relationships between society and the environment" (Craglia et al. 2012, 18).

Following the definitions of data and discussion of its availability, the process involved in capturing and processing sensor data to make it useable is now described. In the case of sensor data there are three logical stages:

- acquisition—observations are made of the object;
- processing—observed data is modified to represent a property of the object; and
- interpretation—processed data is analysed with reference data for a specific end use or application.

Sensors acquire data in the form of observations. This data is processed to become measurements then interpreted to become variables which reflect real world phenomena. The interrelationships between these terms and their relevance to Remote Sensing are summarised in Table 5. The Table also includes examples to illustrate the process. The first EO example traces the stages involved in detecting potential fire hotspots from sensors that detect energy in visible, near infrared, middle infrared and thermal infrared wavelengths. For the sake of clarity, the second non-EO example provides a day-to-day case study which is a simple analogy to the Earth Observation process.

Table 5: Observations, Measurements and Variables.

Stage	Result	Description	EO Example	Non-EO Example
Acquisition		Using sensors carried on platforms	Remote sensor records radiance of land area	Traffic speed camera photographs speeding vehicle
	Observation	Detect energy from an object or feature of interest	Visible and infrared (middle and thermal) images	Photograph vehicle number plate
Processing		Using pre-defined algorithms and prior knowledge about the sensor and/or platform	Land temperature computed from middle and thermal infrared images	Sharpen photograph to match standard clarity
	Measurement	Represent known properties of feature of interest	Brightness temperature image	Clear licence number of vehicle
Interpretation		Using reference information about feature of interest and measurements	Use visible and near infrared channels to exclude bright, non-fire pixels or cloud	Use registration records to link licence number to owner details
	Variable	Relate directly to feature of interest	Hotspot imagery showing potential locations of active fires	Identification of vehicle owner

The initial observations of most sensors are quantitative, but calibrated relative to a sensor-specific sensitivity range. The processing stage converts the initial observations so that they are comparable with a standard measurement scale and/or other data sources. This initial conversion

is often undertaken by the data distributor, so may not be apparent to many users. Some forms of remotely sensed data, for which metadata and/or appropriate models do not exist, cannot be converted into measurements or variables. These data can only be used as observations. For example, historical imagery with no record of what sensor was used or when and where the image was taken, does not have the required information to convert it into a measurement or variable. Thus, considering the logical stages involved with using sensor data, the ability to relate objects or features on the Earth's surface to data acquired by sensors with suitable specifications for that application rests on two underlying, but interrelated, considerations:

- the intrinsic ability of the variables to be resolved in the type of measurements being made—that is, the accuracy and precision of the sensor; and
- the effectiveness of the models that relate physical processes to these measurements.

These two considerations are important because they mean that not all data is created equal. In fact, a large amount of the data collected from sensors and other means are not able to be interpreted into a usable variable. This distinction is referred to by many terms including images versus scientific observations, but for the purpose of this work 'data' is described as everything and 'observations' are described as data which meets the two criteria listed above.

Finding 4: Not all data is high enough quality to become an observation, variable or product (Section 2.3)

Table 4 looked at acquisition, processing and interpretation. These three stages align with the three key groups of people involved in the data supply chain that is: producers, value adders and users. Producers include people who design, build, install and maintain sensors in addition to those who generate measurements from the raw observations. Value adders are professionals who interpret measurements into variables, in addition to people who tailor measurements and variables for a specific audience. Finally users could include people who conduct analysis on all of these data to generate advice, or people who use this data to inform their own decisions. People and organisations can span one, two or all three of these tasks but generally only focus on one.

2.4 Sensor data for managing disasters

As previously defined, a disaster is an event which overwhelms local capacity. Sensor data is one of the few means of reducing complexity and determining what is happening at any point in time to inform what should be done next (Boin et al. 2005).

Using accurate information to reduce complexity in disasters is not a new idea. Following the 1939 bushfires in Australia, the Stretton royal commission discussed the benefits of accurate information:

> *"The detection and ascertainment of the position of the fire in the forest, however inaccessible that position may be, has the advantage of placing the fire-fighting force in possession of accurate information upon which may be based … plan of disposition of forces to take protective measures at places which are accessible and thus to prevent the unfettered spread of the fire and to protect property which may lie in its path." (Stretton 1939, 30)*

Finding 5: The Stretton Royal Commission in 1939 shows how long Australia has used spatial intelligence to improve emergency management decision making (Section 2.4)

Sensor data is commonly used in emergency management. Table 6 shows peer reviewed examples of sensor data being used for emergency management. The list has been collated by the author and identifies how extensively sensor data can be used within emergency management.

Table 6: Published examples of sensor data in disaster mapped to extended EMDAT typology.

Disaster Generic Group	Disaster Sub-Group	Disaster Main Type	Example of EO data
Natural	Geophysical	Earthquake	(Guo et al. 2010; Wächter et al. 2012)
		Volcano	(Jayaraman, Chandrasekhar, and Rao 1997)
		Mass Movement (dry)	(Kerle and Oppenheimer 2002; Tang and Dai 2010)
	Meteorological	Storm	(Jayaraman, Chandrasekhar, and Rao 1997)
	Hydrological	Flood	(Jayaraman, Chandrasekhar, and Rao 1997)
		Mass Movement (wet)	
		Landslide	(Jayaraman, Chandrasekhar, and Rao 1997)
		Avalanche	
		Subsidence	(Colesanti et al. 2003)
	Climatological	Extreme Temperature	
		Drought	(Jayaraman, Chandrasekhar, and Rao 1997)
		Wild fire	(Voigt et al. 2007)
	Biological	Epidemic	
		Insect infestation	(Jayaraman, Chandrasekhar, and Rao 1997)
		Animal Stampede	
	Extra-terrestrial	Meteorite/asteroid	(Plado and Pesonen 2002)
		Geomagnetic Storms	
		Solar Radiation Storms	
		Radio Blackouts	
Technological	Complex Disasters		(De Longueville et al. 2010)
	Famine		(Thornton et al. 1997)
	Displaced populations		(Giada et al. 2003)
	Industrial Accident	Chemical Spill	
		Collapse	(Wegmuller et al. 2000)
		Explosion	
		Fire	(Chrysoulakis and Cartalis 2003)
		Poisoning	
		Radiation	(Yasunari et al. 2011)
		Oil spill	(Jha, Levy, and Gao 2008)
		Gas leak	(Mcrae 1989)
	Transport Accident	Air	(Kaplan et al. 2005)
		Road	(J. White et al. 2011)
		Rail	(Clark 2004)
		Water	(Raspini et al. 2014)

Table 6 shows that at least 23 of the 34 main disaster types (68%) have published examples of sensor data being used to assist with emergency management. This shows that sensor data are prevalent in the majority of disaster types. Table 6 is limited given it only demonstrates the use of data in given disaster types in the EMDAT typology, and those which are documented within the scientific literature. One example of this limitation is the exclusion of published examples of space weather disasters. For example there are current satellite missions flying for that exact purpose such as the Solar TErrestrial RElations Observatory or STEREO mission which is the third in NASA's Solar Terrestrial Probes program (National Aeronautics and Space Administration 2013).

All of these papers demonstrate the relevance of sensor data in emergency management. The existing literature focuses on data products for a specific disaster or event. None of them consider the broader emergency management context including, whether or how their product may have been used by emergency management decision makers.

Finding 6: Scientific literature has shown that sensor data has been used in at least 68% of disaster types (Section 2.4)

Sensor data can be used for many different purposes in managing a disaster. In Figure 5 Justice et al. (2003) provide a clear example of the diverse applications one type of sensor data, satellite imagery, can have for bushfire management. The figure also illustrates the temporal resolution of different sensor data products, with examples of annual, fortnightly, weekly and daily resolution products.

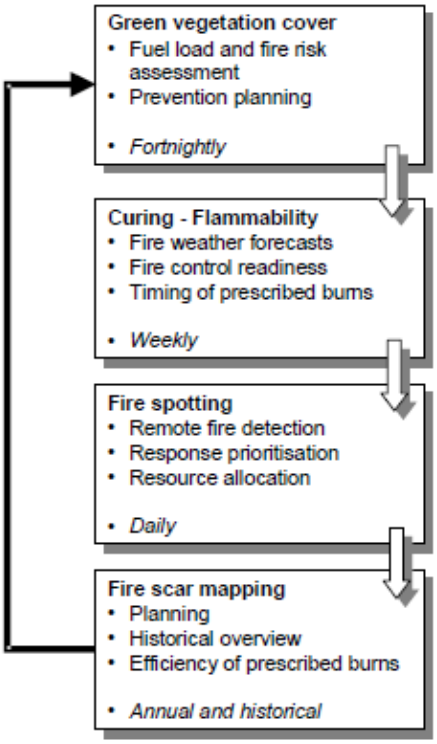


Figure 5: Uses of satellite remotely sensed data for bushfire mitigation and management in Australia (Justice et al. 2003).

As the Figure illustrates, sensor data is used across the majority of disaster types and can be used in all four phases of emergency management. Further examples of the use of sensor data across PPRR phases include: planning (Tolhurst, Shields, and Chong 2008; Kussul et al. 2013), preparedness (Allen and Greenslade 2007; Tang and Dai 2010), response (Lorincz et al. 2004; Laituri and Kodrich 2008) and recovery (Tolhurst 2009). Furthermore, Leidig and Teeuw (2015) explored the use of geoinformation, the majority of which is sourced from sensors, across all four phases of PPRR.

While this literature engages with the emergency management context and there are example of products being tailored to a specific aspect of the cycle, the literature does not address considerations beyond the technical aspects of the product such as data accuracy, algorithms and modelling.

Finding 7: Sensor data can be used in all stages of the emergency management framework: prevention, preparedness, response and recovery (Section 2.4)

There are many facilities which make sensor data products for disasters. One measure of the pervasiveness of sensor data in emergency management is the number of facilities dedicated to that task. The World Meteorological Organisation's (WMO) work on meteorology is relevant to emergency management, particularly cyclones and floods. WMO has 188 members from 183 countries who, although primarily involved in weather, have a strong emergency management data focus (WMO 2009). In addition, there are at least 9 facilities[1] which are fully operational facilities dedicated to using satellite sensors (not including aerial and ground sensors) for the purpose of emergency management.

One would expect that with 9 operational facilities, questions of uptake would have been systematically considered but this is not the case. Some facilities have clear data policies (SERTIT, ZKI, EMS, UNOSAT), some have clear product specifications (ZKI, EMS, NDRCC, UNOSAT) and some have world class product accuracy (SERTIT, ZKI, EMS, UNOSAT). That said, none have explicitly engaged with how their products have been targeted to specifically improve emergency management decision making processes. Of most relevance to this thesis, none of these facilities have specifically considered Australian requirements. These facilities improve disaster preparedness of their specific regions but their impact could be improved by better incorporating their products into emergency management decision making.

Finding 8: Dedicated operational satellite mapping facilities for disasters are common in Europe and Asia (Section 2.4)

Data and emergency management research to date has focused on specific technical or implementation issues such as data quality (Clifford et al. 2008; Yue, Gong, and Di 2010; X. Li et al. 2011), data policy (von der Dunk 1999; R. Harris and Browning 2003), the increase of Earth Observation data as evidence in legal proceedings (Purdy 2006; M. Davis 2012), usage of crowd sourced observations in emergency management (Goodchild and Glennon 2010), designing an architecture for moving data within emergency response (Butterfield, Pearlman, and Vickroy 2008; Gray et al. 2011; Ji and Zhu 2012) and even scientific corrections to remove

[1]

1. France, SErvice Régional de Traitement d'Image et de Télédétection (SERTIT)
2. Germany, German Aerospace Center - Center for Satellite Based Crisis Information (DLR-ZKI)
3. China, Centre for Resources Satellite Data and Application (CRESDA)
4. China, National Disaster Reduction Centre of China (NDRCC)
5. Hindu Kush Himalayas, International Centre for Integrated Mountain Development (ICIMOD) Geoportal
6. Europe, European Commission Joint Research Centre – Institute for the Protection and Security of the Citizen - Copernicus Emergency Management Service
7. Europe, European Space Agency's (ESA) Centre for Earth Observation (also known as the European Space Research Institute or ESRIN) 24 hour watch office
8. Global, UNITAR Operational Satellite Applications Programme (UNOSAT)
9. Global, International Charter for Space and Major Disasters

glint or cloud from moderate resolution optical images (Irish et al. 2006; F. Li et al. 2012; Masek et al. 2006; Zhu and Woodcock 2012). The relevance of these types of research to disaster management must now be analysed.

Sensor data is often said to "help" or "benefit" emergency management with no discussion of how the technology is relevant, or whether a requirement even exists. For example, Masek et al. (2006, p. 68) states that the *"new surface reflectance dataset should help researchers more easily use the GeoCover data for tracking land-cover changes in North America, including fire, forest harvest, urbanization, woody encroachment, and changes in agriculture."* This type of statement suggests a strong emergency management focus and relevance. Unfortunately, this connection to emergency management practices is not fleshed out anywhere else in the paper.

Papers often use a disaster management case study to illustrate their research, while leaving no explanation of the relevance or tailoring of the product for the application. Yue et al. (2010, p. 271) use wildfire *"as an example to help understand metadata tracking during service chaining and to illustrate how metadata tracking can contribute to data provenance."* Gray et al. (2011, p. 8856) use flood response planning to *"demonstrate the use of our semantic sensor web architecture".* Gray et al. (2011, p. 8856) and his sixteen co-authors in fact open the paper with the uncited claim that *"Sensor networks are increasingly deployed to monitor the state of the physical environment around us."* While there are clear examples of increasing numbers of sensors in the world which have been explored earlier in this thesis, this claim implies usage which is not at all clear. These papers imply through the selection of a disaster case study that their new technology or research contribute to emergency management. What is lacking is any exploration of how, or if, this type of research is used in products for emergency management decision making. Yue et al. (2010) and Gray et al. (2011) are strong examples of the disconnect that exists between producers and value adders creating data products and referencing users which appear to have never been asked whether they want or need that product.

Authors sometimes refer to how their technology is relevant to emergency managers, but do not explore or measure this relevance. Butterfield et al. (2008, p. 327) identifies an emergency management requirement which can illustrate a technology, *"Timely dissemination of information to reduce the loss of life and property from natural and human-induced disasters was chosen as an example of one of the desired SoS-level operational capabilities for GEOSS."* Ji and Zhu (2012, p. 314) go a step further by identifying a need for which the technology they are investigating could address, in this case being *"The accurate and real-time urgent relief demand information is almost inaccessible."* These papers identify the problem they attempt to solve but pay little attention to understanding the problem or measuring the impact of the technical solution they hope to impose on, or have welcomed by, emergency managers. While there is no doubt that these papers achieve the technical objectives of their paper, the lack of inclusion, consultation or even consideration of emergency management users reduces the

likelihood of emergency managers trusting the solution and hence lowers the likelihood of the solution being used.

Finding 9: While there is an active and diverse academic debate around improving the technical or implementation issues of using sensor data for emergency management, the utility to emergency managers is often unclear (Section 2.4)

2.5 Management of digital products

Having discussed how technical solutions often do not connect to user experience, it is worth considering whether non-technical literature, outside of the disaster management field, is relevant to targeting data products to a given audience. There is a collection of fields that look at what drives the usage of one data product over another, including marketing, social science and the law. After a review of these fields, three papers were identified in three additional fields which are the most relevant to this topic. These papers are related to data quality, data policy and data presentation. Before covering these fields an understanding of the data supply chain is required.

All types of products progress through a standard lifecycle of development, introduction, growth, maturity and decline (Sudarsan et al. 2005). While in many ways data products can be treated like any type of product, one significant difference is that data products can be completely virtual for their entire lifecycle, meaning they can move through this lifecycle faster than traditional products.

Gartner Hype curves are one of the most common tools within the technology sector which characterise *"the typical progression of an emerging technology from user and media overenthusiasm through a period of disillusionment to an eventual understanding of the technology's relevance and role in a market or domain"* (Linden and Fenn 2003, p.1). The standard Hype curve is shown in Figure 6.

Figure 6: Gartner Hype Curve (Linden and Fenn 2003).

During the positive hype stage an application is shown to be possible. During the negative hype stage, access is created to the application and provides an opportunity to ensure that the users have the relevant skills to use the product. Finally, out towards the plateau of productivity, users have come to trust the application and are using it regularly but not to the amount that the initial hype predicted.

While useful, the hype curve does not show the quality of the product or how the product is used. The most popular measure for the quality of a product is the performance S-curve, shown in Figure 7. This curve shows that the quality or performance of a product starts slowly, rapidly increases after launch, then plateaus once a product matures.

The traditional adoption curve shows market adoption over time, also shown in Figure 7. One significant problem with the *adoption* curve is that it does not separate people using a product for interest's sake from people using a product within their decision making. This distinction is one of the focuses of this thesis. To address this distinction clear definitions of the following terms are required *adoption*, *awareness*, *usage* and *uptake*. *Awareness* is the familiarity with a given product or item. *Usage* is the number of times a product or item has been accessed or used. *Uptake* is the inclusion of a product as evidence within a decision. For the purpose of clarity, *usage* is not inclusive of *uptake*. Finally, a*doption* is the total amount of usage inclusive of uptake.

Examples of each of these terms in an emergency management context further clarify these definitions. *Awareness* is the most basic level where emergency managers have knowledge of a product, such as having heard of social media but not using it. *Usage* is where emergency

managers use a product in their work, such as under laying imagery on a map without analysing the imagery. *Uptake* is the highest level where a product is not only used but the information and knowledge extracted from the product is used to improve emergency management decision making, such as an emergency manager increasing the readiness of their staff based on a weather forecast.

Finding 10: The distinction between awareness, usage and uptake is critical in assessing the effectiveness of a sensor data product (Section 3.2)

The distinction between *uptake* and *usage* is particularly important. In many cases, a dataset, such as bushfire hotspots, may be popular and have high usage metrics but this is different to it actually being used in emergency management decision making. Uptake is far more difficult to measure. As shown in the literature review, many publications refer to their research being useful to emergency managers. In some cases this claim is proven through usage metrics, but as you cannot distinguish between who used it, this metric does not show whether or not their research is helping emergency managers directly in making decisions, or just providing information to the broader community.

The distinction between usage and uptake is particularly important for data products because digital usage can be caused by a machine rather than human usage of a physical product. For example, Hudson and Mueller (2009) celebrated the 5.2 million hits during the Black Saturday fires in Victoria, Australia, as a resounding success of the Sentinel bushfire hotspot system, even though through subsequent investigation they were unable to confirm if the system improved operational decision making. Figure 7 shows an extended version of the Gartner Hype curve, the performance S-curve, the adoption curve and a splitting of the area under the adoption curve into *usage* and *uptake*. Depending on the context *usage* can be defined as inclusive of *uptake* but as this thesis seeks to define and focus on product *uptake, usage* is defined as exclusive of *uptake* to aid in data capture and analysis, particularly in the survey in Chapter five.

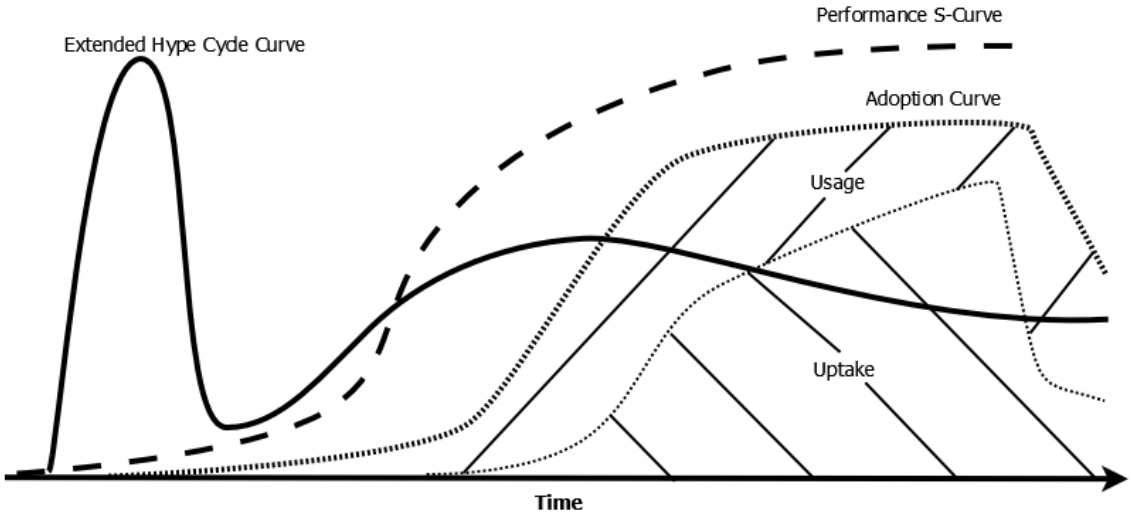


Figure 7: Technology lifecycle models adapted and expanded from Linden and Fenn (2003).

Product awareness, or hype, is large at the beginning of a product's life, then usage takes over before uptake becomes the dominant metric once a product matures.

Turning now to the three fields related to the management of digital products, the first is data quality. With 2300 citations to date, Wang and Strong (1996) is one of the most common and accepted data quality works in recent history. Through the use of intuitive, theoretical and empirical studies Wang and Strong (1996) established a framework for assessing data quality, which is regarded as the foundation paper on the topic. This hierarchical framework is as follows, with the relative importance from most important (1) to least important (15):

Table 7: Wang and Strong (1996) conceptual framework for data quality.

Intrinsic data quality	Believability (1)
	Accuracy (4)
	Objectivity (8)
	Reputation (11)
Contextual data quality	Value-added (2)
	Relevancy (3)
	Timeliness (9)
	Completeness (10)
	Appropriate amount of data (15)
Representational data quality	Interpretability (5)
	Ease of understanding (6)
	Representational consistency (12)
	Concise representation (13)
Accessibility data quality	Accessibility (14)
	Access security (7)

The second relevant topic is data policy. In most cases, emergency management data is supplied to emergency management agencies by other government agencies or the private sector. This means that the data policy and associated conditions used to supply data to the emergency management agencies can affect the trust of those data. For example, if a data provider offers a licence on a bushfire boundary map which only grants access to the map and not the underlying dataset, quality or process by which the map was created, then no assessment of data quality can be made by the emergency manager. This then leads to potential distrust of the dataset by the emergency manager particularly when the emergency manager may be held accountable for the decision based on that data. As described by von der Dunk (2008) about emergency managers using sensor data:

> *"… such activities, normally undertaken with the best of intentions, might be subjected to legal scrutiny and run into legal obstacles or at least raise legal issues which may make potential rescuers think twice before doing the seemingly obvious."*

von der Dunk (2008) specifically addresses the legal issues of using space-derived geospatial information for emergency response. While not often considered by product creators, data policy has been identified as a significant issue for using data within emergency management by authors including von der Dunk (2008), Lowell et al. (2011) and Purdy (2010). von der Dunk (2008) explores the legal issues, including data policy, related to the use of data in

emergency management. He also provides synthesis of the four most common legal issues in the field. As quoted from von der Dunk (2008, p. 22) these are:

1. *"The application of copyrights to geospatial information products relevant for emergency response as far as resulting from satellite activities.*
2. *The international regime applicable to access to data, which result from Remote Sensing, and the application of copyrights.*
3. *Responsibilities and (in particular) liabilities which may result from satellite-based geospatial information operations and activities.*
4. *Security and dual-use issues in the context of using geospatial information for emergency response, to the extent that existing international arrangements may have a bearing on the legal context within which certain emergency services or products might be provided."*

Von der Dunk (2008, p. 22) does not suggest that these four issues are an exhaustive list, but other issues such as privacy would be *"one step further removed from the core aspect of using satellite-generated data for emergency response".*

The third relevant topic is data presentation. Artz and Gil (2007) look at how data can be presented in a manner which drives trust in that data's content. In their paper they focus on the emerging field of the semantic web, developing a list of factors that influence content trust on the internet. While similar, this list adds to those factors discussed in Wang and Strong (1996), by bringing in a focus on modern technologies. Artz and Gil (2007) reduce the risk of divergent definitions of trust between different disciplines such as between social science and computer science through its use of discipline specific definitions. The 19 factors proposed by Artz and Gil (2007) are as follows:

1. *Topic considered*
2. *Context and criticality of the need for information*
3. *Popularity of the resource*
4. *Recognized authority of associations*
5. *Reputation by direct experience*
6. *Referrals by other users*
7. *Association by other trusted resources (e.g., citations)*
8. *Provenance and pedigree*
9. *Expertise of the user*
10. *Perceived bias of source*
11. *Perceived incentive in providing accurate information*
12. *Absence of other alternative resources*
13. *Agreement with other resources*
14. *Precise and specific content*
15. *Likelihood of content being correct given what is known*
16. *Time of creation of the content*
17. *Professional appearance*
18. *Likelihood of deceptive behavior*
19. *Recency of factors under consideration*

This thesis intends to look at how algorithms and packaging changes affect the likelihood that an emergency manager will use a product in a decision. This type of assessment can be referred to as a data adoption framework. There are several examples of data adoption frameworks in non-emergency management fields such as quality measurement for imaging satellites (QA4EO Secretariat 2007) and satellite based habitat monitoring (Vanden Borre et al. 2011). Unfortunately the only example of a data adoption framework for emergency managers is for satellite-derived fire products of resource managers in southern Africa (Trigg and Roy 2005). This paper is restricted only to satellite data, only for fires and only for southern Africa. There is a gap in the understanding of how to target a sensor data product for inclusion in emergency management decision making.

Finding 11: There is a lack of research and understanding into how to optimise sensor data products for emergency managers (Section 2.4)

This lack of research has been identified as a problem within several different fields. Harris and Browning (2003, p. 274) from the data policy field, using two disaster case studies, identify that data discovery is a large problem:

> *"Much of the information required for an earthquake monitoring project was unearthed only after extensive searching, and some could not be located at all."*

Harris and Browning's quote highlights the issue of data discovery but also illustrates problems with usability (extensive searching was required) and relevance (even after 'extensive searching' no relevant information could be located).

In the context of a habitat monitoring study, Vanden Borre et al. (2011, p. 124) goes one step further:

> *"We call upon monitoring experts and remote sensing scientists to enter into a dialogue, discover what can reasonably be expected, define exact user and product requirements, exchange ideas, data and results, set standards for a common validation framework and strive for integration and synergies between remote sensing and field approaches."*

In their paper, aimed at settling divisions between ground based and space based observers, Vanden Borre et al. (2011) highlight many issues including accuracy, relevance, usability, data source and presentation. Goodchild and Glennon (2010, p. 240) expand this to look at wildfires in Santa Barbara. Their paper examines the key issues associated with Volunteer Geographic Information and its potential role in disaster management, finding that:

> *"Research is also needed to interpret what is known about trust and volunteerism in the specific context of crowdsourced geographic information, to devise appropriate mechanisms and institutions for building trust in volunteer sources."*

In this quote the requirement to design data adoption frameworks which build trust in crowd sourced information is established, noting both technical mechanisms and institutional changes are required. Both papers flag that there is a requirement to research how to present products, both to aid discovery and to research what drives an emergency manager to trust one product over another. This thesis explores the design choices at a technical and institutional level which lead to an emergency manager choosing to consider one data product in a decision making process over another.

Finding 12: There is a gap in the literature and a need to research what changes to sensor products will increase the likelihood that an emergency manager will incorporate a sensor product in their decision making (Section 2.4)

2.6 Summary of findings

Finding 1: Impacts of natural disasters are a rapidly growing problem (Section 2.2)
Finding 2: Types of disasters are grouped differently depending on the purpose of the classification, the agency, or the author's background (Section 2.2)
Finding 3: Sensor numbers, quality and delivery speed are exponentially growing (Section 2.3)
Finding 4: Not all data is high enough quality to become an observation, variable or product (Section 2.3)
Finding 5: The Stretton Royal Commission in 1939 shows how long Australia has used spatial intelligence to improve emergency management decision making (Section 2.4)
Finding 6: Scientific literature has shown that sensor data has been used in at least 68% of disaster types (Section 2.4)
Finding 7: Sensor data can be used in all stages of the emergency management framework: prevention, preparedness, response and recovery (Section 2.4)
Finding 8: Dedicated operational satellite mapping facilities for disasters are common in Europe and Asia (Section 2.4)
Finding 9: While there is an active and diverse academic debate around improving the technical or implementation issues of using sensor data for emergency management, the utility to emergency managers is often unclear (Section 2.4)
Finding 10: The distinction between awareness, usage and uptake is critical in assessing the effectiveness of a sensor data product (Section 3.2)
Finding 11: There is a lack of research and understanding into how to optimise sensor data products for emergency managers (Section 2.4)
Finding 12: There is a gap in the literature and a need to research what changes to sensor products will increase the likelihood that an emergency manager will incorporate a sensor product in their decision making (Section 2.4)

Chapter 3: Design choices in developing sensor data products

3.1 Aim and overview of this chapter

Chapter two explored the literature on sensor data in disasters and found a gap in looking at how to optimise data products for an emergency management audience.

The introduction to this thesis hypothesised that there are many options for how to design a data product. The objective of this Chapter is to explore these options, or what this thesis terms design choices. The Chapter will first explore the idea of design choices. It will then conduct a case study examination of four large and reputable data systems which process the same raw ingredient - medium resolution optical sensor data into data products. Despite starting with the same ingredients, the four systems produce very different products. The case study will show that this is a result of the different design choices made in each system. By comparing and contrasting the four systems, the case study highlights key design choices and their impact on the resulting products.

In demonstrating, that system level design choices impact the resulting product and starting to identify what some of these design choices are, this study provides a foundation which future studies build upon.

The Chapter is structured as follows:

3.2 Design choices

Before commencing the case study, it is important to define what is meant by the term 'design choices'. The distinction between awareness, usage and uptake shifts the focus from getting more users aware of sensor data, to increasing the uptake of sensor data products in emergency management decision making. This leads to an important question: Can sensor data products be designed to meet a given consumer's needs or are they simply a function of the sensor? The central hypothesis of this thesis is that sensor data products *can* be designed in order to improve uptake and they are *not* simply a function of the input sensor data.

Design choices are broadly the collection of decisions made to create a sensor data product. These choices cover scientific, technical, legal, aesthetic and business models. All these things will impact how a product is received. As these are decisions made by the product's creators this thesis uses the term 'choices' to make clear that creators choose how their consumers interact with their product. This thesis uses the term '*design choice',* defined as a decision taken by a product producer which influences how a product is received or used.

This is important because if a consumer underestimates a creator's capacity to change or tailor a sensor data product, it limits the potential usage and uptake of the sensor data. If consumers do not influence how they interact with a product then creators will always make the minimal amount of changes to the original sensor data rather than creating a product which meets the needs of a consumer. To do otherwise would likely involve guesswork (as to user needs) and/or inefficiency (in expending unasked-for or unnecessary effort).

Finding 13: Consumers who underestimate a creator's capability to tailor the design choices of a sensor data product dramatically limit the potential usage and uptake of that product (Section 3.3)

There are a large number and variation of design choices and this thesis casts a wide net to capture all possible options. This chapter will start by putting forward some choices that are evident to the author from the literature. The studies in this thesis will then build on this to make a comprehensive list of design choices related to emergency management.

The best known design choices are technical design choices specifically related to the choice of sensor and its specifications. Attributes of a specification are discussed in Section 2.3, including spatial, spectral, radiometric and temporal resolutions to name a few.

Metadata, or data which describes data, is an increasingly important choice. Product creators can choose or choose not to generate, encapsulate and distribute metadata about a product. The provision of metadata increases the interoperability and transparency of a product because it provides the user with evidence of how a product was made, and to what standard

(Moreau et al. 2008). One form of metadata which deserves a specific mention is provenance, which describes how a product is created. Often referred to as lineage, this information can build confidence in a sensor data product. Quality information is another form of information where creators can describe the accuracy and limitations of a given product. All of these forms of metadata are decisions by the creator of the product to disclose how a product was created, its quality, its desired purpose and caveats for its use.

Data policy is an area often overlooked in data product creation, potentially due to its legal nature. Prices are often represented as fixed rather than as a choice made by the creator. Other forms of data policy include licencing, indemnity, liability and distribution rights (Harris and Browning 2003). Data policy, including licence and cost, are choices made by the product creator and can be influenced by the consumer.

Presentation is another area where product creators can make design choices which affect uptake. Traditional areas include file format, data projection and colour schemes. These are all relatively simple changes. Other more complex changes include, the speed which a product is generated after the measurement is taken, otherwise known as timeliness. This is particularly changeable with the advent of High Performance Computing (HPC).

The business model of the product is another choice. The most common business models in sensor data products are processing on demand and rolling generation. Processing on demand involves storing data and generating a product on receipt of a request, such as making a single map of a fire at the request of an emergency manager. Processing on receipt involves generating products on receipt of data regardless of whether there is any relevant information within that data product, for example the rolling or continuous generation of the weather forecast even on days with good weather.

Finding 14: Product creators have a myriad of design choices which can be altered in order to affect the uptake of a product (Section 3.3)

3.3 Medium resolution optical data products case study

3.3.1 Background

This case study focuses on data systems that use medium resolution optical sensor data. Medium resolution optical sensors record visible and infrared wavelengths with a geometric pixel size greater than 10 metres, and less than or equal to 80 metres. They are commonly considered as ‘paddock scale’ or agricultural sensors (Hudson et al. 2011).

Data systems refer to the process through which raw data is processed into data products and distributed. As discussed earlier, Earth Observations are taken which detect energy from an object or feature of interest. These observations are processed using predefined algorithms into measurements which represent known properties of a feature of interest once interpreted beyond raw data becoming a value added product. The measurements are then interpreted through reference information to generate a variable which directly represents a feature of interest. For example, the Landsat-8 satellite images the Earth creating observations, these observations are processed into surface reflectance measurements, and this measurement is then interpreted to generate a burn intensity map of the fire burning within the satellite image.

Improvements in scientific algorithms for the processing and interpretation of satellite imagery means systems are no longer just providing observations, but are now monitoring complex variables, which are now commonly being distributed. This capacity to provide biophysical or geophysical variables that can be interpreted by non-EO specialists represents a key step in the mainstreaming of Earth Observation data (Wulder 1998). Simplified data will in turn allow for rapid growth through the mainstreaming of data extraction from optical data by technical users not just imaging specialists (Sellars et al. 2013).

All medium resolution optical sensor data generation systems are the most prevalent systems in the public sphere. They have been categorised by the author into broad system generations as shown in Table 8. These generations are defined by differences in data processing and distribution characteristics. A timeline for these generations is not appropriate as different countries have moved through the system generations at significantly different speeds hence the generations vary by more than a decade depending on country.

Table 8: System generations for data processing and delivery systems for medium resolution optical data.

Characteristic	First generation	Second generation	Third generation	Fourth and current generation
Distribution medium	Physical medium (CD, DVD, Tape)	Internet	Internet	Internet
Distribution model	User pull	User pull	User pull	User pull and supplier push
Processing method	Manual	Manual and automatic	Automatic	Automatic
Processing model	Once ordered	Once ordered	On receipt	On receipt
Interaction method	Website	Website	Website and web services	Website, web services and mobile apps
Product	Satellite scene	Satellite scene	Satellite scene and pre-processed observations for ROI	Pre-processed observations for ROI
Product type	Measurements	Measurements	Measurements	Measurements and variables

In order to assess what design choices can be made in building systems, this Chapter compares Earth Explorer, the United States system which defined the third generation of delivery systems, with fourth generation systems either recently released or under development from the United States of America, Australia and China.

The United States' Earth Explorer system (http://earthexplorer.usgs.gov/) was launched in January of 2012 by the United States Geological Survey (USGS). USGS describes the system: *"Earth Explorer (EE) is a client/server interface that provides access to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center archive"* (USGS 2009). The objective of providing access is synonymous with an objective to increase usage. This system is a process on receipt system where users can download a variety of different datasets, in the form of satellite scenes, but also some value added products which have been clipped to predetermined boundaries such as countries. The medium resolution optical data, all from the Landsat series, are delivered as pre-processed scenes which can either be downloaded one by one, or through a bulk downloader following a registration and confirmation process.

Also from the United States, the Web Enabled Landsat Data (WELD) system (http://landsat.usgs.gov/WELD.php) was developed by South Dakota State University and the USGS. Developed through a NASA grant, awarded in May 2008, the system was launched in October 2010 (Roy et al. 2010). The system processes imagery from the Landsat satellite series to high accuracy and then generates monthly, seasonal, and annual, composited products of the continental United States. The aim of this system is to make imagery more accessible and thereby increase usage (Roy et al. 2010). The system is currently under redevelopment in order to generate global mosaics and incorporate the Landsat 8 data stream.

Earth Observations from space are the single most important and richest source of environmental information for Australia (AATSE and AAS 2009). Yet, Australia has no satellites and is therefore fully dependent on foreign-owned satellites for supply of this critical information. For this reason, systems which improve the surety of access are a high priority in Australia. Initiated by the Cooperative Research Centre for Spatial Information (CRC-SI) in February 2007 as the Platform for Environmental Modelling Support (PEMS), the now Australian Geoscience Data Cube (AGDC) has had many incarnations. In 2015, following its development by Geoscience Australia, the AGDC is a joint Geoscience Australia and Commonwealth Scientific and Industrial Research Organisation (CSIRO) capability hosted on the National Computational Infrastructure (NCI). While not publically accessible in 2014, the system has already generated a national flood history of Australia back to 1998 (Geoscience Australia 2014). As described in a promotional video for the system, *"The data cube is a way of organising satellite data, it chops the data up into tiles and stacks them up and delivers them through time so we can analyse the data in a way which is not dependent on a particular satellite."* The objective of the system is *"to make better decisions for the Australian government, for the community and for business, for anyone"* (Geoscience Australia 2013b). While there is a scene based version of the product referred to as the Australian Reflectance Grid 25 metre, the AGDC is the archive wide version which shall be analysed in this Chapter (Geoscience Australia 2013a).

The final system compared is China's SatSee system, currently under development in the Institute of Remote Sensing and Digital Earth in the Chinese Academy of Science (RADI-CAS). The system uses quicklook images, compressed JPEG images from the ground station, instead of full uncompressed bands which are the standard in the sector. Quicklooks are commonly used by ground station operators as a form of quality assurance. This system however, uses quicklooks in full resolution, not sampled as is typical, and uses these data as the product to distribute and to generate derived products. This system will offer a subscription service by which users can select a Region of Interest (ROI) and receive updated imagery straight to their computer or mobile device immediately once the satellite images a ROI. The concept is described as Location-Based Instant Satellite Image Service (LBISIS) and the aim of

this system is *"to increase the amount of users from the public and to promote the value of these data"* (Liu et al. 2014, 94).

All of these systems have slightly different objectives but in short they hope to allow less technical users to access more data faster. Earth Explorer is a traditional third generation system from which WELD and AGDC are the natural evolution into fourth generation systems. SatSee, while still fourth generation, is different and potentially quite disruptive as products are pushed to users rather than being accessed by logging in. It may also lead to improvements in timeliness which makes real time decision making possible from this data. SatSee could be attractive to a group of users which have not been reached by traditional systems.

3.3.2 Systems comparison

This section compares the third generation Earth Explorer and three fourth generation systems, the publically available WELD system and the still under development AGDC and the SatSee system. This section firstly presents detailed comparisons of key design choices such as the backend, archival and data management processes, and the front end data and distribution policies. This is followed by an analysis of what impact these design choices have on data accuracy, timeliness and system maturity.

The differences in the data sources and data management design choices of each system show that each is using a slightly different combination of medium resolution optical data to generate the data products. Table 9 displays the detailed archival and data management design choices of each system. Table 9 is derived from the author's technical examination of each system. In order to limit the scope, this Chapter does not consider the derived products (such as Digital Elevation Models) in Earth Explorer.

Table 9: Comparison of archival and data management system design choices.

Characteristic	Earth Explorer	WELD	AGDC	SatSee
Temporal coverage	1972-Present	2003-2012	1986-2013	ROI registration – present (Project commenced 2012, data not retrospective)
Sensors	Landsat 1-8, SIR-C, Orbview-3, EO-1, IKONOS-2, AVHRR and Aerial	Landsat 7	Landsat 5; Landsat 7	Landsat 8; HJ-1A; HJ-1B
Central data archive format	GeoTIFF	1° x 1° tiles NetCDF	1° x 1° tiles GeoTIFF	Full paths in RAW
Local data archive format	N/A	N/A	N/A	Full path in JPEG
Data storage and management	Database + structured file store	Unknown	Database + structured file store	Unknown

Table 10 highlights the data policy and distribution design choices of the four systems. Data distribution shows significant changes with the addition of web services and mobile applications in the fourth generation.

Table 10: Comparison of data policy and distribution system design choices.

Characteristic	Earth Explorer	WELD	AGDC	SatSee
Access/download method	HTTP or Bulk Download Application	HTTP and web services	Web services	HTTP, SatSee downloader or mobile application
Mosaic	Nil, standard satellite scene	Composited mosaics	Composited mosaics	Nil, satellite path clipped to ROI
Data distribution format	GeoTIFF	GeoTIFF, HDF, Single Pixel Time Series and OGC compliant browse imagery	User defined	Custom in JPEG
Data retrievable as time series	No	Yes	Yes	No
Registration required	Yes	No	TBA	Yes
Open access	Yes	Yes	Yes	Yes
Licence	Unlicenced open data policy	Unlicenced open data policy	Creative Commons 3.0 By Attribution	Unlicenced open data policy

Table 11 considers the corrections applied to medium resolution optical source data in order to generate the final product. As previously discussed, SatSee uses full resolution quicklook imagery in compressed JPEG format and so has less corrections applied. This is designed to increase the speed with which it can be delivered to users.

Table 11: Comparison of data accuracy system design choices.

Characteristic	Earth Explorer	WELD	AGDC	SatSee
Geometric correction	LPGS L1T standard GCPs from GLS2000	LPGS L1T standard GCPs from GLS2000	LPGS L1T standard GCPs from GLS2000 and local	Reverse projection
Cloud/cloud shadow flagged	Nil	Yes, ACCA (Irish 2000; Irish et al. 2006)	Yes, ACCA (Irish 2000; Irish et al. 2006) and Fmask (Zhu and Woodcock 2012)	Nil
Atmospheric correction	Yes, Top of atmosphere reflectance LEDAPS (Masek et al. 2006)	Yes, Top of atmosphere reflectance LEDAPS (Masek et al. 2006)	Yes, Top of atmosphere reflectance and BRDF corrected surface reflectance NBAR (F. Li et al. 2010)	Nil
BRDF topographic correction	Nil	Nil	Yes, (F. Li et al. 2012)	Nil
Pixel compositing	All observations are preserved	Best available pixel compositing is applied in side laps	All observations are preserved	All observations are preserved
Projection/Datum		Albers Equal Area WGS84	Latitude/Longitude WGS84	Unprojected

Table 12 compares the timeframes for processing and distribution of each system. The timeliness, or time from acquisition to delivery, is critical for applications such as emergency management but also is perceived as quite important by the public at large (Cooper and Kleinschmidt 1994).

Table 12: Comparison of timeliness system design choices.

Characteristic	Earth Explorer	WELD	AGDC	SatSee
Processing mode	On receipt	Batch	Batch	On receipt
Ephemeris[2]	Precise (Definitive)	Precise (Definitive)	Precise (Definitive)	Predicted
Data push/pull	Pull	Pull	Pull	Push

3.3.3 Analysis

All systems consume at least one of the Landsat satellite series, with Earth Explorer having a more diverse set of data, and SatSee with sensors from China. This means that all systems consume the same type of Landsat data hence an examination of the choices which lead to the differences in products begins to show possible design choices.

The four system's archiving and data management practices are indicative of the users they are targeting. Earth Explorer, WELD and AGDC are similar in that they provide archive data from a central archive. Satsee only provides data from the data of registration, showing its focus on real-time decision making and high timeliness applications.

While there are some differences in user registration policies and use of specific legal licences, all systems hold an open data policy. The selection of an open data policy, user registration or no licence, are all choices which the system's creators made.

Open data is now the norm in the sensor data sector because of its proven impact on usage. Following the unsuccessful commercialisation of the United States Landsat program in 1984, the United States Geological Survey and the National Aeronautics and Space Administration adopted a new open data policy in January 2008 (Wulder and Coops 2014). As a result, data usage has increased dramatically. For the entire year of 2001, 25,000 images were purchased, whereas in 2009, 108,214 scenes per month were downloaded. In 2010, after the final parts of the archive were opened up, downloads reached 233,241 per month, with more than 250,000 images each month in 2012 (Wulder et al. 2012). These downloads took place through two online systems, the USGS Global Visualization Viewer or GloVis and the Earth Explorer system. Following this success, the global Group on Earth Observations released its GEOSS Data Sharing Principles in 2009 making it global best practice for all environmental information to be released under an open data policy (GEO 2009).

[2] Precise ephemeris, or definitive ephemeris in Landsat terminology, takes two days for the final orbit parameters to be received.

Technical advances over recent years have been accompanied by breakthroughs in scientific corrections such as Masek et al. (2006), Irish et al. (2006), Zhu and Woodcock (2012) and Li et al. (2012). These new corrections generate imagery to represent the Earth's surface so accurately that the effects of the atmosphere, terrain shadow, clouds and cloud shadows can be removed or masked. These new corrections are expected to generate observations capable of scientific analysis, which can be stored in a time series to understand changes to the earth over time. These time series can contain not just images from one satellite over time, but images from similar sensors even outside that satellite series. For example with these style of corrected time series of medium resolution optical images built not just out of Landsat 5, Landsat 7 and Landsat 8 data but also including corrected observations from outside the Landsat series of satellites such as Sentinel 2a/b and Gaofen-1/6's Wide Field Imager.

Based on the number of different corrections, accuracy appears to be the main focus for the AGDC, slightly less important for both Earth Explorer and WELD, and not a priority at all for SatSee. Both the WELD and SatSee systems aim to improve their respective data qualities in the future, but this can only go so far for the SatSee system while it is based on compressed data that cannot be corrected without reducing timeliness.

Finding 15: Open data, technological and scientific developments have meant that product creators can now increasingly change and tailor sensor data products (Section 3.3.3)

Timeliness is clearly the focus for SatSee. Timeliness is prioritised over all other design choices with processing on receipt and pushing the data to the users. Data is still processed on receipt by Earth Explorer but downloaded by users. Both WELD and AGDC bulk process and then are downloaded by users.

Historically, the size of satellite datasets has meant that processing and distribution of these 200-400 megabyte per scene datasets has always been a bottleneck. With technological advances allowing for faster processing and easier transmission, this is being addressed. In 1979 when the Australian Landsat Station opened, Australia was acquiring Landsat data before the country had a computer fast enough to process one scene (Leslie 2008). Now thousands of scenes can be processed each day by the modern equivalent to the Australian Landsat Station, Geoscience Australia. The processing model is now capable of processing all data immediately on receipt, rather than processing data one scene at a time, if and when they are ordered. This means data distribution systems can push out the data, rather than just responding to the traditional 'user pull' model. Users now interact with these data systems not just through website portals but through mobile applications and through system-to-system interaction using

web services (Chen et al. 2011). Greater technological capacity also means that products are no longer limited to the traditional satellite geometry defined by the scene in the camera, but can cover the user's Region of Interest (ROI), as demonstrated in the Satsee system, which may be larger or smaller than a standard satellite scene by using pre-processed archives of observations ready for delivery.

As established by Wright (2001), there is an inverse relationship between accuracy and timeliness. Using the timeliness and accuracy information defined above, Figure 8 plots the timeliness compared with accuracy of each system. The scale bars have been removed to avoid readers focusing on a specific value rather than the purpose of these graphs which is to illustrative the inverse relationship.

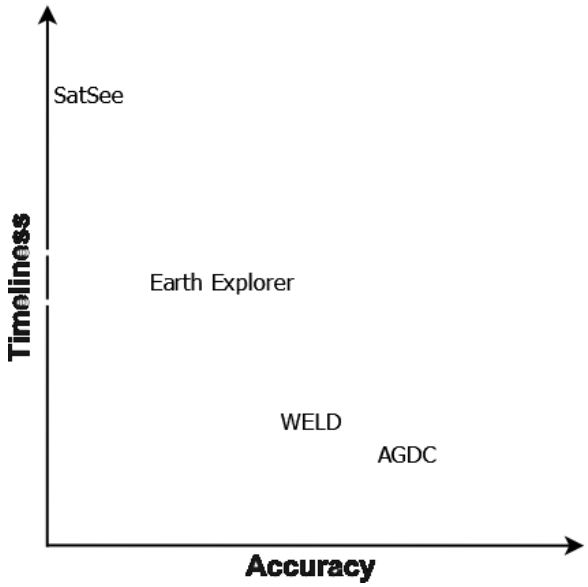


Figure 8: Chart showing the relationship between timeliness of each system and the accuracy of each system.

This graph illustrates that SatSee is the fastest system and AGDC has the highest accuracy products. These were active choices made by those designing these products. The AGDC employs every possible correction including two types of cloud/cloud shadow masking, two types of atmospheric correction, sun sensor geometry corrections and topographic corrections all to maximise accuracy. On the other hand SatSee does not even wait for the entire dataset to be transferred from the ground station, it provides compressed quicklook images with no corrections to maximise timeliness. This relationship not only shows the design choices of accuracy and timeliness but illustrates how changing the design of the system can affect how the product is received. Systems targeted at different stakeholder groups must actively considering how to trade off accuracy and timeliness.

Table 13 presents a comparison of system maturity design choices. System maturity is an independent measure of the completeness of a system. While many different maturity models

exist (such as the NASA technical readiness levels for flight hardware and the computer software industry's Capability Maturity Model Integration) this Chapter uses a system developed by the US National Oceanic and Atmospheric Administration (NOAA).

The NOAA maturity model described in Bates and Privette (2012) assesses the completeness of climate data records and is applicable to this context, as each of the medium resolution optical data archives can be considered a similar style of product to a climate data record. The model has been slightly adapted to apply to data systems rather than just the data product[3]. The author has used Bates and Privette's (2012) methodology, particularly their 1-6 scale maturity model to describe the maturity of the various parts of each system.

Table 13: Comparison of maturity design choices.

Characteristic	Earth Explorer	WELD	AGDC	SatSee
Software Readiness	6, No code changes expected; Stable and reproducible; portable and operationally efficient	4, Some code changes expected	3, Moderate code changes expected	2, Significant code changes expected
Metadata	6, Updated and complete at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets current international standards for dataset	3, Research grade; meets international standards; ISO or FGDC for collection; netCDF for file	3, Research grade; meets international standards; ISO or FGDC for collection; netCDF for file	1, Little or none
Documentation	6, Public C-ATBD and OAD; Multiple peer-reviewed publications on algorithm and product	5, Public C-ATBD, Review version of OAD; Peer-reviewed publications on algorithm and product	4, Public C-ATBD; Draft OAD; Peer reviewed publication on algorithm; paper on product submitted	2, C-ATBD Version 1+; paper on algorithm reviewed
Product Validation	6, Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation; quantified errors	3, Uncertainty estimated for select locations/times	3, Uncertainty estimated for select locations/times	1, Little or None
Public Access	6, Record is publically available for Long-Term	4, Data and source code archived and publicly available; uncertainty estimates	2, Limited data availability to develop familiarity	2, Limited data availability to develop familiarity

[3] Where the model calls for an Operational Algorithm Description (OAD) or Climate Algorithm Theoretical Basis Document (C-ATBD) equivalent documents have been accepted as these terms are specific to the meteorological community.

	archive; Regularly updated	provided; Known issues public		
Utility	6, Used in published applications; may be used by industry; assessments demonstrating positive value	6, Used in published applications; may be used by industry; assessments demonstrating positive value	4, May be used in applications; assessments demonstrating positive value	3, Assessments have demonstrated positive value
Average	6	4.2	3.2	1.8
Min	6	3	2	1

According to Fisher and Kingma (2001) there are three variables that influence the way decision makers use information: information overload, experience levels of the decision-makers and time constraints. These three variables can be considered as design choices related to relevance (too much detail), simplicity (too complex) and timeliness (too slow). These design choices can help product creators determine how to optimise a system to a stakeholder group. Emergency managers must make quick decisions, often in the absence of high quality information. Emergency managers also require systems with high reliability due to the literally 'life and death' nature of decisions such as deployment of response teams or issuing warnings. High reliability means that high maturity and low timeliness is critical to emergency managers. Decision makers and planners require the highest quality information in order to reduce uncertainty and to justify their decisions. Scientists have a diverse range of requirements meaning that customisation is critical so that information is targeted for their specific inquiry. The public, by definition, is the broadest possible user group giving them the broadest possible set of requirements, this often leads to systems targeted at accessibility to enable the broadest possible user base to access the system. These characterisations of different user groups show how different design choices can be tailored to appeal to that group.

Unfortunately, as Chapter two showed, there is a lack of systematic research into optimising data systems for a particular user group. This study shows that there is a large diversity of design choices which create varied products from the same sensor data. This study illustrates that the perception that a data product is purely a function of the input data is not true.

Finding 16: In most cases no system is better than another. They are simply choosing a different collection of design choices to target a different groups of users, therefore different agencies and countries interpret user's needs in different ways. (Section 3.4.3)

3.4 Summary of findings

Finding 13: Consumers who underestimate a creator's capability to tailor the design choices of a sensor data product dramatically limit the potential usage and uptake of that product (Section 3.3)
Finding 14: Product creators have a myriad of design choices which can be altered in order to affect the uptake of a product (Section 3.3)
Finding 15: Open data, technological and scientific developments have meant that product creators can now increasingly change and tailor sensor data products (Section 3.3.3)
Finding 16: In most cases no system is better than another. They are simply choosing a different collection of design choices to target a different groups of users, therefore different agencies and countries interpret user's needs in different ways (Section 3.4.3)

Chapter 4: Data uptake in Australian disaster inquiries

4.1 Aim and overview of this chapter

Chapter three explored how data systems with the same input can make different design choices to create varied products. This was achieved through exploring the main system design choices of moderate resolution optical data delivery systems and how these vary across different groups.

This Chapter focuses on Australia in an effort to gain more specific insights. This Chapter analyses disaster inquiries in Australia to identify examples of any data usage and concerns raised about data.

Following this Chapter, these uptake examples and concerns are added to the findings of previous Chapters and tested through a user survey in Chapter five.

The Chapter is structured as follows:

4.2 Study logic

This Chapter identifies examples of data uptake and data related concerns from Australian disaster inquiries. Post event inquiries scrutinise the management of emergencies and given the critical role of sensor data in emergency management much can be learned from these inquiries relevant to this thesis. Due to the highly specific nature of this study many inquiries contain no relevant information for this thesis, hence a prioritisation is conducted to determine which inquiries warrant further analysis. This prioritisation is achieved through word frequency analysis of data related keywords. In addition to word frequency analysis across all inquiries a targeted classification of all bushfire inquiry recommendations is undertaken. Following this prioritisation and classification, in-depth document analysis collects the data uptake examples and data related concerns.

The objectives of this Chapter are:

- To identify the usage and uptake of data within recent Australian disasters;
- To analyse the relationship between different types of data, uptake and usage; and
- To analyse the circumstance around data usage and/or uptake.

The scope of this Chapter is restricted to official investigations of a disaster by an Australian authority. This scope allows for disasters which did not occur on the Australian mainland such as maritime incidents. Official investigations refer to investigations funded through the public purse or which have been endorsed through subsequent usage within the community. These include royal commissions, parliamentary inquiries, coronial inquests, audit reports, internal agency reviews and independent reviews.

4.3 Study method

4.3.1 Dataset

The dataset upon which this Chapter is based is a collection of Australian disaster inquiries. This includes both post disaster inquiries and reviews of the sector; this distinction is often blurred by the reality that most reviews of the sector are triggered by events. The dataset includes seven inquiry types: Agency, audit, coronial, governments, independent, parliamentary and royal commission. An agency inquiry is an official review by a government agency either into itself or another agency. An audit inquiry is generally a performance audit into a specific agency or aspect of an agency conducted by a Federal or state government audit office. A coroner's inquest is an inquiry to determine the cause of an unexplained, sudden or traumatic death or the cause of a fire conducted by state or territory government coroner’s court. A governments inquiry is a cross government inquiry conducted by the Council of Australian Governments (COAG) or a collection of politicians and public servants. An independent inquiry

is one where the chair is either self-appointed or appointed with autonomy from politicians and government officials. A parliamentary inquiry is an inquiry run by either house of the Federal or State parliaments in Australia. Finally a royal commission is the highest profile form of inquiry in Australia. They are appointed by a Federal or State government and have additional powers such as the power to compel testimony. It is important to note that the status and impact of inquiries is different depending on type, not only do inquiries make recommendations but they can have significant political and policy impact.

An initial list of inquiries was compiled through the fusion of three existing lists (Casus Calamitas Consulting 2013; Casus Calamitas Consulting 2012; Eburn and Dovers 2015) and discussions with experts in the sector, the final dataset contains 257 inquiries from 1886 to 2013. This list was then used to source digital versions of each inquiry from a range of internet sources including the original inquiry website, online parliament archives, historical collections of inquiries accompanying more recent inquiries and other webpages. Following this process 174 inquiries were digitally acquired in a searchable version of the Portable Document Format or PDF, 9 inquiries were acquired in PDF but were not in a searchable form but just photos of the original inquiry. Finally 74 inquiries were not found online. Of the 183 inquiries which were acquired many had multiple volumes and parts, for example the Victorian Black Saturday Royal Commission is 88 separate PDF documents. In addition inquiries can be made up of reports, interim reports, depositions, minutes of meetings and submissions. In this study only interim reports and reports were analysed due to practicality and the limited benefit gained from further exploration. For example in the 1902 Royal Commission into the Mount Kembla Colliery Disaster the commission created 40 documents including depositions and minutes of meetings, only three of these documents are the report. These multiple versions meant that 303 PDF documents covering 183 inquiries of which 174 were taken forward for further analysis. A summary table of these inquiries can be found in Appendix A.

In addition to the above mentioned inquiries which were not in a searchable form, two individual PDFs from inquiries which had multiple documents were not searchable due to unknown technical issues. These included:

- Part 5 of 13 “Part E Term of Reference Three: The Way Forward” from the 2003 Victorian Inquiry into the 2002-2003 Victorian Bushfires; and
- Part 2 of 2 “The Canberra Firestorm: Inquests and Inquiry into Four Deaths and Four Fires between 8 and 18 January Volume 2” from the 2006 Coronial inquest into Canberra bushfires.

While not used in the word frequency analysis, Volume 2 of the Canberra firestorm inquest was used in the document analysis due to the significance of the event.

4.3.2 Word frequency analysis

Once the dataset of 174 inquiries had been collected, it became clear that reading all inquiries would not be possible with the scope of this work due to the 10.2 million words or conservatively 20,000 pages of inquiries. For this reason methods to narrow the scope were explored. This Chapter aims to identify examples of data uptake and concerns related to the use of data, to best achieve this aim diversity is important to ensure that any findings apply to all types of sensor data products and all types of hazards. To ensure a representative sample arbitrary approaches such as working backwards from the most recent or restricting by state, hazard type or inquiry type were not pursued. Instead word frequency analysis of a group of data related keywords was used across all 174 inquiries.

Frequency analysis was run on every word in every report from which the keyword frequencies were then extracted. The word frequency data was extracted from each report using Sobelsoft's PDF Word Count & Frequency Statistics Software.

Twenty keywords were chosen to cover data capture technologies and words generally used in relation to data. Keywords were shortened to make sure different versions of a word were found such as "sens" was used instead of sensing or sensor. The following is a list of the twenty data related keywords with the shortened versions expanded in brackets:

> *Data, information, observation, satellite, plane, aircraft, camera, sens (sensing/sensor), instrument, measure, radar, forecast, predict, project, model, surveillance, reconnaissance, intelligence, map, meteorol (Meteorologist/meteorology)*

The word frequency of each keyword was extracted. Steps were taken to ensure that only words of the correct context were included in the count. Firstly, out of context words were not included such as "planet" and "sensory" under the "plane" and "sensor" keywords. Due to inaccuracies in digitisation many words were stored in long strings rather than individual words. For example "remotesensing" which is in context and included or "andtoimplementappropriatecontrolmeasures" which is out of context and not included. In this case many counts were merged such as the example mentioned above of sensing and sensor. After the data was cleansed manually the keyword counts from the multiple PDF inquiries were merged into a single keyword count for each inquiry. These inquiry wide keywords were then converted into a percentage to the total report's word count to reflect how often a keyword was mentioned and not the length of the inquiry's report. One significant limitation of this method is that by merging multiple volumes from an inquiry a data specific report may be diluted in the statistics. For this reason all PDFs titles were checked for direct relevance to this thesis.

Based on the keyword's percentage of total word count, the top five inquiries with the most frequent use of each of 20 data related keywords were identified. Accounting for the many

inquiries which were flagged multiple times, the initial 174 inquiries were restricted to 61 inquiries which had specific data related content.

4.3.3 Bushfire recommendation classification

In addition to the word frequency approach, a targeted study was conducted classifying the recommendations from bushfire inquiries. This approach restricted the dataset from the original 257 inquiries to a more manageable 87 inquiries relevant to bushfires and bushfire management. Similar to the word frequency analysis 36 inquiries were not readily available and so 51 inquiries were taken forward for further analysis. The reports that are the subject of this review include operational reviews (such as the McLeod Inquiry into the Operational Response to the 2013 Canberra fires), parliamentary inquiries (such as the New South Wales parliament's *Joint Select Committee on Bushfires: Report on the Inquiry into the 2001/2002 Bushfires*) coroner's inquiries, Auditors-General reports on fire management and the operation of fire services, and commissioned inquiries (such as the Malone review of the Queensland Rural Fire Service).

These 51 inquiries produced 1728 recommendations. These recommendations were then coded into categories which after some iteration created 31 categories. These categories then were analysed for similarities and were able to be grouped into six broad themes, three of which align with the PPRR emergency management framework. The coding was then independently verified by a colleague, Michael Eburn. The six themes were:

A – Shared responsibility;

B – Preparedness;

C – Response;

D – Recovery;

E – Fire agency organisation; and

F – Research and technology.

Disagreements on the assigned code were discussed and allowed for iterative development of the final 31 categories.

4.3.4 Document analysis

Document analysis was used to analyse the remaining data relevant 61 inquiries. The document analysis began with checking for why inquiries were flagged in the word frequency analysis. The report was then tested for usage of any additional data related keywords. Finally each report was reviewed in order to identify any further areas of relevance to this thesis.

Through each of these steps any example of data uptake, usage or awareness was recorded. Concerns regarding data were also recorded. If reports were found to not yield content relevant to this thesis they were removed from the analysis.

Finally all collected examples were summarised and grouped when terms were similar. These terms were then analysed for clustering around a particular issue or development of an issue overtime.

4.4 Study results

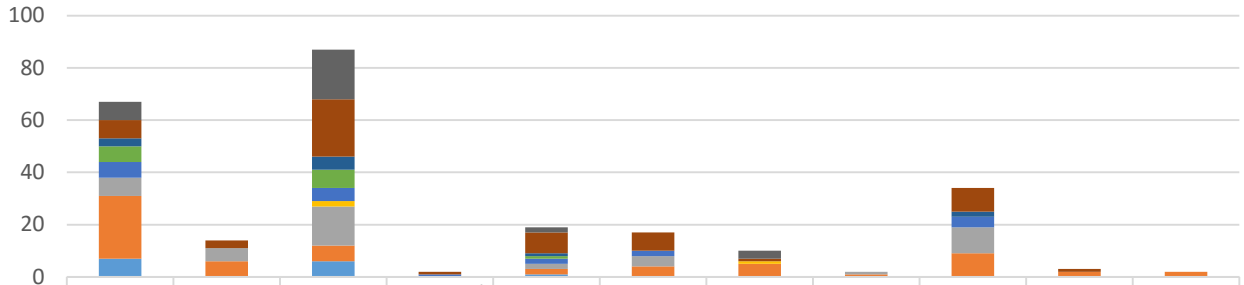
4.4.1 Dataset

As explained in the methods section, 257 Australian disaster inquiries have been analysed in order to produce examples of data update and concerns regarding data in formal disaster inquiries. This dataset yielded many ideas. Although the overall dataset is not the focus of this thesis a basic overview is useful for context.

Of the 257 disaster inquiries in Australia 61 are independent, 55 are parliamentary, 43 are audits, 40 are agency, 28 are coronial, 22 are royal commissions and 7 are governments. By region the Federal government has the most inquiries with 60 inquiries closely followed by Victoria with 59 inquiries.

As shown in Figure 9, the main types of hazards which generate inquiries in Australia are bushfires with 87 inquiries, all hazards (disaster type ambivalent) with 67 inquiries and technical accidents with 34 inquiries. Of the bushfire inquiries 41, or 47% of inquiries, are from the Victorian and West Australian governments which indicates the strong history of bushfires which cause losses in those states. All hazard inquiries seem to be a Federal government focus with 24, or 36% of all hazard inquiries, coming from the Federal government.

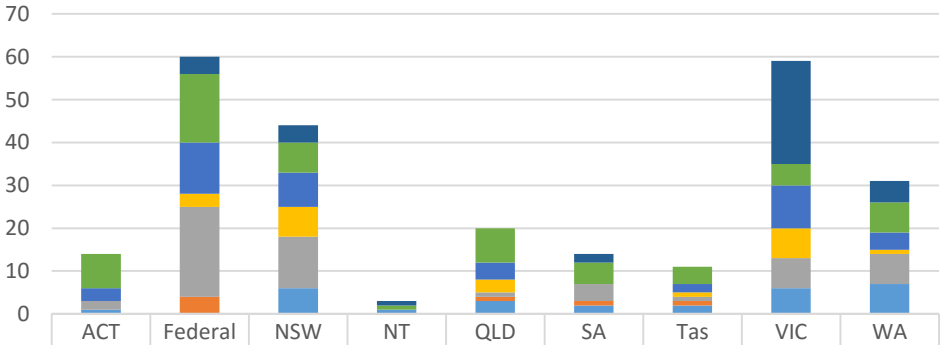
States and Territories also have different exposure to different types of hazards. A simple example is the ACT has never had a maritime, oil spill or tsunami inquiry because it is a landlocked Territory (excluding discussions of Jervis Bay). One commonly held view within the emergency management community is that Queensland is the disaster state due to being impacted by a wide range of hazards including: fires, floods, cyclones, earthquakes and landslides. As shown in Figure 9 this view is not reflected in the inquiry dataset. Queensland only has had 20 inquiries, substantially less than Victoria, New South Wales and Western Australia.



	All hazard	Biological	Bushfire	Cyclone/ windstorm	Fire	Flood	Maritime	Oil Spill	Technical accident	Terrorism	Tsunami
WA	7		19		2		3				
VIC	7	3	22	1	8	7	1		9	1	
Tas	3		5		1				2		
SA	6		7		1						
QLD	6		5	1	2	2			4		
NT			2				1				
NSW	7	5	15		2	4		1	10		
Federal	24	6	6		2	4	5	1	9	2	2
ACT	7		6		1						

Figure 9: Number of disaster inquiries by jurisdiction and hazard type.

This dataset is of the number of inquiries and not number of disasters. This distinction is important because there are numerous occasions where multiple inquiries are called to address the same hazard. For example the 2003 Canberra bushfires had four separate inquiries: the 2003 ACT independent inquiry into the operational response, the 2003 ACT independent review into recovery, the 2005 COAG inquiry into Bushfire Mitigation and Management and finally the 2006 coronial inquest.



	ACT	Federal	NSW	NT	QLD	SA	Tas	VIC	WA
Agency		4	4	1		2		24	5
Independent	8	16	7	1	8	5	4	5	7
Audit	3	12	8		4		2	10	4
Royal Commission		3	7		3		1	7	1
Parliamentary	2	21	12		1	4	1	7	7
Government(s)		4			1	1	1		
Coronial	1		6	1	3	2	2	6	7

Figure 10: Number of disaster inquiries by jurisdiction and inquiry type.

Inquiry statistics are affected by a jurisdiction's culture. Victoria's position as the most inquiry common state may not be accurate as the 24 of Victoria's inquiries are agency inquiries which may be more a measure of Victoria's ability to release information on the internet rather than a prevalence of inquiries. Further evidence to this is that NSW, a larger state in population terms, only has four agency inquiries making it unclear whether Victoria is the inquiry state or the state of more open government.

This dataset is definitely worthy of further study but for the purpose of this Chapter provides useful context into the frequency and diversity of disaster inquiries in Australia.

4.4.2 Word frequency analysis

As discussed above, of the original 257 inquiries 174 were run through word frequency analysis. These frequencies were converted into a percentage of the total word count in order to reflect the amount a topic was discussed and not the size of the report. Of the 10.2 million words analysed in the 174 inquiries, 37 thousand or 0.37% were flagged as data related keywords. Appendix C summarises the 61 inquiries which were in at least one of the top five most frequently mentioned data-related keyword.

In addition to sorting out the most frequently mentioned keywords in an inquiry, the accumulative measure of how often all twenty of these data related keywords are in each inquiry. For example, data related keywords are most common in governments inquiries with 0.72% of content, second is audits with 0.6% and third is agency with 0.59%, in last place are royal commissions with 0.12% of content being data related keywords. This suggests that the lower profile style of inquiry have the most data related discussion and by extension potentially technical discussions in general. This is logical due to the tendency to adopt adversarial techniques in larger inquiry types such as royal commissions and audits. These inquiry types are chaired by former judges and assisted by lawyers who are trained to be adversarial. The adoption of a legal mode of inquiry may derive more from custom and practice than inquiry requirements (Pascoe 2010; McGowan 2012). This means that the most high profile and political inquiry type, the royal commission, is least likely to consider data related topics and potentially technical discussions in general. The more political an inquiry, the less technical the content of the inquiry.

Finding 17: The more political the structure of an inquiry the less technical the content of the inquiry. (Section 4.4.2)

4.4.3 Bushfire recommendation classification

An overview of the 1728 classified recommendations from the 51 bushfire and bushfire management inquiries can be found in Table 14.

Table 14: Summary results categorising 1728 recommendations from 51 Australian bushfires and bushfire management inquiries between 1939-2013 including percent of each recommendation type and for the last several decades.

Topic	Subtopic	# recs ('39-13)	% total recs ('39-13)	% recs ('90-'99)	% recs ('00-'09)	% recs ('10-13)	Description
Preparedness	Building codes, land use planning and refuges	82	4.7%	6.8%	5.1%	4.1%	Building codes/building design/bunkers/building maintenance/land use planning/refuges/safer places
	Electricity infrastructure	29	1.7%	0.0%	1.1%	1.7%	Electricity infrastructure/electrical authorities
	Fire bans and weather warnings	8	0.5%	0.0%	0.0%	0.3%	Fire bans/fire danger periods/restricting actions in fire danger periods/fire weather warnings
	Hazard reduction burns	71	4.1%	0.0%	4.4%	4.5%	Hazard reduction burns public/private/roadside
	Pre fire season preparation	115	6.7%	0.0%	7.3%	4.2%	Pre fire season preparation (other than hazard reduction burns) including maintaining fire trails preparing/prepositioning equipment, checking and installing gear, clearing vegetation for trail access
Response	Access to fire ground	19	1.1%	0.0%	1.1%	1.6%	Road blocks, access fire ground (residents/others)
	Access to water	13	0.8%	0.0%	0.7%	0.5%	Access to water
	Community warnings and communication.	90	5.2%	2.3%	4.9%	7.2%	Community warnings and communication.
	Cooperation between emergency services	59	3.4%	0.0%	3.3%	4.5%	Cooperation between emergency services
	Emergency powers	9	0.5%	0.0%	0.1%	0.8%	Emergency powers (Commandeering assets, declaring state of emergency, requiring people to assist)
	Evacuation and shelters	25	1.4%	2.3%	1.2%	1.9%	Evacuation/Stay or go/shelter in place
	Fire ground and interagency communication	43	2.5%	4.5%	3.1%	2.0%	Fire ground and interagency communication
	Incident Management Teams	92	5.3%	4.5%	4.5%	8.1%	Incident Management Teams (Performance/ membership)
	Incorporate local knowledge	17	1.0%	0.0%	0.8%	1.6%	Incorporate local knowledge
	Role of police	9	0.5%	2.3%	0.1%	1.1%	Role of police
Recovery	Insurance and legal liability	25	1.4%	0.0%	2.4%	0.2%	Insurance/Compensation/legal liability
	Relief and recovery	32	1.9%	0.0%	2.2%	1.9%	Relief and recovery
Research and technology	Assets and technology	106	6.1%	4.5%	6.2%	6.1%	Assets and technology to be deployed in firefighting - tankers, aircraft, PPE
	Mapping and data quality	53	3.1%	0.0%	3.4%	3.3%	GIS/Mapping/Data related topic for future sorting
	Research	56	3.2%	0.0%	4.2%	1.3%	Research
Shared responsibility	Community education and preparedness	103	6.0%	4.5%	7.5%	4.4%	Community education/engagement/preparedness
	Inquiry, audit and after action review	76	4.4%	6.8%	5.5%	4.1%	Inquiry, audit and after action review
	Offences	9	0.5%	0.0%	0.1%	0.2%	Law enforcement/offences
	Personal responsibility	14	0.8%	0.0%	0.5%	0.8%	Personal responsibility
	Role of Commonwealth Government	16	0.9%	0.0%	0.9%	0.3%	Role of Commonwealth and Cth agencies (including BoM)
	Role of Local Government	47	2.7%	0.0%	2.2%	2.3%	Role of Local Government
	Whole of government response/State government responsibility	51	3.0%	4.5%	1.8%	3.8%	Whole of Government response/State government responsibility
Fire agency organisation	Doctrine, plans, standards and legislative reform	152	8.8%	11.4%	9.2%	9.9%	Doctrine, counter disaster or emergency plans and standards, content of AIIMS, recommendations for legislative reform
	Fire agency organisation, management and authority	157	9.1%	38.6%	5.5%	10.8%	Fire agency organisation/management/funding/role/authority
	OH&S	33	1.9%	0.0%	3.1%	1.1%	OHS
	Training, skills and behaviours	117	6.8%	6.8%	7.5%	5.6%	Training, Skills and behaviours; paid and volunteer
	Total number recommendations	1728	639	1728	44	849	

Table 14 above shows the number of recommendations from 51 bushfire inquiries in each of the 31 categories identified by the researchers. In addition, the percent of each recommendation type has been calculated which gives a measure of how inquiries have focused on this topic in relation to other topics. This percentage has also been calculated for the last several decades to give an indication of the trend of certain topics. For example, community warnings and communication are becoming more common with 2.3% of recommendations on the topic between 1990 and 1999, 4.9% of recommendations between 2000 and 2009 and 7.2% of recommendations between 2010 and 2013.

Finding 18: Data quality has been a minor topic in Australian bushfire inquiries with only 53 or 3.1% of the 1728 recommendations made between 1939 and 2013 related to mapping or data quality. (Section 4.4.3)

Figure 11 continues with this analysis technique showing how topics have gone in and out of fashion as a topic of interest for post event inquiries. Fire bans and weather warnings were important topics in the 1960s, less so in the 1970s then went silent until 2010 where they have been mentioned several times since. Mapping and data quality were not an issue until the mid-1980s, they became very relevant in the early 2000s after which they declined. Since 2008 they have shown a steady rise as a re-emerging issue.

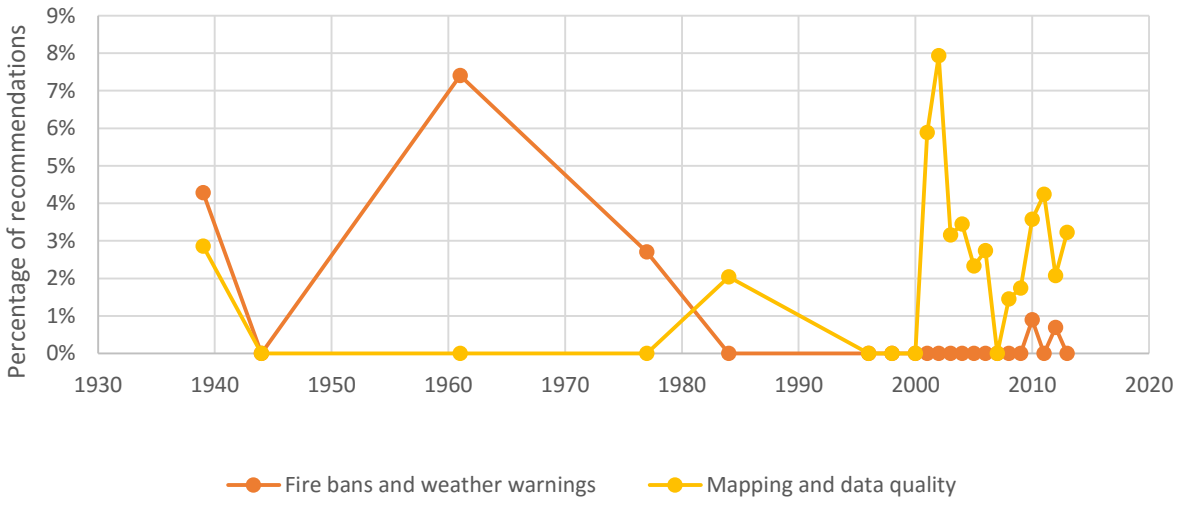


Figure 11: Percent of Australian bushfire inquiry recommendations overtime for the following topics: Building codes/land use planning/refuges, fire bans/weather warnings, insurance/legal liability and mapping/data quality.

Figure 12 shows that different types of inquiries have tended to have different foci. Agency and independent inquiries are more response focused, audits focus on shared responsibility whilst parliamentary inquiries and royal commissions focus on preparedness.

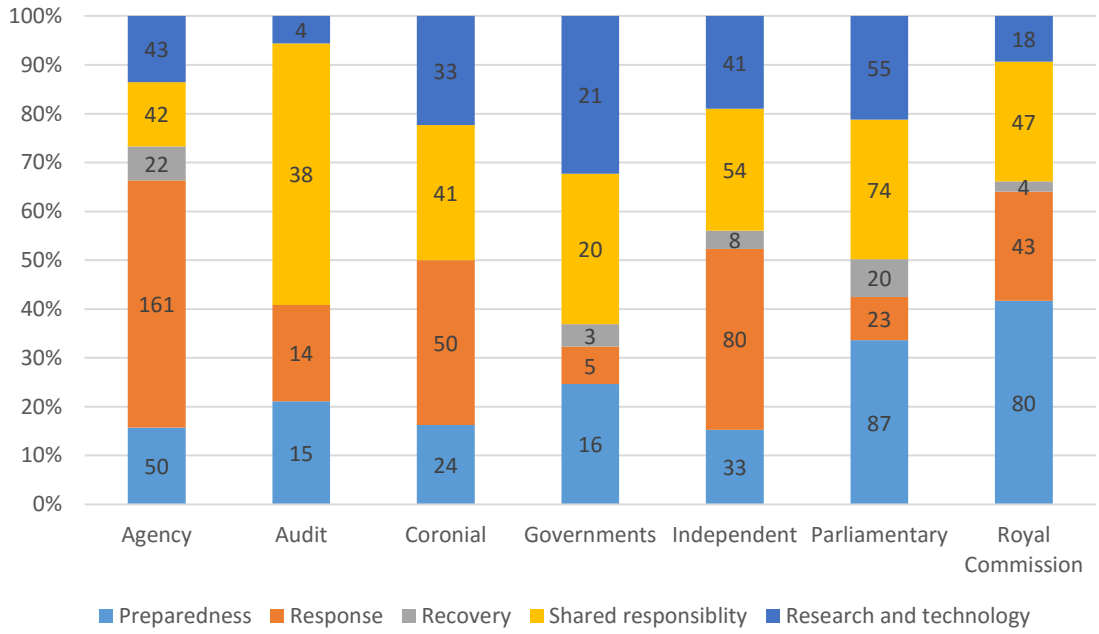


Figure 12: Classified bushfire recommendations across subject categories.

4.4.4 Document analysis

Of these 174 inquiries analysed in the word frequency analysis, the top five inquiries with the most frequent use of each of the twenty data related keywords were identified. This could have led to 100 inquiries but due to the fact that one data related discussion is likely to use more than one data related keyword there were many overlaps. As a result, 61 inquiries were flagged by the word frequency analysis for further analysis.

Document analysis was used to analyse the remaining 61 inquiries. 32 inquiries yielded examples of data uptake and/or data concerns. The remaining 29 reports did not yield content relevant to this thesis. This was due to flagged keywords being used out of context for this thesis, for example ‘adequacy of measures’ or ‘legislative instrument’.

To understand the state of data uptake and concerns related to data the key examples, in the form of quotes, found in the 32 relevant inquiries are presented followed by a synthesis of common usage and concerns.

Although not specifically in the context of presenting sensor data to emergency managers, much content about warnings was relevant because it is about how emergency managers should present information to the community. Recommendation 1 from the 2011 (Victoria) TriTech Lubricants factory fire review from the Office of the Emergency Services Commissioner is a clear example where design choices are balanced to create better community warnings. These

design choices included consistency, relevance, timeliness, accuracy, availability and interoperability. Examples of how to communicate to the community is in the scope of this study but examples of managing community expectation are out of scope. Specific and relevant examples regarding warnings are used to inform this thesis.

The first objective of this Chapter is to identify cases where data awareness, usage or uptake have been an issue. To ensure a widest possible dataset was captured any discussion of awareness, usage or uptake of a sensor data product was captured. An inquiry specific list of data usage and concerns can be found in Appendix D.

This cross sector of inquiries intensified by the word frequency analysis showed 35 mentions of at least 18 different sensor data products which are being considered in decision making (uptake), used or emergency managers are aware of the data product.

In Table 15 each of these 35 mentions have been grouped to show the number of mentions, whether the reference is about raw data or a specific data derived product and finally the source or domain of the measurements used in the dataset or product.

Table 15: Data product/source mentions in Australia disaster inquiries.

Data product/source	Mentions	Type	Measurement domain
Weather forecast	7	Product	All
Weather warnings (including fire)	6	Product	All
Satellite hotspots	2	Product	Space
Fire scar/regime mapping	2	Product	Space/air
Satellite or aerial photography	2	Data	Space/air
Ground based (including ships) RADAR	2	Data	Ground
Satellite RADAR	2	Data	Space
Gauges	2	Data	Ground
Aerial visual surveillance	1	Data	Air
Ground based fire look-out towers	1	Data	Ground
Satellite vegetation mapping	1	Product	Space
Seismometers	1	Data	Ground
Satellite positioning	1	Data	Space
Aerial linescan	1	Data	Air
Multispectral imagery	1	Data	Space/air
Handheld thermal cameras	1	Data	Ground
Flood footprints	1	Data	Space
Fire modelling	1	Data	Model

Finding 19: Of the 61 Australian disaster inquiries which were analysed in detail 32 inquiries, or 53%, had examples of data usage across at least 18 different types of data. (Section 4.4.4)

In the 31 inquiries there were 111 concerns or discussions about ways to use or improve data related products. Of these 31 inquiries 3 inquiries concerns were raised in the context of warnings. Many of these concerns were quite similar or a specific component of a more general concern. For example 24 hour availability and reliability are both concerns raised in the inquiries, but availability is simply one measure of a high reliability system. For this reason the concerns were grouped. Table 16 shows the resulting grouping with individual concerns, number of mentions and total grouped number of mentions. A detailed inquiry specific breakdown is in Appendix E.

Table 16: Grouped concerns from Australia disaster inquiries.

Grouped concerns	Concern as stated in inquiry (Number of mentions)	Total number of mentions
Maturity	Awareness (1) Clarity of message (1) Cleaned of extraneous information (1) Common boundaries (1) Consistency (8) Consistent terminology (1) Efficiency of the system (1) Lack of a manual (1) Lack of situational awareness (1) Maturity (1) Repeatability (1) Rigor (1) Tightening of connections between staff (1)	20
Accuracy	Accuracy (9) Errors of commission (1) Errors of omission (1) Human error (1) Quality (4)	16
Timeliness	Responsive (1) Right time (1) Timeliness (12)	14
Relevant	Coverage (3) Detection without identification (1) Extent of detail (1) Fitness for purpose (1) Relevance (3) Right information (1) Tailored (1)	11
Effectiveness	Coordination (1) Cost (2) Effective use (1) Effectiveness (1) Funding (1) National coordinated (1) Optimisation (1)	8
Reliability	24 hour availability (1) Availability of communications (1) Redundancy (1) Reliability (3) Scalability (1)	7
Availability	Availability (5) Frequency (1)	7

	More monitoring (1)	
Presentation	Dissemination (1) Omitted data (1) Over aggregation (1) Presentation (1) Right form (1) Technical means of filtering/triaging inputs (1)	6
Trust	Misinformation (1) Not relied upon (1) Rumours (1) Trust (3)	6
Experience	Availability of experts (1) Experience (1) Lack of knowledge (1) Training (1)	4
Culture	Authorising environment (1) Culture (1) Data used too late (1) Information flow to decision makers (1)	4
Accessibility	Accessibility (2) Availability of maps in the field (1)	3
Uptake	Uptake (2)	2
Flexibility	Flexibility (1) Interoperability (1)	2
Third party source	Third party source (1)	1

One finding from this list is that all data related discussions were concerns, there was no discussion about what worked well to compare to what did not. This lack of positive lessons is well known and discussed further within Eburn and Dovers (2015).

Finding 20: Based upon Australian disaster inquiries, the circumstance around data usage and/or uptake are governed by at least 15 design choices: Maturity, accuracy, timeliness, relevant, effectiveness, reliability, availability, presentation, trust, experience, culture, accessibility, uptake, flexibility and third party source. (Section 4.4.4)

4.5 Study discussion

One of the key aims of this Chapter was to identify what types of data products were being used in emergency management and to what extent. During the early stages of the study it became clear that using the definition that data *uptake* is the active inclusion of a dataset to inform a decision was too high a bar and would yield a small dataset. For this reason the scope of data products was broadened to include data *uptake, usage* or *awareness*. This broadened scope covering 61 inquiries yielded 35 mentions of 18 different sensor data products. This number is low for the quantity of inquiries and the size of the average inquiry. Although

mentions of data exist in Australian inquiries, discussion of what evidence contributes to key decisions in disasters is limited. Few inquiries questioned the veracity of a data product which contributed to a key decision. This seems unusual given poor data quality has contributed to at least two high profile disasters outside of Australia. The explosion of the space shuttle Challenger in 1986 and the shooting down of an Iranian Airbus by the USS Vincennes in 1988 were the result of in part poor data quality (Fisher and Kingma 2001).

Although 18 different sensor data products were identified in the inquiries the traditional nature of every product mentioned is striking. All of these products have existed for at least 20 years. More modern technologies such as Forward Looking Infrared Cameras or FLIR were not found. Many reports have quite detailed discussions about disseminating warnings and information through social media, that is Agency to Crowd flows, but there were no examples within the 61 inquiries of emergency managers using social media as a data source, that is Crowd to Agency flows, upon which to base a decision.

Finding 21: Inquiries tend to discuss more traditional technologies but do not discuss emerging technologies such as the use of social media as a data source for emergency managers. (Section 4.5)

Another finding is that of the 18 sensor data products found in the inquiries, only five of them or 28% were products, the rest were raw sensors or data feeds. The implications of this are that firstly, it implies that the majority of data used within emergency management has little value add. This means that operators must be responsible to interpret the data which is often quite complex, this additional work for operators could lead to much of this data being captured but never used as evidence to support decision making. Further supporting this finding is that the two data products which were mentioned the most, the weather forecast and warnings, are both mature data products. In fact the weather forecast and warnings are so mature that their original source observations are completely invisible to the user with millions of observations from satellites, airborne platforms and ground based sensors contributing to the model of the forecast every hour (WMO 2009). This also provides evidence that one individual measurement domain such as space, airborne or ground and observation or model does not increase the likelihood of usage but integration of multiple domains does seems to increase usage. So with relatively low levels of usage of upstream raw data feeds and high levels of usage of downstream integrated products leads to a finding that the higher the level of processing and integration of a product the more likely an emergency manager is to use it in a decision.

Finding 22: The more mature and integrated a sensor data product is the greater its usage and uptake. (Section 4.5)

While the 35 mentions of data products was less than expected, data concerns were quite common with 111 concerns raised. This could be explained by the historic fixation on attribution of blame in these inquiries where explaining what happened or how to improve a system is overlooked and consumed by discovering failings and assigning blame (Boin et al. 2005; Eburn and Dovers 2015). Of the 111 data related concerns many were duplicates and so 67 specific concerns were identified which were grouped into 15 overarching concerns. Of these 111 concerns 17 were raised in the context of warnings but were still relevant to the uptake of data. When talking about warnings the conversation was generally more mature than about sensor data. In fact in the 2011 review of the TriTech Lubricants factory fire the Office of the Emergency Services Commissioner in Victoria estimates that *"the response of the correct brigades to the correct location was delayed by four minutes and 56 seconds".* The accuracy of this statement could be questioned as being overly precise but this style of finding is on the rise and could appear in future inquiries about data. This overly precise finding uses the evidence that acting on evidence at the time it was received rather than four minutes and 56 seconds later. This specificity is both persuasive and more actionable meaning it is more likely to drive reform in Standard Operating Procedures (SOPs) and improve organisational culture. This in turn could lead to the greater inclusion of highly specific data driven finding in future inquiries.

Across the inquiries the complexity of discussions was highly variable. In addition, the complexity of the discussion was not related to time. For example the 1939 bushfire royal commission covers how to balance the strengths and weaknesses of different technologies in order to gain maximum coverage and the issues related to what is referred to in defence as a barrier surveillance model – that is that one must observe a target more frequently than it can move a distance you judge to be significant. This style of discussion shows a level of understanding in 1939 which is commonly absent from recent reports which are often boiled down to overarching statements such as *"emergency managers are reliant on timely and high quality data".*

Finding 23: The discussion of data in inquiries is not new or complex with discussions in the 1939 bushfire royal commission often more complex than recent inquiries. (Section 4.5)

The 2013 Munro Review of the Bureau of Meteorology's extreme weather and seasonal forecasting capacity describes the different design choices required to deliver products as *"quality, timeliness, frequency, accessibility and presentation"*. This collection of design choices closely resembles some of the 15 overarching concerns identified as part of this study. This suggests two points, firstly that the design choices determined in this study are indeed relevant and secondly that this topic is being considered within the emergency management sector. This consideration may not be framed using the terms used in this thesis like contribution to decision making and uptake but more as "how do I increase usage" but either way the issues under consideration are similar.

One of the common discussions within the literature is whether or not inquiries help emergency managers to learn the lessons of the past, or whether or not they are simply revisiting the same issues without improving intelligence or learning (Eburn and Dovers 2015). The 2011 report *Bushfire Management* from the Tasmanian Auditor General actually gives an assessment of previous inquiries' progress in implementing recommendations. For example they assess that the COAG 2004 recommendation 5.2 *"that the Australian Government and the state and territory governments jointly provide additional resources and work in partnership to establish and refine a national program of fire regime mapping"* is only 25% implemented. For inquiries to comment on the implementation of other inquiries more than five years before suggests that many of the lessons are not being learned. This finding can be taken further though by a quantitative analysis of the 15 concerns, comparing frequency over time as shown in Figure 13. In Figure 13 the four most common concerns (Maturity, accuracy, timeliness and relevance) have increased dramatically recently. This in isolation could be explained by the large increase in inquiries recently but it does not explain the stability of the next most common design choices. Effectiveness, reliability and availability are all issues which the sector has been aware of for over twenty years but do not appear to have been fixed. One attribute that these three items have in common is that they are all highly subjective.

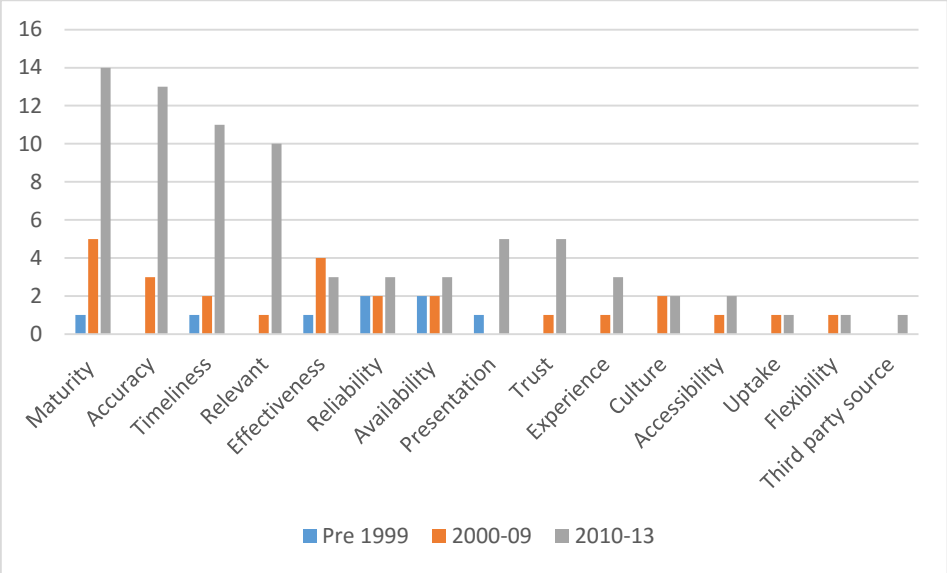


Figure 13: Data related concerns in Australian disaster inquiries over time.

This Chapter has improved our understanding of 15 design choices which are related to the uptake of a sensor data product but there are limitations of this Chapter. One theme which became clear in the concerns was the interconnectivity between the various design choices. The 2013 Federal inquiry *Recent trends in and preparedness for extreme weather events* contained a clear example of this on page 109 when it said, "*However, while weather forecasting is much more accurate than in the past, the committee heard that people still need convincing to trust and act on this information."* What this quote illustrates it that this individual study may have identified many concerns which control whether or not sensor data is used this study has not managed to create independent variables. Elements such as uptake, trust and maturity all have overlap with other design choices. Due to this overlap Chapter six establishes an independent set of variables. In addition the dataset used in this study gives some clues about the relative importance of various design choices but on its own the dataset is not large enough and the differences are not significant enough to determine a clear weighting between the various design choices.

Data related content is much less covered in inquiries than expected by the author. Using the 1728 recommendations from 51 inquiries into bushfire management and response, only 9% or 163 of the recommendations were vaguely related (Topics include: Fire bans and weather warnings, Mapping and data quality, Assets and technology, Research) to the evidence used to make decisions in preparing or responding to disasters. More worrying is that only 0.5% or 8 recommendations since 1939 focused on data quality and mapping concerns. The low level of interest in this seemingly critical information which drives or at least greatly affects decision making in disasters is troubling and raises concerns about the value of disaster inquiries in Australia.

This study found that sensor data has a low level of consideration within Australian disaster inquiries. Where sensor data has been considered it is related to data types which have existed for several decades. In addition, all discussions of sensor data in Australian inquiries are negative; this problem is not limited to the sensor data domain. Finally, data is not considered in the context of uptake and hence this research is highly relevant in finding how to use sensor data to improve decision making.

4.6 Summary of findings

Finding 17: The more political the structure of an inquiry the less technical the content of the inquiry. (Section 4.4.2)
Finding 18: Data quality has been a minor topic in Australian bushfire inquiries with only 53 or 3.1% of the 1728 recommendations made between 1939 and 2013 related to mapping or data quality. (Section 4.4.3)
Finding 19: Of the 61 Australian disaster inquiries which were analysed in detail 32 inquiries, or 53%, had examples of data usage across at least 18 different types of data. (Section 4.4.4)
Finding 20: Based upon Australian disaster inquiries, the circumstance around data usage and/or uptake are governed by at least 15 design choices: Maturity, accuracy, timeliness, relevant, effectiveness, reliability, availability, presentation, trust, experience, culture, accessibility, uptake, flexibility and third party source. (Section 4.4.4)
Finding 21: Inquiries tend to discuss more traditional technologies but do not discuss emerging technologies such as the use of social media as a data source for emergency managers. (Section 4.5)
Finding 22: The more mature and integrated a sensor data product is the greater its usage and uptake. (Section 4.5)
Finding 23: The discussion of data in inquiries is not new or complex with discussions in the 1939 bushfire royal commission often more complex than recent inquiries. (Section 4.5)

Chapter 5: Barriers to uptake: Emergency management community's assessment

5.1 Aim and overview of this chapter

Chapter three compared four data systems which generated quite different products allowing us to identify the design choices which lead to those differences. Chapter four expanded on our collection of design choices by logically grouping data related discussions in Australian disaster inquiries. However neither of these studies revealed detailed information about the relative weighting or interaction of these design choices.

This Chapter focuses on the emergency management community's views on the barriers to uptake of sensor data. Using a web survey targeted at Australian emergency managers, the study explores levels of knowledge about different datasets, differences between specific datasets and the relative importance of design choices leading to the uptake of data in emergency management.

Following this Chapter, this quantitative data is combined with the findings of previous Chapters into a discussion encompassing the entire topic. Chapter six then forms the basis of a framework for maximising uptake of sensor data products in emergency management.

The Chapter is structured as follows:

5.2 Study logic

This Chapter collects the views of people involved in emergency management on the topic of "Sensor data in disaster decision making". The survey identifies people's level of awareness, usage and uptake of various existing datasets in order to establish current trends. It also looks at existing barriers to uptake based on concerns raised in the previous study. Finally, this survey collected quantitative data around the design choices which drive uptake, identified within the previous study and the literature.

The objectives of this Chapter are:

- To identify the level of awareness emergency managers have of existing sensor data products;
- To identify the main barriers to uptake of data for emergency managers;
- To understand which datasets are more trusted than others; and
- To identify which design choices emergency managers believe contribute to the use of data in decision making.

The survey is targeted at members of the Australian emergency management sector while not excluding participants from outside the sector. One key sorting mechanism for the survey is the location of the participant within the data supply chain: that is acquisition, value add or user. See Chapter two for further definitions.

5.3 Study method

5.3.1 Research design

This study collected a dataset of generalised beliefs through a web survey to inform the research questions through quantitative results. A large structured dataset was collected through the use of a web survey. The survey was conducted online because of the simplicity, low cost, anonymity, confidentiality, free expression and fair temporal response (D. L. Davis 2004). Demographic style questions were general enough to ensure nobody could be individually identified while sufficient to enable identification of respondent's role in the sector. The survey was designed to measure specific beliefs held within the target community, the emergency management sector. The results from the survey represent beliefs of a cross section of the target community, that can then be projected to sufficiently represent the views of the entire target community (Davis 2004).

Key informants were directly involved in the design, testing and collection for this survey. By targeting the survey at key informants, such as decision makers within the emergency management sector, the survey targeted people with specialist knowledge on the topic making further insights more likely (Kumar, Stern, and Anderson 1993).

According to Davis (2004) the main sources of error within a survey are: planning, collection, analysis and reporting. To reduce the effects of each of these errors the following strategies have been used:

- Planning Error: Impartial evaluation of the survey proposal and methodology through the Australian National University (ANU) Statistical Consulting Unit and the ANU Human Ethics approval process;
- Collection Error: Periodic managerial evaluations during the collection period; and
- Analytical Error: Outside evaluation of the results by research supervisors and peers.

In order to reduce planning error in accordance with Davis (2004), impartial evaluation of the research design was required. To achieve this, three groups representing the main stakeholder communities each tested and refined the survey, these were the Australasian Fire and Emergency Service Authorities Council, the Bushfire & Natural Hazards Cooperative Research Centre and the Cooperative Research Centre for Spatial Information. In addition further evaluation was carried out following ANU compliance guidelines through a formal Human Ethics review process undertaken on the survey (Protocol number: 2014/077). This review looked at privacy, security and integrity considerations. On 31 March 2014, unconditional approval was gained by the ANU Ethics Committee to proceed with the survey.

This survey asked 21 questions over 5 pages to identify what drives the uptake of datasets within the emergency management sector, a full copy of the survey can be found in Appendix F. For this reason the population of interest was the emergency management sector and the providers of data to this sector. The rationale for the remaining questions is established in the remainder of this section.

Through careful research design and data collection, the survey data focused on one targeted group. This target group created a homogeneous dataset which reduces errors such as bias. The target audience can be split into different groups through a stratified sampling strategy often referred to as sorting questions. In this survey stratification questions were used for experience, employer type, age, location and role in the data supply chain. These questions were phrased as follows:

1. How long have you been involved in emergency management (in any capacity)?
2. What type of organisation are you primarily associated with?
3. What is your age?
4. Where is your current organisation located?
5. My role in the data supply chain mainly involves:

Next, it was important to determine the level of awareness of emergency managers to different datasets. This information is critical to understanding what level of processing emergency managers need in their datasets; for example an upstream product like raw satellite

telemetry or a downstream integrated product such as the weather forecast. The following questions were asked to judge the respondent's awareness of different data products:

6. In your current role, do you use sensor data (data from satellites, planes and ground based sensors including social media)?
7. Do you think sensor data should be used in emergency management decision making?
8. How aware are you of the following range of sensor data products? Weather forecast; Weather warnings; Stream gauge; Flood warning; Seismograms; Earthquake alerts; Satellite or aerial imagery (Photo like/optical); Satellite or aerial imagery (RADAR); Satellite or aerial imagery (Multispectral); Imagery derived perimeter/extent/footprint information for either fire, flood, oil slick or landslide; Burn intensity map; Fuel load map; Emergency phone calls (Triple zero); Individual social media message e.g. a twitter tweet; Social media trend alert e.g. a trending keyword like earthquake; Satellite positioning data e.g. GPS
9. What types of sensor data do you use in your current role?

The first formal aim of this study was to identify the main barriers to uptake of data for emergency managers. Barriers to access such as training or cost are generic issues which must be measured in most surveys of this type. These generic issues are important because rather than being dataset or provider specific issues they are generally focused on the industry as a whole. To analyse these industry-wide barriers the following questions were raised:

10. Which of the following issues do you think are relevant to the use of emergency management sensor data today? Availability of data; Cost of the data; Cost of data systems; Openness and licencing; Skills in the use of the data; Documentation of data products; Quality of data; Timeliness of data products; Trust of the data; Other
11. How much do you think the following factors influence the use of sensor data in emergency management decisions? Lack of expertise and knowledge about sensor data; Concerns about legal liability in using sensor data in decision making; Government directives that limit the flexibility of emergency management decision-makers to use sensor data; Emergency management budgets are too tight that sensor data cannot be considered; Using sensor data creates difficult political issues; Meeting community expectations for emergency suppression makes it hard to consider other goals and priorities; In emergency management decisions there is not enough time to take account of all the available data including sensor data; Emerging sensor data products are not relevant to emergency management decision making
12. Do you have any comments regarding factors that may encourage or discourage the use of sensor data in emergency management decisions?

The second aim of this study was to understand which datasets are more trusted than others. One limitation of the previous Chapter on disaster inquiries is that it did not give detail as to which design choices are more important than others. To address this question specific comparisons, such as between a university and a government agency, are useful to draw people's attention to issues such as the mandate of the provider. These considerations are often not clearly understood in a more direct question. Specific issues were only raised where the inquiry study had indicated there might be a problem. In addition questions were raised about

the scope of sensor data, these questions allow discussion of potential parallels between more trusted data or less trusted data. Questions about which datasets are more trusted than others were asked through the following questions:

13. How likely would you be to base a high consequence decision (e.g. life threatening decision) on the following dataset? Data collected by staff within your own organisation; Bureau of Meteorology weather forecast data ingested and displayed in your organisation's system; Bureau of Meteorology weather forecast data displayed on their public website with commercial advertising; Weather forecast data from a private company on their website; Coarse resolution (250 metre) satellite imagery from the NASA website; Bushfire hotspots on the Geoscience Australia Sentinel system; Bushfire hotspots ingested and displayed in your organisation's system; A single stream gauge measurement; An official warning from the Bureau of Meteorology; A university created satellite based fire perimeter map with the associated image; A university created satellite based fire perimeter map without associated image due to licencing restrictions; A government agency created satellite based fire perimeter map with the associated image; A government agency satellite based fire perimeter map without associated image due to licencing restrictions; A single tweet from twitter saying there is a fire at a location; An alert from a commercial service which tracks trends in social media; Emergency phone calls (Triple zero)
14. Would your answers to question 13 be different if the consequences were lower, e.g. the decision had resource implications, but was not life threatening?
15. Is an emergency phone call (Triple zero) a form of sensor data?
16. Is social media information a form of sensor data?

The final aim of this study was to identify which design choices emergency managers believe contribute to the use of data in decision making. Following on from the first objective, dataset or provider specific design choices play an important role in driving the uptake of data. The survey asked for relative weighting for each design choices, so a quantitative dataset could be built around the relative importance of the design choices. These design choices were raised in both the literature and the inquiries study. The question was raised as follows:

17. Which quality factors affect the likelihood of a sensor data product being used to inform an emergency management decision? Accuracy of a sensor data product; The speed which a data product is delivered to the user i.e. Timeliness; Reliability of a data products e.g. its ability to be consistently reproduced; The clarity or simplicity of sensor data products content and/or presentation; The completeness of a sensor data product in coverage and/or presentation; The time it takes to become familiar with how to use a product i.e. useability; The consistency within one data product or across a time series of data products; The description of how the data product was made i.e. provenance; The product complies with relevant standards and meets predefined specifications; The quantity of documentation which accompanies the product; The interoperability of the data product to connect with your systems
18. Which reputational factors affect the likelihood of a sensor data product being used to inform an emergency management decision? The mandate of the provider to be producing emergency management data products; The reputation of the provider; Your familiarity with the data provider; The popularity of the data product; The business model of the data product such as daily weather forecasts vs. a once off burn intensity

map; The sensor was owned and/or operated by your country i.e. sovereignty; The ability to access the data product securely; The security of the network which transported the data product; Whether or not the sensor is civilian or defence operated i.e. dual-use

19. Which data policy factors affect the likelihood of a sensor data product being used to inform an emergency management decision? Cost of the sensor data product; Access restrictions on the raw data which created the sensor data product; Ability to publically disclose the source of the data; Ability to publically release the raw data; Restrictions on your ability to distribute the data i.e. copyright; The responsibilities and liabilities associated with your use and the use of those to whom you distribute the data product
20. In your opinion, what are the most important features that a sensor data product must have if it is going to be used in a decision making process?
21. Do you have any additional comments on this survey?

5.3.2 Data collection procedure

The survey was conducted using the online tool, Survey monkey (https://www.surveymonkey.com/). This tool was selected due to its simplicity and familiarity to the Australian emergency management and spatial sectors.

As previously discussed, the Australasian Fire and Emergency Service Authorities Council, the Bushfire & Natural Hazards Cooperative Research Centre and the Cooperative Research Centre for Spatial Information each reviewed this survey before launch to ensure relevance and industry specific terminology was used. In addition, these three groups assisted in distribution through sending the survey out on mailing lists, posting it on their websites and promoting the survey in relevant forums. This assistance provided a high level of penetration into the target population.

Links to the survey were also posted on the emergency management public affairs blog and the social networking site Linked In's emergency management groups. Finally, the Dillman, Millar, and Messer (2010) method for increasing response rate was used with regular reminders sent to increase response rates.

5.4 Study results

5.4.1 Survey statistics and validity

The survey was opened on 17 March 2014 when initial testing was carried out, with official invitation emails being sent out in the first week of May. The collector was closed after 84 days on 9 June 2014. In total the survey received 230 responses.

As the survey was posted on social media and re-sent by many recipients, a formal response rate could not be calculated. 230 responses is considered a strong response rate for this sector. For example, a recent survey focused on the level of economics knowledge within the

Australian emergency management sector had a response rate of 59 respondents (Clayton et al. 2014).

A verification of Non-Response Bias is an important way of assessing the quality of a survey. The standard method of measuring Non-Response Bias is through a follow up survey, this was not possible due to the anonymity of participants. It should be noted that Non-Response Bias can be minimised through a high response rate (Lessler and Kalsbeek 1992). Even so, key informants further reviewed the survey responses and determined the results as consistent with their experience and hence valid. This technique of using key informants to test Non-Response Bias has shown promising results in other sectors (White et al. 2007).

A raw set of survey results are presented in Appendix G.

5.4.2 Respondent profile

This survey used a stratified sampling strategy employing five sorting questions to stratify respondents by experience, organisation type, age, location and role in the data supply chain. Gender information was not collected because this work is about tailoring products to emergency managers and provider or user gender is not relevant.

Table 17: Experience respondent profile.

Experience	Frequency	Percent
Less than 5 years	31	14%
Between 5-10 years	38	17%
Greater than 10 years	156	68%
I am not involved in emergency management	4	2%
N=229		

Table 17 shows the experience respondent profile. In this profile the majority of respondents (68%) have over 10 years emergency management experience, with statistically valid responses from people with less experience. Four responses outside the sector is not a large enough sample to compare people involved or not involved in emergency management.

Table 18: Organisation type respondent profile.

Organisation type	Frequency	Percent
Federal government	29	12.7%
State government	164	71.6%
Local government	9	3.9%
Research sector	4	1.7%
Private sector	7	3.1%
Non-Governmental Organisation	16	7.0%
N=229		

Table 18 shows the organisation type respondent profile. This profile shows the majority of respondents are from State government (72%), Federal government (13%) and Non-Government Organisations (7%). The bulk of responsibility for emergency management is with

State government agencies, hence their high representation is not unusual in surveys on this topic. While it could be argued there is a smaller role for Local government, researchers and the private sector in emergency management than for the State and Federal governments, the response rate of these groups was proportionally lower than expected. This low response could be explained by survey fatigue, at least in the research sector, but it could also be explained by the phrasing of the question. The question asks about the organisation type and not the specific role; this could mean that many State government respondents are involved in research but this assertion requires further study.

Table 19: Age respondent profile.

Age	Frequency	Percent
Under 35 years old	35	15.4%
35-49 years old	83	36.4%
50-64 years old	104	45.6%
65 years or older	6	2.6%
N=228		

Table 19 shows the age respondent profile with a strong distribution of age groups across the workforce. A small number of respondents are in the over 65 age bracket some of which may be retired.

Table 20: Location respondent profile.

Location	Frequency	Percent	Population ('000)	Population (%)
Australian Capital Territory	24	10.5%	368	2%
New South Wales	59	25.8%	7,218	32%
Northern Territory	6	2.6%	231	1%
Queensland	23	10.0%	4,477	20%
South Australia	29	12.7%	1,640	7%
Tasmania	14	6.1%	512	2%
Victoria	41	17.9%	5,538	25%
Western Australia	15	6.6%	2,353	11%
Other (please specify)	18	7.9%	N/A	N/A
N=229				

Table 20 shows the location respondent profile along with the Australian State and Territory population from the 2011 census (Australian Bureau of Statistics 2014). This profile closely matches the population distribution of Australia with NSW and Victoria having the largest number of respondents and population in Australia respectively. This survey shows a minor over representation of Tasmania and the ACT and an under representation of Western Australia when compared with population in these locations. The ACT's over representation can be explained by the Federal government presence as well as the Territory emergency service. Tasmanian and Western Australian underrepresentation is potentially caused by their underrepresentation in the groups which distributed this survey. Finally the "Other" category of

respondents are made up of 3 respondents who answered ‘national’, ten New Zealand respondents, five Nigerian, one Kenyan, one Fijian, one Jamaican and one Chinese respondent.

Table 21: Role in the data supply chain respondent profile.

Role in the data supply chain	Frequency	Percent
Data collection related tasks	27	12.0%
Value adding existing datasets	21	9.3%
User of data	139	61.8%
Other (please specify)	38	16.9%
N=225		

Table 21 shows the role in the data supply chain respondent profile. Here the strong focus on users can be seen. This is positive given these users are the focus of the research and have been under represented in previous related research such as Lowell et al. (2011) and Sustineo (2011). The “Other” category was made up of a variety of roles but seven respondents listed all of the above and three listed a mix of two areas in the data supply chain. The remainder of “Other” respondents were generic role titles, such as Director of Training or Manager of performance information.

Finally, question 6 of the survey asked users if they use sensor data in their current role. 166 or 83% use sensor data in their current role. Question 7 found that 197 or 97% thought sensor data should be used in emergency management decision making.

Finding 24: 97% of emergency management survey respondents believe sensor data should be used in emergency management decision making. (Section 5.4.2)

5.4.3 Data preparation

One standard problem with web surveys is incomplete submissions. In this survey there were 230 survey respondents, with the smallest number of respondents to a single question reaching 175 or 76% of survey responses. Given the large number of “rate between 1-7” questions towards the end of the survey this rate is not surprising and still provides a solid response rate. Of the initial sorting questions the minimum response rate was 225 or 98%. Rather than excluding survey responses, the number of respondents and percentages used in this study is based upon the number of responses to that specific question rather than the total 230 respondents or 225 respondents who proceeded past the sorting questions.

To allow the data to be analysed in a quantitative manner all non-numerical values were removed from the quantitative results. For example, quantitative response answers like “rate from 1-7” were corrected from a descriptive answers such as “Not likely at all 1” or “N/A” to “1” or “NULL” respectively.

5.5 Study discussion

The survey discussion is structured by analysing the headline results of each question, the stratification questions (age, location, experience, sector, role) then by any specific topics setup by the question. This section presents results in four subsections which align to the objectives of the study: data awareness, barriers to uptake, trust, and design choices leading to uptake.

5.5.1 Data awareness

In this survey users' role within the data supply chain was used as a sorting question. The types of products respondents actually use in their work was also measured. This is often referred to in upstream and downstream terms. For example an upstream product could be a raw commodity like uncorrected satellite telemetry and a downstream product could be an integrated data product with many data sources such as the weather forecast. Question 9 asked "What types of sensor data do you use in your current role?"

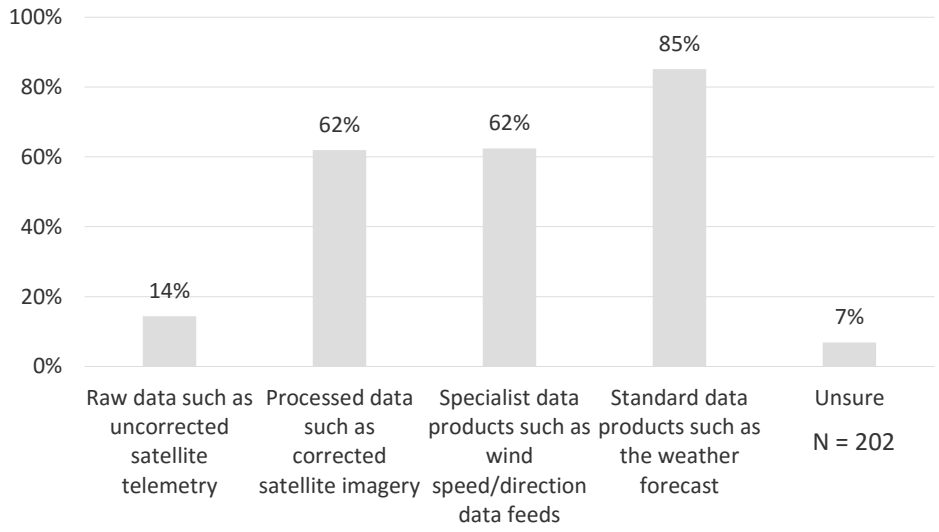


Figure 14: Survey response to what types of data is used (Question 9).

As can be seen from Figure 14, usage is higher the further downstream you go. Put another way the higher the level of product integration the higher the usage. In order to generate a highly integrated data product the following steps are required, firstly raw data is processed into a basic product, then specialist products are required to convert from basic measurements into variables and these variables are then integrated into a final product. The conversion from basic measurement products into specialist variables does not increase usage (both 62% in Figure 14). This finding has large implications for data producers and value adders where projects which create specialist products then assess usage before proceeding to creating the standard downstream integrated products. With no increase in usage found at the specialist variable stage

many projects would not proceed to the standardisation stage due to perceived problems. This suggests usage should only be assessed after the initial processed data stage or after the standard data product stage.

Once broken down by location this question shows that the ACT uses more upstream data products than any other jurisdiction. 40% of ACT respondents use raw data and 75% use processed data. The second highest using jurisdictions are Western Australia of which 23% use raw data and the Northern Territory of which 67% use processed data. One similarity of these jurisdictions is their relatively low size or population density in the case of WA – this suggests that smaller or sparsely populated jurisdictions use more data than other jurisdictions. In addition, as the Federal government is located in the ACT this suggests the Federal government's role as one of the main mechanisms for data capture.

Question 8 asked users to rate "How aware are you of the following range of sensor data products?" This was done on the following scale: Never heard of it, heard of it, know it, used it, and based a decision off it. This scale was used to clearly differentiate awareness, usage and uptake.

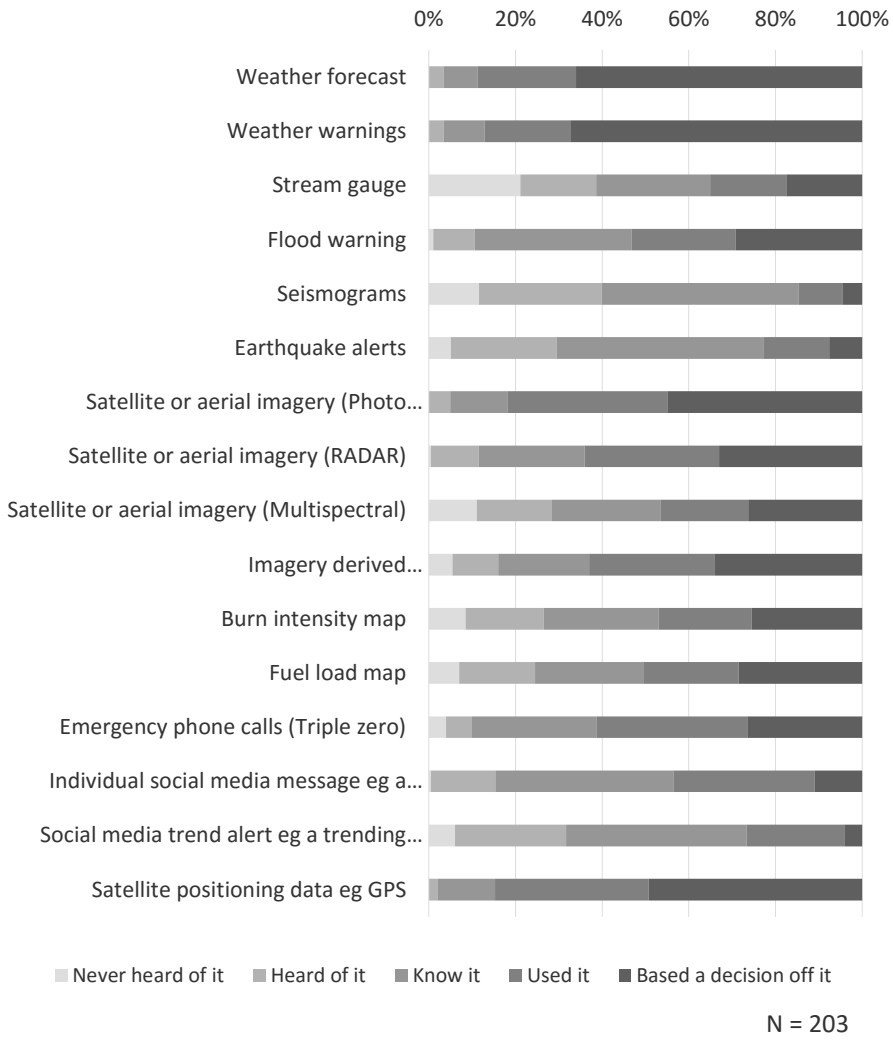


Figure 15: Survey response on sensor data product awareness (Question 8).

The survey responses to question 8 and 9 clearly agree that downstream products are more used than upstream products. The three highest uptake or "based a decision off it" products were weather warnings (67%), weather forecast (66%) and positioning (49%) – all of these products are highly integrated downstream products. Conversely the three most "Never heard of it" products are all upstream raw or less processed data feeds being stream gauge (21%), seismogram (12%) and multispectral imagery (11%). That said seismic hazards are relatively small in Australia and so a low level of knowledge about seismometers is not surprising.

Finding 25: The higher the level of product integration the higher the usage. (Section 5.5.1)

One key relationship in this thesis is between usage and uptake. Question 8 directly measures this distinction through the terms "used it" and "based a decision off it". This provides a clear measure of products people use but would not rely upon. Using this metric the products with greater usage than uptake in order are: an individual social media message (22%), social media trend alert (19%), emergency phone calls (8%), earthquake alerts (8%) and seismograms (6%). The earthquake alert and seismogram logically would have high usage and low uptake because of the rapid nature of an earthquake hazard, by the time an alert is issued the event is generally over. The other positive numbers should be noted. The top two numbers are the two forms of social media on the list but they are also related to the third highest amount being emergency phone calls. This suggests that many emergency managers have used social media but either do not trust it enough to act on it or do not have the tools/doctrine (Note: Doctrine refers to EM doctrine) to incorporate intelligence from social media into their decision making. Furthermore, the datasets with the highest usage in relation to low uptake are all subjective reports from humans. This suggests a certain distrust in human reports which until recently have been the traditional means of contacting the emergency services.

This question can also be used to measure *awareness*, *usage* and *uptake*. By combining the "heard of it" and "know it" categories can give a fair approximation of *awareness*, "used it" accurately reflects *usage* and "based a decision off it" is in fact an even higher level than the working definition of *uptake* but still a fair approximation. Figure 16 plots the question 8 responses based on the groupings above and ordered from the lowest level of *uptake* to the highest level of *uptake*.

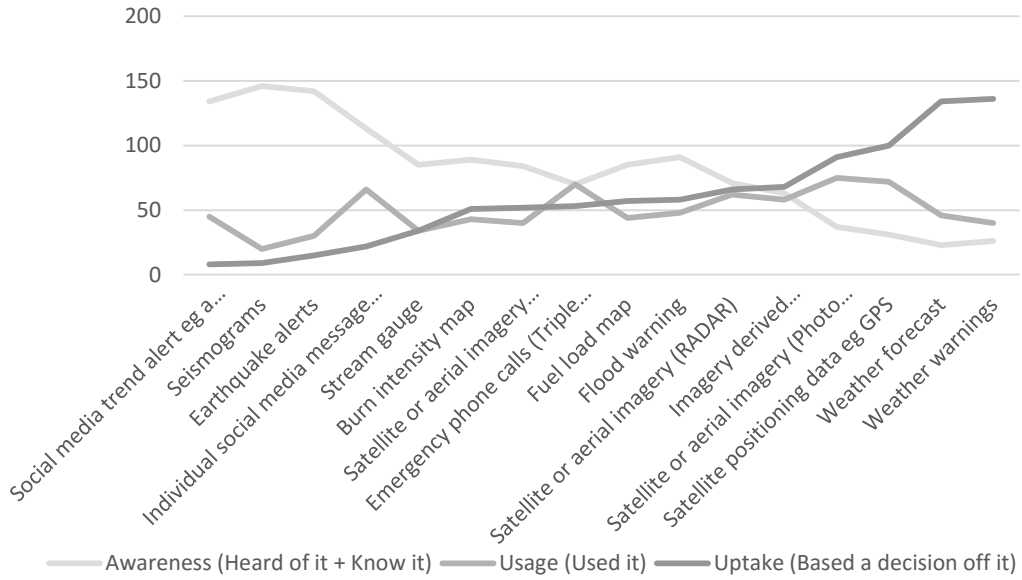


Figure 16: Question 8 survey responses separated into awareness, usage and uptake ordered by uptake.

The above graph shows a broad resemblance to the Gartner Hype Curve showing a large initial awareness of new products such as social media which drops off before building back up to high levels of uptake for established products such as weather related products. Hype curves are a common tool within the technology sector which characterise *"the typical progression of an emerging technology from user and media overenthusiasm through a period of disillusionment to an eventual understanding of the technology's relevance and role in a market or domain"* (Linden and Fenn 2003, 1). This relationship between survey respondents and the hype curve illustrates the long term progression of data products beginning with awareness and eventually moving towards uptake of established products.

5.5.2 Existing industry barriers to uptake

Many industry-wide barriers are described in the literature such as data availability in Andrew (2011) and trust in Haynes, Barclay, and Pidgeon (2008). These existing industry barriers have been analysed in a binary fashion in Question 10 of this survey and in a weighted fashion in Question 11. It should be noted that emergency managers have been targeted for this survey and they may or may not be knowledgeable about EM industry barriers to sensor data uptake.

Question 10 asks "Which of the following issues do you think are relevant to the use of emergency management sensor data today?" Respondents can tick as many issues as they wish and the results are shown in Figure 17.

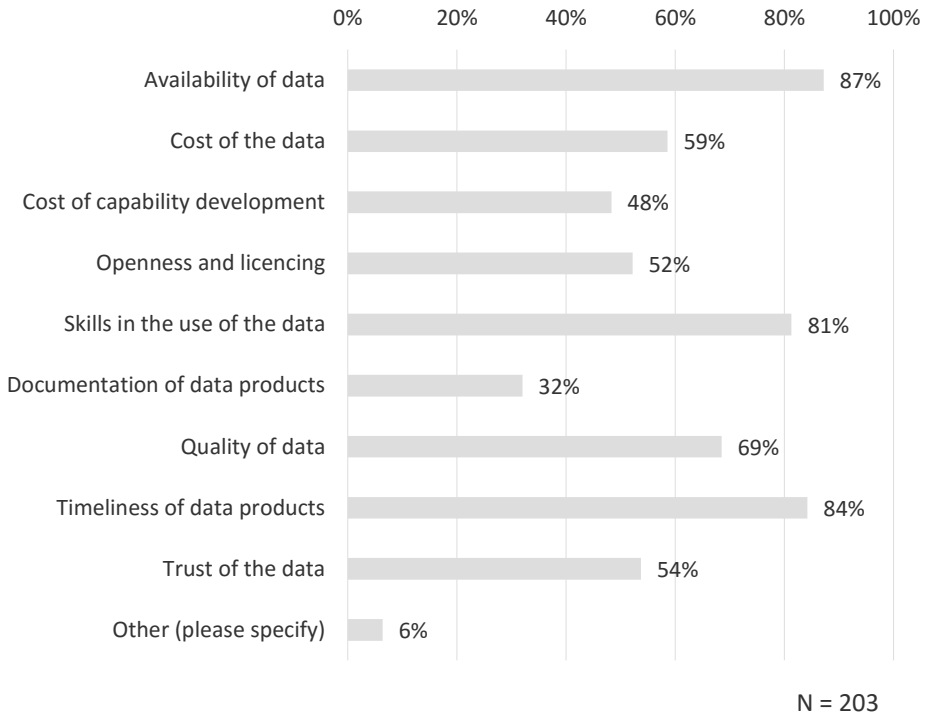


Figure 17: Survey response on industry-wide barriers to uptake (Question 10).

As Figure 17 shows the most often rated barriers are availability of data (87%), timeliness of data products (84%) and skills to use the data (81%). Taken collectively it is clear that most emergency managers feel they are not getting products or they do not arrive fast enough to be useful or even if they do they are either not skilled to use them or they are presented in a format which is too complex to be useful to emergency management decision making.

Finding 26: Availability of data, timeliness of data products and skills to use the data are the most common issues facing the emergency management sector. (Section 5.5.2)

These results sorted by their role in the data supply chain suggest that the higher in the supply chain the respondent is the lower the issues with sensor data. Taking an average of all issues in question 10 provides a metric to compare how dissatisfied a given stratified group is relative to the community. This dissatisfaction metric for the data supply chain suggests more dissatisfaction further up the supply chain (producers 57%, value adders 54% and providers 50%). While a spread of 7% is not significant for an individual issue in question 10, it can be considered when using an average of all issues. This suggests that providers and value adders feel they are removing barriers but perhaps these developments have not yet changed the views

of the user community. A different and perhaps more positive perspective on this is that producers have the highest standards for data products, followed by producers then users – this is quite positive because it means that the groups with the most responsibility for products aim for the highest standard.

Finding 27: Stakeholders higher up the supply chain have higher quality thresholds, meaning data producers and value adders often block products which are still useful to emergency managers. (Section 5.5.2)

While availability, timeliness and skills are the most common barrier for all groups there are some different perspectives on other barriers. The cost of capability development is the equal most common barrier for value adders (81%) whereas users view this as a moderate issue (46%) and producers a small issue (26%). In addition both users and producers view trust of the data as a moderate barrier (55% and 52% respectively) but value adders only view this as a minor issue (31%). Finally, users believe data quality is a large issue (71%) while this is only a moderate issue for producers and value adders (56% and 50% respectively). These three findings together suggest that value adders and to a lesser extent producers are quite optimistic about the potential of sensor data but they require more effort or potentially funding to make the capabilities meet the expectations of the users.

Industry barriers from an age perspective suggests that younger people believe that openness and licencing is a larger issue (Less 35 – 63%, 35-49 – 57%, 50-64 – 48%) while quality concerns increase with age (Less 35 – 59%, 35-49 – 68%, 50-64 – 71%). For these values returns of over 65 year olds were too low for statistical valid findings and hence excluded.

The level of experience did not show differing views except for on the topic of trust where trust became a larger barrier with more experience (Less 5 years – 40%, 5-10 years – 50%, More 10 years – 57%). Respondents not involved in emergency management were not large enough for statistical validity.

Barriers to the uptake of sensor data for emergency management varied greatly by sector and hence this information has been represented in Table 22. The largest and smallest values of each barrier have been highlighted to enhance readability.

Table 22: Survey response by sector for industry-wide barriers to uptake, largest and smallest values highlighted (Question 10).

	Federal government	State government	Local government	Research sector	Private sector	Non-Governmental Organisation
Availability of data	81%	88%	89%	75%	86%	93%
Cost of the data	65%	59%	44%	50%	71%	50%
Cost of capability development	46%	52%	22%	75%	71%	14%
Openness and licencing	62%	49%	44%	50%	86%	57%
Skills in the use of the data	81%	81%	78%	100%	86%	79%
Documentation of data products	35%	32%	22%	50%	14%	36%
Quality of data	65%	71%	56%	75%	43%	71%
Timeliness of data products	88%	84%	89%	50%	86%	86%
Trust of the data	46%	55%	44%	75%	43%	57%

Based on the percentages shown in Table 22 several insights about perceived barriers to uptake can be explored. The cost of capability development is viewed as a much larger issue to the research and private sectors than all other sectors, this view is potentially stemming from self-interest from those sectors for greater investment. Licencing is viewed as a far larger issue by private sector followed by Federal government than other sectors, this is important given these two groups are commonly considered to hold the main opposite views on licencing with government's need for more open licencing and private sector's need to protect their intellectual property. Researchers not surprisingly believe documentation is a larger issue which potentially is caused by the requirement for peer review in that sector. The research sector is also the most concerned about quality and trust while being least concerned about timeliness being a barrier to uptake. This is not surprising given researchers do not often participate in operational activities.

Question 11 builds on Question 10 by using a 1-7 judgement about the relative importance of various design choices. This question is posed slightly differently to the previous question through using phrases rather than individual words and through the wording of the question "How much do you think the following factors influence the use of sensor data in emergency management decisions?" This makes the respondents view the factors shown in Figure 18 as negative influences rather than barriers with the hope that this provides a less binary and more quantitative answers.

Figure 18: Box plot with mean value of survey response on factors influencing data usage (Question 11).

From the above box plot, lack of expertise has the highest average rating (5.8), followed by budgetary priority (5.3) and lack of time (5.1). Lack of expertise has the lowest standard deviation (1.2) of all other factors. A lack of expertise is essentially the same barrier to access as skills which was the third most popular response in Question 10. This agreement gives a high level of confidence that the questions were understood and the responses reflect industry views.

When looking at the sector specific results people outside government have a differing view to those within. Political issues had the lowest average (3.1) of all the factors but was rated as important by the private sector (5.3) and the NGO sector (4.2). For the budgetary priority the private sector (6.3) and research sector (6.0) both have the highest average well above the average (5.3). Again the private sector (6.6) and the NGO sector (5.4) were the most concerned about government directives limiting flexibility. Finally, the private sector (5.3) and the research sector (5.0) are most concerned about legal liability and licencing of sensor data. Groups outside government appear to have consistently higher concerns than those within government. One potential narrative which links these heightened concerns is that those outside government think sensor data is not a budgetary priority, feel concerned that raising data is politically sensitive but feel that current government directives including licencing limit the use of these technologies during disasters.

The amount to which government directives were perceived to limit flexibility is inversely proportional to age. For this design choice we see decreasing importance as age decreases: under 35 (5.4), 35-49 (4.5) and 50-64 (4.1). This could potentially be related to older staff generally being more senior hence having greater involvement in setting government directives. Another way of looking at this is that younger people have a higher appetite for risk and hence do not feel the need for these directives. Either way this design choice shows a wide variety of views (Quartile 3 - Quartile 1 = 3).

5.5.3 Trust of existing datasets

Question 13 has been designed to present examples which isolate specific design choices leading to trust such as mandate, the effect of advertising, private sector involvement, data policy and social media. This question also allows for further examination of previous findings about the relationship between uptake and the level of project integration, as found in the inquiries study. In addition Question 13 sets up a later comparison to look at the role of consequence. Question 13 is a 1-7 likelihood judgement of, "How likely would you be to base a high consequence decision (e.g. life threatening decision) on the following dataset?" While question 10 showed that trust is only a moderate issue, the term best describes what question 13 is attempting to determine although the wording of the question itself does not mention trust. The results in box plots are shown in Figure 19.

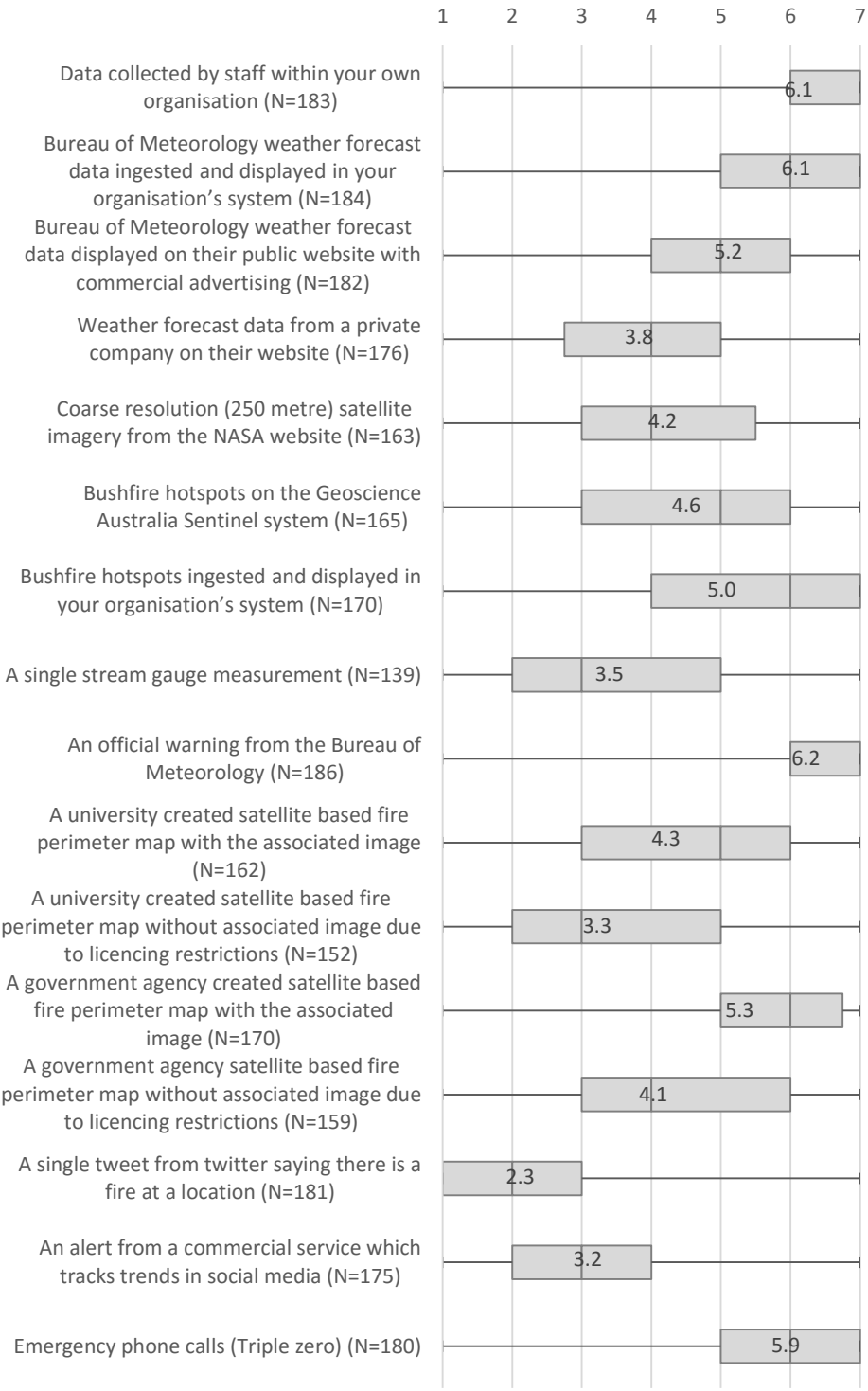


Figure 19: Box plot with mean value of survey response likelihood to use a dataset (Question 13).

Based on the results in Figure 19 an official warning from the Bureau of Meteorology (6.2) and data from own organisation (6.1) are the most trusted datasets. The least trusted datasets are both from social media being a tweet (2.3) and a trend alert (3.2).

This data shows several usage patterns such as respondents from the NT trust imagery related products more than any other jurisdiction (Coarse res average 4.2, NT 6.0; GA hotspots

average 4.6, NT 6.4; Hotspots own average 5.0, NT 5.8 etc.). This style of geographic analysis is not the focus of this study as there is little evidence that below national level location plays a large role in driving uptake. Instead the analysis of this question focuses on potential design choices which may drive the trust of a data product such as mandate, use of advertising, private sector involvement, data policy, social media and consequences.

Official data or data from an organisation with an official mandate is more trusted than data from an organisation without a mandate. In this question four datasets related to fire perimeter maps were used to identify the importance of mandate in the trust of data. The comparison with the associated/source image showed higher likelihood of trust from the government agency (5.3) than from the university (4.3) and the same results without the associated image from the government agency (4.1) and the university (3.3). Furthermore, the research sector is much less likely to trust university created products (University fire map with image average 4.3, researchers 2.0; University fire map without image average 3.3, researchers 2.0) than any other group. The mandate of an organisation increases the trust in their data products.

Finding 28: Official data or data from an organisation with an official mandate is more trusted than data from an organisation without a mandate. (Section 5.5.3)

In an effort to drive savings, some government websites in Australia, such as the Bureau of Meteorology, have been trialling advertising in order to increase revenue (http://www.bom.gov.au/advertising/). From this data a clear decrease in trust is seen when advertising is added to a government agency website dropping from 6.1 without advertising to 5.2 with advertising. Regardless of the sector of the provider, advertising adversely affects trust.

Finding 29: Advertising concurrent with data displays or portals negatively affects trust by emergency managers. (Section 5.5.3)

Data in disasters is either (i) collected by the private sector and provided to the public sector emergency management agency, (ii) collected by a public data agency and provided to the public sector emergency management agency or (iii) collected by the private sector who provides that to a public sector data agency who in turn provides that data to a public sector emergency management agency. This survey considered whether the trust of private sector data is increased when using a public sector intermediary such as the Bureau of Meteorology. There

was a strong preference towards public sector information, with Bureau ingested data into the organisation's own system (6.1) showing much higher results than a private sector website (3.8).

Commercial advertising is primarily a private sector function with the findings above of decreased trust in sites with advertising further supported by the private sector being less trusted to provide emergency management data than the public sector. Looking at the sorting questions, both private sector examples showed the private sector was more likely and Tasmania was significantly less likely to use data from private companies (Commercial weather average 3.8, private sector 4.7, Tasmania 3.0; commercial social trend average 3.2, private sector 3.9, Tasmania 2.1). In addition to these findings free text answers covered this topic with one respondent noting, "Some of the datasets are great for 'situational awareness' but you'd never rely on them for any more than that (i.e. weather forecast data from private company on their website vs data from BoM)." Emergency managers show a clear preference to having data provided to them from other public sector organisations, however this does not discount private sector data being provided through a public sector intermediary.

Finding 30: Emergency managers prefer data products to be delivered to them by a public institution even if the data was collected by the private sector. (Section 5.5.3)

Data policy can have dramatic effects on usage as shown in the opening up of the Landsat data policy in the early 2000's (Wulder et al. 2012). Unfortunately data policy is not considered by many providers, value adders and users due to its legal nature being seen as out of their field. In the survey satellite based fire perimeter maps with or without an associated image due to licencing restrictions were considered for both government agencies and universities. In both comparisons the likelihood of trust was decreased when licencing restrictions were added with government agencies showing a 1.2 value drop and universities showing a 1 value decrease in trust. This suggests that licence restrictions not just on the data product but the source data can decrease the trust in a dataset.

Finding 31: Licence restrictions on the data product or the original source data can decrease the trust in a dataset. (Section 5.5.3)

As already discussed, social media appears to be the least trusted form of data based on this survey. This could be explained by social media being new and many people have not been exposed to using social media data as a data source in a work context. Supporting this,

researchers, developing new applications from modern technology, were the most likely (3.5) to use data and local government, with the smallest capacity to implement new technologies, were the least likely to trust a tweet (1.6). In an effort to determine how comfortable people are treating people as sensors generating observations, questions 15 and 16 specifically asked whether emergency phone calls or social media are actually forms of sensor data. Here the majority of people are comfortable using humans as a form of sensor generating evidence for emergency management decision making, but a minority of people disagree, with the same proportion unsure about the concept (Emergency phone calls Yes 67%, 14% no, 19% unsure and social media Yes 63%, 20% no, 17% unsure). Social media's emergence as a potential data source is still contested with many people being uncertain about its role.

Finding 32: Social media's emergence as a potential data source is contested with many people being uncertain about its role. (Section 4.5)

Following question 13 about the likelihood of using information in a high consequence decision, question 14 asked "Would your answers to question 13 be different if the consequences were lower, e.g. the decision had resource implications, but was not life threatening?" 53% of respondents stated that consequences would not affect decision making with 34% stating that consequence affects decisions and 13% were unsure. These responses were surprisingly constant across all sorting questions. Significantly different responses were found for people outside the sector and over 65 years old but both of these groups did not have a large enough sample for statistically valid conclusions. Survey comments such as "reliability is not so relevant when lives are not at risk" were common but contradictory to the emergency management imperative for doctrine, standards and procedure which are to be used regardless of situation or consequence. While minimal in the scale of difference in answers, consequences do appear to change an emergency manager's approach to using sensor data.

5.5.4 Design choices affecting uptake

This thesis identifies a set of design choices which influence whether a data product is used in decision making or not. While questions 10 and 11 focused on industry or organisational wide barriers to uptake, questions 17-19 are focused on the design choices which affect the uptake of an individual data product. All three of these questions are the same question but divided into different groups of design choices for readability reasons. Questions 17-19 determines a quantitative 1-7 judgement of, "Which quality, reputational and data policy factors affect the likelihood of a sensor data product being used to inform an emergency management decision?"

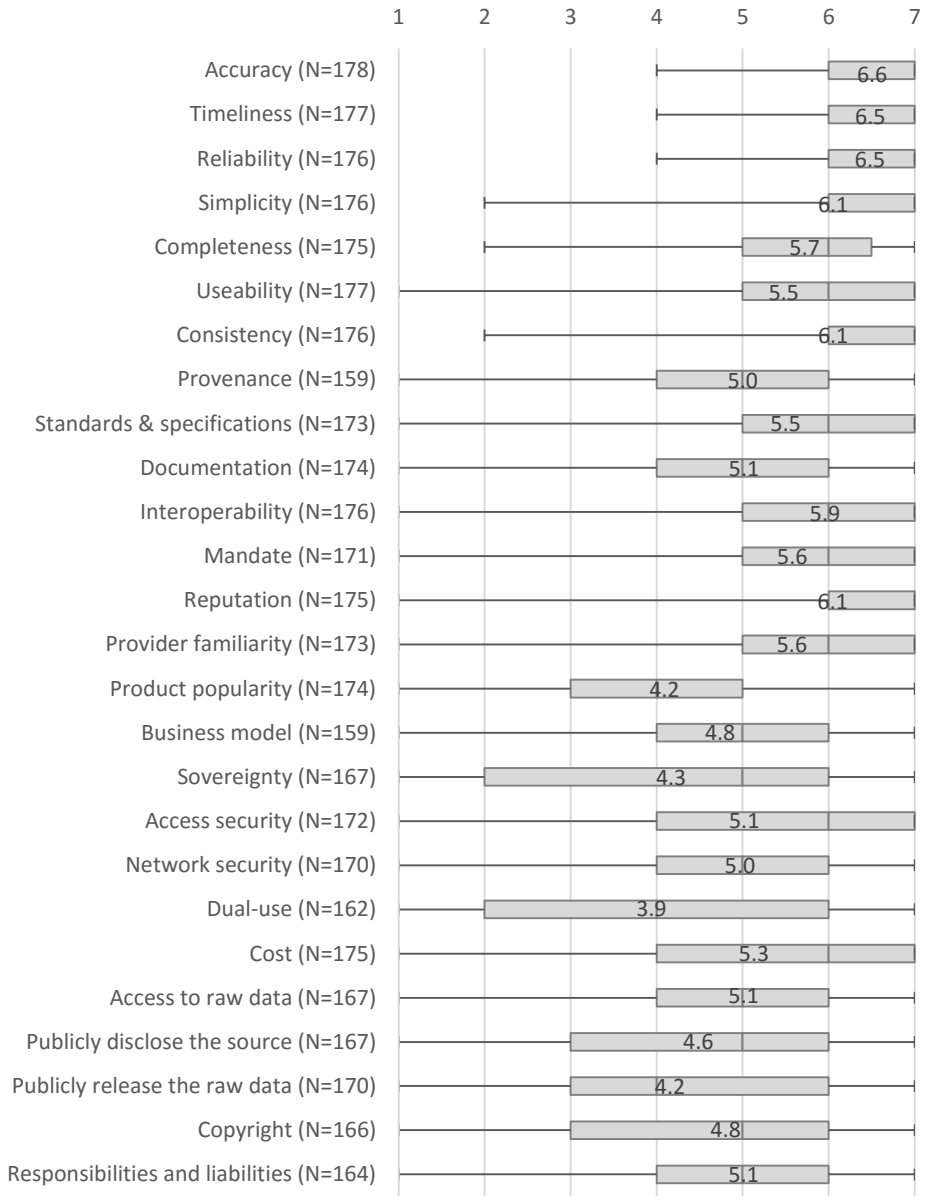


Figure 20: Box plot with mean value of survey response design choices affecting uptake (Questions 17-19).

The next Chapter in this thesis is focused on the design choices which lead to the uptake of sensor data in emergency management. To avoid repetition the study specific discussion focuses on views from the perspective of the sorting questions: age, experience, location, organisation type and area in the data supply chain. Appendix H presents the raw averages of questions 17-19 broken down by each of the sorting criteria.

As shown in Figure 20, Australian emergency managers believe the most likely design choices to inform decision making are accuracy (6.6), timeliness (6.5), reliability (6.5), simplicity (6.1), consistency (6.1) and reputation (6.1). The least important variables were dual-use (3.9), publicly release raw data (4.2), product popularity (4.2) and sovereignty (4.3). Of all the design choices the greatest range of answers or standard deviation was with sovereignty (2.0) and dual-use (1.9). In addition to the mean and standard deviation the number of responses or "N" value is also important because it gives an indication of the most misunderstood design choices which were provenance (159), business model (159) and dual-use (162).

Finding 33: Australian emergency managers believe the most likely design choices to inform decision making are accuracy, timeliness, reliability, simplicity, consistency and reputation. (Section 5.5.4)

Experience in the field showed little variation across the design choices. People with less than 5 years' experience found usability, provenance and business model to be significantly less important than the average (Usability 4.7/5.5, provenance 4.5/5.0 and business model 4.2/4.8). These three design choices are related to the ease of use or simplicity of a data product but no difference was found on simplicity (6.0/6.1). This could potentially lead to the conclusion that younger people feel more confident using data products and do not need as much assistance themselves but see the value in that assistance being available for other potential users.

There was a significant difference of opinion across the various states and territories of Australia as to what design choices are more important than others. In the ACT useability (6.1/5.5), copyright (5.4/4.8) and responsibilities/liabilities (5.8/5.1) are considered more important with mandate (4.9/5.6), sovereignty (3.2/4.3), access security (3.9/5.1), network security (4.1/5.0), dual-use (3.4/3.9) and cost (4.8/5.3) less important than in the rest of the country. This collection of design choices could be explained by the Federal government attempting to service many customers in all the states hence valuing open data release and less restrictive security while clearly enforcing attribution and liability in their data policies. New South Wales considers sovereignty (4.8/4.3) and access security (5.6/5.1) more important.

Provenance (5.6/5.0), documentation (5.7/5.1), sovereignty (5.3/4.3), access security (5.7/5.1), network security (5.8/5.0), dual-use (5.4/3.9), publicly disclose the source (5.4/4.6) and publicly release the raw data (4.8/4.2) are all greater than the national average in the Northern Territory. In Queensland mandate (6.2/5.6) and cost (5.8/5.3) are more important with provenance (4.2/5.0), documentation (4.6/5.1), interoperability (5.4/5.9) being less important. In South Australia the ability to publicly disclose the source (4.0/4.6) is less important. In Tasmania many design choices are less important including useability (4.8/5.5), business model (4.3/4.8), access security (4.5/5.1), access to raw data (4.5/5.1), publicly disclose the source (3.9/4.6), publicly release the raw data (3.5/4.2), copyright (3.4/4.8) and responsibilities/liabilities (4.1/5.1) with only provider familiarity (6.1/5.6) being more important than the national average. With almost all of the data policy design choices lower than the national average this could imply that Tasmania has been less exposed to data policy issues than the rest of the country. In West Australian useability (6.2/5.5) and cost (5.9/5.3) are more important with provider familiarity (4.9/5.6) being less important. Finally, Victoria has no design choices with views more than 0.5 away from the national mean, this is potentially due to greater recent focus on data related policy development such as the Victorian Information Network for Emergencies (VINE) project. While most states and territories agree on the relative importance of quality design choices, significant disagreements exist on reputational or data policy design choices.

The type of organisation also showed significant variation. Federal government is less interested in standards/specifications (4.8/5.5), cost (4.7/5.3) than the rest of the nation. Local government, researchers, private sector and NGOs all had 10 or greater design choices which were more than 0.5 away from the national mean and can be found within Appendix H. Finally State government has no design choices with views more than 0.5 away from the national mean.

Views vary slightly amongst younger emergency managers but otherwise are quite consistent. Emergency managers aged 35-49 and 50-64 do not have views more than 0.5 away from the national mean. Under 35s viewed many design choices as more important than the national average include product popularity (5.0/4.2), sovereignty (5.3/4.3), access security (5.6/5.1), dual-use (4.4/3.9), cost (6.0/5.3), responsibilities/liabilities (5.6/5.1). In fact the average of all design choices across age showed under 35's were generally more concerned than other age groups (4.6 vs 4.2 and 4.3).

Providers and users have similar views with value adders placing less importance on the majority of design choices. Providers were more concerned by restrictions on the data they provided such as publicly release the raw data (4.9/4.2) and responsibilities/liabilities (5.9/5.1) and less concerned with how the product was used such as standards/specifications (4.6/5.5) and interoperability (5.4/5.9). Value adders were less concerned about consistency or security than the national average as shown through the following design choices: standards/specifications (4.8/5.5), documentation (4.6/5.1), access security (4.4/5.1), network security (4.2/5.0) and dual-

use (3.0/3.9). Users did not express any views which were more than 0.5 from the national norm.

To check the results from questions 17-19, question 20 asked, "In your opinion, what are the most important features that a sensor data product must have if it is going to be used in a decision making process?" This free text answer had many responses but perhaps the simplest analysis of this data is the word frequency analysis technique used in Chapter four. Using the same technique, word frequency was extracted, similar words such as timeliness/timely were merged and the top six design choices mentioned were: accuracy (53 mentions), timeliness (47 mentions), reliability (39 mentions), ease (10 mentions), access (8 mentions) and source (7 mentions). These results agree quite closely with the results from the survey and provide a solid dataset of the most important design choices to consider in the next Chapter.

5.6 Summary of findings

Finding 24: 97% of emergency management survey respondents believe sensor data should be used in emergency management decision making. (Section 5.4.2)
Finding 25: The higher the level of product integration the higher the usage. (Section 5.5.1)
Finding 26: Availability of data, timeliness of data products and skills to use the data are the most common issues facing the emergency management sector. (Section 5.5.2)
Finding 27: Stakeholders higher up the supply chain have higher quality thresholds, meaning data producers and value adders often block products which are still useful to emergency managers. (Section 5.5.2)
Finding 28: Official data or data from an organisation with an official mandate is more trusted than data from an organisation without a mandate. (Section 5.5.3)
Finding 29: Advertising concurrent with data displays or portals negatively affects trust by emergency managers. (Section 5.5.3)
Finding 30: Emergency managers prefer data products to be delivered to them by a public institution even if the data was collected by the private sector. (Section 5.5.3)
Finding 31: Licence restrictions on the data product or the original source data can decrease the trust in a dataset. (Section 5.5.3)
Finding 32: Social media's emergence as a potential data source is contested with many people being uncertain about its role. (Section 4.5)
Finding 33: Australian emergency managers believe the most likely design choices to inform decision making are accuracy, timeliness, reliability, simplicity, consistency and reputation. (Section 5.5.4)

Chapter 6: Sector-wide barriers and product specific design choices

6.1 Aim and overview of this chapter

Chapter's three to five of this thesis examined different aspects of uptake for data products in emergency management. Chapter three looked at how various design choices affect the final output of a data product by comparing four medium resolution optical data systems. Chapter four examined the findings and recommendations of Australian disaster inquiries to look at how data has been used (or not used) in emergency management in Australia. Chapter five collected practitioner's perceptions on what drives uptake and the relative importance of specific design choices. This Chapter draws together content from all previous studies and the literature to:

- Discuss sector-wide barriers to the uptake of sensor data in emergency management;
- Synthesise an exhaustive list of product design choices which affect uptake;
- Discuss the definition, dimensions, importance and interactions of the above mentioned design choices; and
- Outline methodological weaknesses and future work.

Following this Chapter, a framework for sensor data product uptake for Australian emergency managers is presented.

The Chapter is structured as follows:

6.2 Sector-wide barriers to uptake

This thesis has a narrow aim, to determine how to improve the design of sensor data products to increase the likelihood that an emergency manager will consider it within decision-making. Before examining the design choices related to data products themselves, it is important to consider whether there are broader issues restricting the awareness, usage or uptake of sensor data within the Australian emergency management sector.

These broader sector-wide barriers are covered in the first half of this Chapter. These include variables that influence the way decision makers use information such as information overload, experience levels of the decision-makers and time constraints (Fisher and Kingma 2001). The limitations within the value-adder community including internal competition, risk-aversion and a blame culture are also explored.

6.2.1 Availability, timeliness and skills

Chapter five looked at survey responses from the Australian emergency management community. Questions 10 and 11 both asked about sector-wide issues affecting the uptake of sensor data. Question 10 asked "Which of the following issues do you think are relevant to the use of emergency management sensor data today?" The three most commonly rated issues were availability of data (87%), timeliness of data products (84%) and skills in the use of the data (81%). Question 11 built upon Question 10 by using a 1-7 relative importance judgement asking "How much do you think the following factors influence the use of sensor data in emergency management decisions?" Again the top three responses, all of which had low standard deviations, were as follows:

1. Lack of expertise and knowledge about sensor data (Mean 5.8, Std dev. 1.2).
2. Sensor data and its development is not a budgetary priority in emergency management agencies (Mean 5.3, Std dev. 1.5).
3. In emergency management decisions there is not enough time to take account of all the available data including sensor data (Mean 5.1, Std dev. 1.7).

A clear agreement can be seen between question 10 and 11 with skills and a lack of expertise, and timeliness, not enough time, the key results. The responses also highlight availability and budgetary priority, which while different issues, are related. This section focuses on these three key issues facing the industry as identified by the survey conducted in Chapter five: availability (including budgetary considerations), skills and timeliness.

Availability is the most common issue raised when talking about sensor data in disaster decision making. 87% of emergency managers raised availability as an issue. Availability however has different meanings for different groups of people. It is also a term which incorporates other factors including skills, timeliness, quality and cost. It is important to

consider these interrelationships when it comes to the availability of sensor data in disaster decision making.

Looking at the stages in the data supply chain, three main problems could be occurring to reduce availability. First, there is not enough data. Second, the data which is acquired is not reaching the users. Third, the data which is acquired is not reaching users in a usable form. Given this section of the discussion is focused upon sector-wide issues and not data product specific issues, the third issue of usability will be covered later in this Chapter when discussing data product specific issues. The question of whether the data which is acquired is the correct type of data, will also be covered in the data product specific section. Two issues therefore remain for discussion: not enough data or that data is not reaching users.

The hypothesis that emergency managers raise availability as an issue because there is not enough data being collected is unlikely. As discussed in Chapter three, more data is being generated than ever before; and its ability to reach users in real time is growing. With the number of devices, most of which are sensors, connected to the internet set to grow from 500 million in 2003 to over 50 billion by 2020 there seems to be no absence of sensors (Evans 2011). In addition, the projected growth in Earth Observations is set to grow to over 150 petabytes in 2030 for the climate domain alone, therefore it is not the quantity of data that is the problem (Overpeck et al. 2011). Finally, the World Meteorological Organisation alone generates data products for more than 260 processes on the Earth just in the weather and climate. There is a large and ever increasing number of sensors, data and data products. It is likely that there are some cases where there is not enough on a particular type of data source over a specific location, but based on the above evidence this would be the exception.

This leads to the second hypothesis: that existing data products are not reaching emergency managers. This hypothesis encompasses a number of different issues as shown by this free text response to the web survey:

> *“The timeliness and availability of "sensor assets" is a huge issue in disasters. I have experienced this locally during a disaster where it was difficult to find a "go to" point of contact in government (even through the disaster coordination centre) who understood the range of capability that could be brought to bear, and then have the ability to coordinate and act on it.”*

This quote brings up four separate issues: timeliness, awareness, governance and skills. In addition to these issues, there is also a question of which group of users sensor data may or may not be reaching.

Data not reaching users in time is a key factor in availability. Timeliness is a problem for both individual data products and for the sector. The survey results showed that not only is timeliness the second largest sector-wide issue, but there is also a strong relationship between how big of an issue timeliness is and how close the group is to a disaster. All response related

sectors had results greater than 84%, followed by only 50% of researchers believing timeliness of data products was an issue within the sector. Timeliness can be considered a sector-wide in the sense that governance or cultural issues may mean that information is blocked or slowed before it reaches end users.

Strong governance arrangements for data management and distribution can increase timeliness and availability while keeping costs lower. One common call is for greater centralisation for this function, one respondent argued:

> *"Australia needs a generic data suite, that is all hazards, that can be used across jurisdictions by agencies to provide a source of consistent data"*

Another respondent explains why strong governance can reduce the costs of data collection and distribution:

> *"Sensor to budgetary priority in emergency agencies should not be an issue. There is enough data from events that would allow a prudent collective return on investment business case to be developed that would encompass all agencies allowing them to fund their appropriate needs."*

Although sensor data not being a budgetary priority was the second largest concern in question 11 of the survey, governance plays a key role in determining whether budget is a problem or not, this in turn means that governance increases availability. Effective governance makes data providers easier to discover, reduces duplication and reduces costs of sensor data and associated development.

Skills and training is the third largest sector-wide issue which also is linked to availability. This can be best summed up by another survey respondent:

> *"There is no use having all the best satellites in the world when our disaster management system relies on the locals doing the ground work and not having or knowing about such information or assets being available. It's kind of like developing an evacuation route map and forgetting to educate the locals on what it is, where its found and how to use it."*

Increasing emergency manager's ability to use technology is a large issue but potentially not as simple as more skills and training. Skills was the third most common issue raised in the survey with 81% of respondents flagging it. As described in the free text responses, what is needed is "skills in analysis and interpretation". It could be said however, that data products suffer from a "lack of intuitiveness", as was posed by another respondent. Ten years ago large GIS teams used geo-routing algorithms of authoritative government datasets to calculate the faster way to get from point A to B. In 2015 it is common place for anybody to do this many times a day with their smartphone or computer. Regardless of whether training or intuitiveness is a larger problem one fact is clear – in the survey conducted in Chapter five new technologies (including social media and drones) from the last decade were either not at all or rarely, discussed. This implies that the average emergency manager has not dramatically increased

their technical skill in the last decade at a time when data products and services have become dramatically more useable and are continuing on that trajectory. As a consequence, the responsibility to address emergency manager's technical literacy is inevitably swayed towards useability not training. Both hypothesises, that emergency managers need more technical training and that products need to be more intuitive, are correct to a certain degree but as stated by this respondent it is more complex than simply these factors:

> *"Packaging of sensor data for easy consumption by incident managers is a challenge. Many incident managers are not technically literate so do now know how to use the data, or do not trust it.*
>
> *Accessing sensor data for L1 and L2 (Small and medium) incidents is extremely difficult."*

Data availability is different for different scale events and for different audiences. For example, in a keynote presentation to the 2011 Australasian Fire and Emergency Service Authorities Council Conference, the Queensland Fire and Rescue Service Commissioner Lee Johnson presented Figure 21 explaining the various groups involved in emergency management. Unlike most diagrams of this type, people were not split by location or disaster type, but by the actual roles they undertake.

Figure 21: Types and levels of disaster practitioners (Johnson 2011).

According to Johnson, emergency managers predominately work in two types of roles: disaster operations and incident management. Disaster operations personnel coordinate the response, while incident management personnel are more tactical and deal with specific incidents which combine to make up the disaster. This diagram reveals two separate audiences for disaster information. Firstly, overall disaster information for politicians, disaster managers,

media and interested members of the public is called disaster operations information. Secondly, specific incident information for incident managers and affected members of the public is called incident management information. From a data collection perspective, data for these two groups is often the same, but the product design for disaster operations and incident management must be quite different. Data products for disaster operations often generalise information and present historical context, while incident management information provides as much detail about the current event as possible.

The survey did not collect data about the specific role of respondents but both the inquiries study and survey responses focus the majority of negative feedback on incident management information, such as:

> *"I wish our supposedly World Class fire service actually had any of these things so that frontline fire officers have all the relevant info when making decisions on the fire ground."*

This leads to the conclusion that data is available but it is not targeted for incident management. This finding is supported by the sector breakdown of the survey responses. When looking at the sectors of people who flagged availability as an issue, people further away from the incident rated the issue as less important than people closer to the incident. 93% of NGOs rated availability as an issue while 75% of researchers rated it as an issue. This divide between the quality of data for disaster operations and incident managers could be caused by Federal and State government disaster mandates. Federal governments often are responsible for data capture particularly from larger collection platforms like satellites due to the cost. In Australia the Federal government, however, has a limited role in incident management, logically this leads to a situation where disasters operations personnel, in both Federal and State government, receive more targeted and higher quality data products due to the focus of Federal government resources and assets. Using Johnson's terms discussed in Figure 21, data appears to be more available to disaster operations professionals than to incident management professionals.

Finding 34: Sensor data is available to higher level decision makers but less available to front line incident management staff. (Section 6.2.1)

6.2.2 Producer community issues

The previous section explored sector-wide issues related to sensor data in disaster decision making. Through reviewing disaster inquiries, surveying emergency managers, and subsequent follow up, issues within the producer community have been shown to impact the use of sensor data for disaster decision making in Australia. This section will explore these issues.

These issues are sector-wide and affect all hazards, data types and quality of data products from the highly regarded weather forecast to new products just created.

In the early 1990s disaster experts coined the term 'Battle of the Samaritans' to describe inter-organisation competition and disagreement during disasters (Rosenthal, 't Hart, and Kouzmin 1991). This problem has developed in many guises including funding, mandate and even technology choices. Many types of responder collaboration are more rhetoric about collaboration than actual practical collaboration (Berlin and Carlström 2011). Regardless of the true state of collaboration as discussed by Rosenthal et al. (1991):

> *"By defining, funding and evaluating network-level projects and outcomes to supplement and partly replace existing funding/accountability streams of individual organizations, incentives can be created to take collaboration seriously, and improve interpersonal and interorganizational trust prior to crises."*

This Battle of the Samaritans has been further explored by Boin et al. (2005) who noted that not only do emergency management agencies participate in this battle but also *"Agencies representing different technologies of crisis coping find it difficult to align their actions"* (Boin et al. 2005, 12). In testing the survey scientifically trained personnel often suggested comparing which technology was 'better' demonstrating that different technologies and products are seen to complete with each other. What compounds this is that, as emergency management uses more scientific information such as sensor data, more scientists are involved. Scientists are by training critical and work in a system which promotes the critical assessment of other scientist's work, it is the basis of the scientific profession and it is called peer review. Peer review is exceptionally important between scientists but can be misinterpreted when conducted in public. This approach can result in confusion among the user community who cannot get clear technical advice on which products to trust.

The technological Battle of the Samaritans has led to many challenging battles (Berlin and Carlström 2011). The most traditional battles are between different emergency management services or between different levels of government such as between the Federal and State governments. Vanden Borre et al. (2011) examine settling divisions between ground based and space based observers but there are many other examples. Based on the author's professional experience, traditional adversaries never miss an opportunity to reignite old battles, these include, but are not limited to: Providers vs. value adders also known as data providers vs. cartographers, and the author's personal favourite numerical modellers vs. pure observers which is a particularly academic battle.

Finding 35: Technologies, often complimentary, participate in the Battle of the Samaritans to discredit other technologies and promote their own. (Section 6.2.2)

There are many potential solutions to this competitive culture which have been written about but all involved a form of aligning goals and objectives through co-production (Newhall with IAVCEI Subcommittee for Crisis Prot 1999; Aspinall et al. 2003; Aspinall and Cooke 2008).

Coproduction involves including all stakeholders from the conception of a product through to its final decommissioning. This approach can ensure that users get products which are not driven by a new technological innovation but an actual requirement. Of the 18 sensor data products found in the inquiries, only five of them or 28% were actual products the rest were raw sensors or data feeds. This implies that the remaining 72% of data feeds failed for some reason, potentially political constraints such as discussed above. Furthermore, the two data products which were mentioned the most, the weather forecast and warnings, are both mature integrated data products with a blend of satellite, aerial and ground data processed using observations and models. This also provides evidence that one individual measurement domain does not increase the likelihood of usage but integration of multiple domains does increase usage.

Given the wide variety of data sources and stakeholders the field of sensor data for emergency management suffers is prone to a lack of coherence. This not only makes the products less useable, but saps trust from data users. Groups who integrate technologies and avoid the Battle of the Samaritans are the most used products in the disaster sector.

Finding 36: Integration of technologies and co-production can reduce the Battle of the Samaritans. (Section 6.2.2)

6.2.3 Risk aversion

The inquiries study found only 35 mentions of data products in the 31 most data centric disaster inquiries in Australia's history. Meanwhile 111 concerns or comments placing blame on how data was collected or misused were found. This suggests a fixation on assigning blame after a disaster through the juridification of inquiries (Boin et al. 2005; Eburn and Dovers 2015). As described by Boin:

> *"Accountability is hollow when the investigation and debate that lie at its heart become ritualized." (Boin et al. 2005, 102)*

Scientific data is increasingly being used as a basis for important decisions by governments and individuals, and as evidence for policy development and policy implementation. There have been recent cases of scientific organisations being criticised or successfully litigated against due to the miscommunication of their data, or others misusing their data, such as in the 2009

L'Aquila earthquake or the 2010 Deepwater Horizons oil spill respectively (Alexander 2010; Cartlidge 2011; McNutt et al. 2011). These cases have led to a significant amount of research retrospectively studying the use of data in emergency response (Bojanowski 2011; McNutt et al. 2011; Camilli and D'Emilio 2012).

In response to the legal risks and blame culture risks, emergency managers fall back on rigid doctrine or Standard Operating Procedures (SOP). Originally doctrine was created to build clear command and control, giving clear instructions to all staff so everything goes according to the plan. Doctrine is now prevalent in the emergency management sector to protect agencies and individuals against blame falling upon them during the inquiry. Blame culture is so prevalent in Australia that, a common joke in emergency management sectors is that doctrine says the first step in any disaster is to sack the commissioner responsible for that disaster.

During an anonymised interview with researchers published in Eburn (2012a) one senior Australian fire officer described this problem as follows:

> *"... lawyers are writing the plans, or helping us write the plans. They are so prescriptive as to be almost irrelevant. Every operation has its own unique dynamic. Plans should be, you know, principle based and fairly broad and give a large landscape in which to operate with some principles in which to comply with.*
>
> *But we're getting so much prescription ... Well, that's great, but then you've got the documents and then you've got the environment which you've got to operate it within. I'm yet to be convinced that the two will ever align. ... So I don't think plans are a measure of success because they're becoming very legalistic." (Eburn 2012a, 8)*

In a follow up piece of research Eburn remarks that:

> *"At the moment, the true lesson from the last, and previous inquiries, it is that the single most important thing an incident controller must do, is keep the paperwork up to date; keep your eye not on the event but the next post event inquiry." (Eburn 2012b)*

Firstly, it is clear that the over use of lawyers and bureaucracy as a protection against other lawyers and bureaucracy is not where the public expects emergency managers to be focusing their effort and resources. Unfortunately, wasted time and resources are not the only impact of this problem. The blame culture created by this situation reduces innovation, and doctrine all but eliminates the possibility of emergency managers improvising during a disaster. This rigid operating environment in turn affects groups working with emergency managers such as sensor data producers and value adders. For example, emergency services doctrine demands the use of authoritative government topographic maps even though they are rarely updated and are generally out of date by a disaster. In this case Volunteer Geographic Information (VGI) is often captured to update a map which is no longer authoritative and hence usage of this product could break the doctrine of an agency (Rak 2013).

Finding 37: Rigid emergency management doctrine is not conducive to the acceptance of new technologies. (Section 6.2.3)

A disaster, by definition, is a situation which is so complex that it has broken the standard rules. Therefore professional judgement and improvisation plays a vital role in disaster management. In fact, improvisation is well known as a long standing key success factor for disasters (Mendonça 2007). The original study into improvisation's role in disasters looks at the role of a coffee bar after an earthquake in Southern Italy which was the key coordination point in the recovery, well before formal response organisations were able to respond (Lanzara 1983). More recently, improvisation and innovation have been popularised with NASA's response to the Apollo 13 disaster (Boin et al. 2005). As described most succinctly by Ciborra (1999, p. 77), *"improvisation is a well-grounded process that can be leveraged to face those situations where rules and methods fail".*

Lesson learning, doctrine, improvisation and innovation need to be balanced in disasters. This thesis has reviewed Australian disaster inquiries and shown that at times they can provide valuable insights and accountability, but often there is no evidence of lessons being learned. Lesson learning, particularly for technical matters such as sensor data, must become a more systematic and business as usual affair if it is to provide the maximum benefits. There may be something to learn from the transport sector where air accidents or traffic accidents are investigated by an independent and permanent organisation of subject matter experts. Doctrine is an important tool for justifying decisions and simplifying activities during a disaster, but according to Eburn (2012a) the sector seems to have focused solely on justifying decisions in recent times. Doctrine needs to be used to set out clear boundaries and suggested procedures while leaving room for improvisation and innovation where an activity could be too complex or too dynamic.

Finding 38: Lesson learning, doctrine, improvisation and innovation need to be balanced in disasters. (Section 6.2.3)

One area this thesis has significant implications for is the post disaster inquiry field. Contrary to the view that using sensor data products increases complexity, the likelihood of greater blame during post disaster inquiries is in fact reduced. Sensor data products can be used to justify decision making in disasters during an inquiry. Furthermore, it is common place for sensor data products, specifically maps, to be used to assist post disaster inquiries rather than

hinder. When, in a post disaster inquiry, emergency managers are asked to explain why a decision prioritised one option over another, sensor data can provide a solid, official piece of evidence which can be used to help defend emergency management decision making. During the case Warragamba Winery Pty Ltd v State of New South Wales (No 9) [2012] NSWSC 701 emergency managers were asked to explain why they had prioritised one fire and left another which subsequently burned the Warragamba Winery. One piece of evidence used in this case was the weather forecast whose wind direction forecasts were an important part of emergency management decision making and assisted in this case being dismissed. As discussed in section 6.2.2 integrated products can aid in their communication.

Finding 39: Sensor data when used as evidence to support decision making can reduce blame, particularly in post event inquiries. (Section 6.2.3)

6.3 Establishing a lexicon for data products

This thesis has shown that the literature, the moderate resolution optical data community, Australian disaster inquiry authors, and Australian emergency managers through survey responses all have different terms which either have an overlapping, similar or same meaning.

One of the most important first steps in starting a field of study on data product design choices is to clarify the terms and establish a common lexicon for all those in the field. This also allows emergency managers and product creators to communicate product requirements and the benefits and costs of various choices. Only through such communication can the right trade-offs be made in the design of products.

This section synthesises the dominant academic literature and results from the thesis to create a common lexicon for the design choices which drive the uptake of sensor data in emergency management. This synthesised list of design choices is then further explored for the remainder of the Chapter.

To generate this synthesised list, a wide net is cast to source all possible design choices raised in the literature (quality, legal and reputation) and the results of three studies conducted in this thesis. Each possible design choice is considered with the specific emergency management context in mind, and then either merged with a different term or dismissed as not relevant.

One concern raised by archivist or metadata specialists is how to address definitional specificity when definitions vary across different communities (Yoo and Harward 2013). Discussions about definitional specificity and accuracy have plagued academic communities for

centuries. This thesis, however, seeks to find a set of terms that are fit-for-purpose, that is that they get to the heart of the issue at hand and are comprehensible to the target audience (emergency managers/data users and data producers). This is sufficient because, firstly, this thesis is targeted at data production organisations developing products for emergency managers and the specificity of this target audience reduces the risk of definitional confusion. Secondly, recent advances in metadata technologies mean that different sectors can use different vocabularies. one technology specifically focused upon is the Resource Description Framework (RDF) as one of the central layers of the third version of the internet or Web 3.0 (Berners-Lee 2000; Bruce and Hillmann 2004; Duval et al. 2002). The implication of this is that the final terms used within this thesis are only important for conveying understanding to the reader. Different groups use different terminologies because it gives those sectors a sense of possession and ownership over a concept.

The section presents each possible set of choices in a table format, discussing their source, relevance and context, before reducing and refining the lists to consolidate a set a core design choices.

Turning now to the first set of design choices, Wang and Strong (1996) is the most accepted data quality work in recent history with over 1700 citations making it one of the most cited papers on the topic. Through the use of intuitive, theoretical and empirical studies Wang and Strong (1996) established a framework for assessing data quality which is the foundation paper on the topic. Wang and Strong's framework and a mapping to this thesis is outlined in the Table 23. The design choices are ordered from most important to least as presented in Wang and Strong (1996).

Table 23: Synthesis of design choices from Wang and Strong (1996) conceptual framework for data quality, design choices ordered by relative importance.

Design choice type (source)	Contributing design choices	Action
Data quality (Wang and Strong, 1996)	Believability	Adopted
	Accuracy	Adopted
	Objectivity	Covered by believability
	Reputation	Adopted and expanded to theme
	Value-added	Covered by relevance
	Relevancy	Covered by relevance
	Timeliness	Adopted
	Completeness	Covered by accuracy and maturity
	Appropriate amount of data	Covered by usability
	Interpretability	Adopted broadened to usability
	Ease of understanding	Covered by usability
	Representational consistency	Covered by usability
	Concise representation	Covered by usability
	Accessibility	Covered by usability
	Access security	Adopted broadened to security

As architects of Europe's data policy for the Global Monitoring for Environment and Security program, Europe's largest ever Remote Sensing program, Harris and Browning (2003) is a definitive work on data policy.

Unlike many other studies (such as Lowell et al. (2011) and Purdy (2010)), Harris and Browning (2003) provide a legally grounded perspective on data policy issues in remote sensing. Legal considerations are often instrumental in emergency manager's decisions about whether to use a given data set. In most cases disaster management data is supplied to emergency management agencies by other government agencies or the private sector. This reality means that the data policy and associated legal conditions used to supply data to the emergency management agencies is a critical design choice which can affect the trust of those data. For example, if a data provider offers a licence on a bushfire boundary map which only grants access to the map and not the underlying dataset, quality or process by which the map was created then no assessment of data quality can be made by the emergency management agency hence making them distrust that dataset. As described by von der Dunk (2008):

> *"It may perhaps come as an unwelcome surprise that such activities, normally undertaken with the best of intentions, might be subjected to legal scrutiny and run into legal obstacles or at least raise legal issues which may make potential rescuers think twice before doing the seemingly obvious."*

Harris and Browning's (2003) six data policy characteristics are synthesised in the Table 24.

Table 24: Synthesis of design choices from Harris and Browning (2003) data policy research.

Design choice type (source)	Contributing design choices	Action
Data policy (R. Harris and Browning 2003)	Ownership, privacy and confidentiality	Ownership adopted renamed data policy and privacy/confidentiality adopted renamed data source
	Intellectual property rights and associated legal frameworks	Grouped under data policy
	Standards and metadata	Covered by maturity
	Licensing, distribution and dissemination	Grouped under data policy
	Pricing policy	Grouped under data policy
	Archiving policy	Grouped under data policy

Artz and Gil (2007) provide a list of criteria for measuring trust and reputation in relation to content. Adding reputation and trust allows for consideration of broader issues than quality and legal considerations. It opens consideration of the more subjective reasons for uptake, or a lack of uptake. Reputation is at essence a measure of how much a community trusts an entity, based on their past performance.

Within economics and marketing literature the role of information on reputation is commonly analysed from a game theory and statistical perspective such as in Kreps and Wilson

(1982). While these methods contribute to the discussion later in the thesis they do not provide a set of design choices which contribute to reputation and hence a paper from these fields is not presented in this section.

Artz and Gil (2007) consider trust and reputation in relation to the semantic web. Their paper develops a list of design choices that influence content trust on the internet. This presents a good proxy for the scenario being considered in sensor data products. A subset of these design choices relate to the role of reputation in trust. While these design choices show a large degree of overlap with the previously discussed design choices they importantly add consideration of design choices in relation to modern technologies. For this reason Artz and Gil (2007) can be used to cover reputational design choices and also to provide some redundancy with other existing frameworks previously discussed. The 19 design choices proposed by Artz and Gil (2007) are presented and synthesised in the Table 25.

Table 25: Synthesis of design choices from Artz and Gil (2007) content trust on the internet research.

Design choice type (source)	Contributing design choices	Action
Content trust on the internet (Artz and Gil 2007)	Topic considered	Covered by relevance
	Context and criticality of the need for information	Covered by relevance
	Popularity of the resource	Adopted renamed popularity
	Recognized authority of associations	Adopted renamed mandate
	Reputation by direct experience	Covered by believability
	Referrals by other users	Covered by believability
	Association by other trusted resources (e.g., citations)	Covered by believability
	Provenance and pedigree	Covered by maturity
	Expertise of the user	Covered by usability
	Perceived bias of source	Covered by believability
	Perceived incentive in providing accurate information	Covered by believability
	Absence of other alternative resources	Covered by relevance or mandate depending on meaning
	Agreement with other resources	Covered by accuracy
	Precise and specific content	Covered by relevance
	Likelihood of content being correct given what is known	Covered by believability
	Time of creation of the content	Covered by timeliness
	Professional appearance	Covered by usability
	Likelihood of deceptive behavior	Covered by believability
	Recency of factors under consideration	Covered by timeliness

Transitioning from the academic literature to the studies conducted in this thesis, Chapter four on Australian disaster inquiries identified design choices which should be considered in the new lexicon. 31 inquiries in total were identified as data focused inquiries and examined in detail. In these inquiries 111 concerns or discussions about ways to use or improve data related products were identified. Many of these concerns were similar, or a specific component of a more general concern. For this reason the concerns were grouped. Table 26 shows the grouped concerns created from the Australian disaster inquiry study in Chapter four.

Table 26: Grouped concerns from Australia disaster inquiries.

Design choice type (source)	Contributing design choices	Action
Concern as stated in Australian disaster inquiry (Chapter 4)	Awareness	Covered by popularity
	Clarity of message	Covered by usability
	Cleaned of extraneous information	Covered by usability
	Common boundaries	Covered by relevance
	Consistency	Covered by accuracy and usability depending on context
	Consistent terminology	Covered by usability
	Efficiency of the system	Covered by timeliness
	Lack of a manual	Covered by maturity
	Lack of situational awareness	Covered by relevance
	Maturity	Adopted
	Repeatability	Covered by maturity
	Rigor	Covered by maturity
	Tightening of connections between staff	Covered by maturity
	Accuracy	Adopted
	Errors of commission	Covered by accuracy
	Errors of omission	Covered by accuracy
	Human error	Covered by accuracy
	Quality	Adopted
	Responsive	Covered by relevance
	Right time	Covered by relevance
	Timeliness	Adopted
	Coverage	Covered by relevance
	Detection without identification	Covered by relevance
	Extent of detail	Covered by usability
	Fitness for purpose	Covered by usability
	Relevance	Adopted
	Right information	Covered by relevance
	Tailored	Covered by relevance
	Coordination	Covered by believability
	Cost	Adopted
	Effective use	Covered by believability
	Effectiveness	Covered by believability
	Funding	Covered by believability
	National coordinated	Covered by believability
	Optimisation	Covered by maturity
	24 hour availability	Covered by reliability
	Availability of communications	Covered by reliability
	Redundancy	Covered by reliability
	Reliability	Adopted
	Scalability	Covered by reliability
	Availability	Covered by reliability
	Frequency	Covered by relevance
	More monitoring	Covered by relevance
	Dissemination	Covered by usability
	Omitted data	Covered by usability or believability depending on context
	Over aggregation	Covered by usability
	Presentation	Covered by usability
	Right form	Covered by usability
	Technical means of filtering/triaging inputs	Covered by usability
	Misinformation	Covered by believability
	Not relied upon	Covered by believability

	Rumours	Covered by believability
	Trust	Adopted
	Availability of experts	Covered by believability
	Experience	Covered by believability
	Lack of knowledge	Covered by believability
	Training	Covered by believability
	Authorising environment	Covered by maturity
	Culture	Covered by reputation
	Data used too late	Covered by timeliness
	Information flow to decision makers	Covered by maturity
	Accessibility	Covered by usability
	Availability of maps in the field	Covered by usability
	Uptake	Subject of investigation
	Flexibility	Covered by relevance
	Interoperability	Covered by maturity
	Third party source	Covered by data source

Chapter five presented a survey of the Australian emergency management practitioners. Questions 17-19 asked for a quantitative 1-7 judgement of, "Which quality, reputational and data policy factors affect the likelihood of a sensor data product being used to inform an emergency management decision?" Table 27 shows the design choices surveyed in the three questions:

Table 27: Grouped concerns from web survey results.

Design choice type (source)	Contributing design choices	Action
Web survey questions 10-13 (Chapter 5)	Accuracy	Adopted
	Timeliness	Adopted
	Reliability	Adopted
	Simplicity	Covered by usability
	Completeness	Covered by accuracy and maturity
	Useability	Adopted
	Consistency	Covered by accuracy and usability depending on context
	Provenance	Covered by maturity
	Standards & specifications	Covered by maturity
	Documentation	Covered by maturity
	Interoperability	Covered by maturity
	Mandate	Adopted
	Reputation	Adopted
	Provider familiarity	Covered by believability
	Product popularity	Covered by popularity
	Business model	Covered by relevance
	Sovereignty	Covered by data source
	Access security	Adopted broadened to security
	Network security	Adopted broadened to security
	Dual-use	Covered by data source
	Cost	Grouped under data policy
	Access to raw data	Grouped under data policy
	Publicly disclose the source	Covered by data source
	Publicly release the raw data	Grouped under data policy
	Copyright	Grouped under data policy
	Responsibilities and liabilities	Grouped under data policy

Finally, in addition to questions 17-19 of this survey a free text response field was offered in Question 20 to the question, “In your opinion, what are the most important features that a sensor data product must have if it is going to be used in a decision making process?” This free text answer had many responses but perhaps the simplest analysis of this data is the word frequency analysis technique used in Chapter five. Using the same technique word frequency was extracted, similar words such as timeliness/timely were merged and the top 5 factors mentioned were: Accuracy (53 mentions), timeliness (47 mentions), reliability (39 mentions), ease (10 mentions), access (8 mentions) and source (7 mentions). These results agree quite closely with the results from the survey.

Table 28: Grouped concerns from word frequency analysis of web survey results.

Design choice type (source)	Contributing design choices	Action
Web survey free text word frequency analysis (Chapter 5)	Accuracy	Adopted
	Timeliness	Adopted
	Reliability	Adopted
	Ease	Covered by usability
	Access	Covered by licencing
	Source	Covered by data source

The limitations of the above method have been previously explored in Chapter five and although the method is subjective, it is only a starting point or hypothesis which is required to further progress the stated research questions.

As a result of the above iterative process of elimination and narrowing, a smaller number of key data design choices remain relevant to emergency management. Table 29 is the result of the above synthesis with several topics to be explored further during the remainder of this chapter including data policy, maturity and trust:

Table 29: Synthesised list of design choices affecting uptake.

Headline design choices affecting uptake	Design choices
Quality	Accuracy
	Relevance
	Timeliness
	Usability
Data policy	Data policy
Reputation	Believability
	Data source
	Mandate
	Popularity
	Reliability
	Security
Maturity	To be established
Trust	To be established

6.4 Data product design choices affecting uptake

This section discusses the list of synthesised design choices affecting the uptake of sensor data in decision making by emergency managers in Australia. The objectives and structure of this section are:

- Describe each design choice;
- Present the evidence collected throughout this thesis for why each of these design choices are important to uptake;
- Discuss the various settings and importance of each design choice; and
- Discuss the interrelationships between different design choices.

The evidence collected for each design choice will be presented in a summary Table. These Tables will bring together every contributing design choice outlined in Section 6.4 from the previous six tables (three publications and three studies) used to synthesise the list of design choices. All of these contributing design choices will be collected within an evidence table for each of the design choices outlined in Table 29. The contributing design choices which were not made a design choice in Table 29 will be referred to as design levers and will form the bottom level of the framework developed in this thesis. Table 30 is an example of the evidence tables used for each of the 16 design choices defined in this section:

Table 30: Example evidence Table for the design choice.

Design choice/ lever	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Example	8 (3/67)	176/171	6.1/5.3	1.0/1.4	Private sector 6.6	53 (1/6)

The Table shows the number of mentions a given design choice had within the disaster inquiries study (Chapter four) and its ranking compared with other design choices. Next, the Table presents the results from the survey (Chapter five) showing the number of responses which mentioned that given issue and the mean number of responses. Next the mean is presented along with the mean of all responses, indicating the relative importance of the design choice. Next the standard deviation is presented along with the mean standard deviation which indicates the spread of responses. The outliers for each respondent profile then demonstrate different opinions across different groups including age, experience, role and location. The final column in the Table shows the word count and ranking out of six used within the free text response in question 20 of the survey (Chapter five). Note that the previous section can

highlight a contributing design choice in the literature which did not appear in any of the three studies hence will appear as a blank row.

6.4.1 Quality

Quality is a headline design choice made up on four design choices: accuracy, relevance, timeliness and usability.

Wang and Strong (1996) established a framework for assessing data quality using several groups to describe fifteen key features of data quality under the following areas: intrinsic data quality, contextual data quality, representational data quality and accessibility data quality.

The reason why this thesis does not simply adopt this framework is clearly stated in the conclusion in Wang and Strong (1996, p. 21), "to improve data quality, we need to understand what data quality means to data consumers (those who use data)." This thesis is targeted at improving data products for Australian emergency managers which alters the data quality priorities. For example, rather than being the 9th most important design choice, timeliness takes on high priority in an emergency management context. Due to the need to tailor a framework for a given audience data quality holds different meanings to different audiences.

ISO 9000:2005 defines quality as the "degree to which a set of inherent characteristics fulfils requirements". Simply, data quality measures how much a representation, such as a data product, reflects an object or process, such as a flood moving across the landscape. This involves many different design choices. The synthesis of terms based on available evidence demonstrated that accuracy, relevance, timeliness and usability and are key features of quality for emergency management products.

Due to the breadth and diversity of opinions on data quality, not many direct observations were made on the term quality in studies, the only study involving quality directly was the inquiries study whose results is summarised in the Table 31.

Table 31: Design choices and levers for quality and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Quality	4 (5/67)					

The synthesised lexicon established in Section 6.3 presents three groups of design choices: quality, data policy and reputation. Accuracy, relevance, timeliness and usability which make up quality, all score highly in all three ranking studies presented in this discussion. For this reason,

quality is the most important of the three groups of design choices when you examine the relative importance of its contributing design choices. Quality is key to increasing the uptake of data in emergency management. Quality also has many links with reputation related design choices. These links are covered in the reputation section of this Chapter.

6.4.1.1 Accuracy

Accuracy is the first design choice under the quality headline design choice.

Quality is a measure of how much a representation, such as a data product, reflects an object or process. This includes a measure of how well the product is presented to an audience and how well the product represents the true or accepted values the object or process. Accuracy is the measure of the latter – the closeness of agreement between an observed value and the true value. Two other terms require definition to understand accuracy, these are error and uncertainty. Error is the amount by which an observation differs from its (unobservable) true value. Uncertainty, while highly context specific, is the measure of error about a given measurement or circumstance.

Accuracy can refer to many different aspects of a data product such as positional, temporal or thematic accuracy. Table 32 summarises the generic and specific quality indicators used by the Global Earth Observation System of Systems clearinghouse.

Table 32: Generic and specific quality indicators used by the Global Earth Observation System of Systems clearinghouse (Yang et al. 2013).

Generic quality indicators	Specific quality indicators
Positional accuracy	Absolute external positional accuracy
	Gridded data positional accuracy
	Relative internal positional accuracy
Completeness	Completeness commission
	Completeness omission
Logical consistency	Conceptual consistency
	Domain consistency
	Topological consistency
	Format consistency
Temporal accuracy	Accuracy of a time measurement
	Temporal consistency
	Temporal validity
Thematic accuracy	Quantitative attribute accuracy
	Non-quantitative attribute accuracy
	Thematic classification correctness

Accuracy is generally a quantitative measure, such as 98% accurate which means that 2% of the product is attributed to error or random probability. Accuracy is changed through improvements in the processing or interpretation of a data product such as discovery of a new algorithm. This type of discovery is common, the following papers are all examples of new breakthroughs to improve the accuracy of one specific type of moderate resolution optical data: Masek et al. (2006); Irish et al. (2006) ; (Zhu and Woodcock 2012); and Li et al. (2012). These

new algorithms and processing techniques generate imagery to represent the Earth's surface so accurately that the effects of the atmosphere, terrain shadow, clouds and cloud shadows can be removed or masked.

Table 33 summaries the design choices for accuracy and their related results from the various studies conducted in this thesis.

Table 33: Design choices and levers for accuracy and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Accuracy	9 (2/67)	178/171	6.6/5.3	0.7/1.4		53 (1/6)
Consistency	8 (3/67)	176/171	6.1/5.3	1.0/1.4	Private sector 6.6	
Completeness		175/171	5.7/5.3	1.0/1.4	Research sector 6.3 Private sector 6.4	
Errors of commission	1 (=67/67)					
Errors of omission	1 (=67/67)					
Human error	1 (=67/67)					
Agreement with other resources						

Australian emergency managers believe the most likely design choices to inform decision making is accuracy. Accuracy is the most obvious and commonly considered form of data quality because if a product is not accurate then it may not be able to relate the observed object or feature to the data which was acquired for that purpose. For this reason accuracy is arguably the most important design choice leading to the uptake of a data product in disaster decision making because without accuracy a data product does not represent information that is useful to emergency managers.

Consistency can be discussed in the context of both accuracy, i.e. consistency across a product, and usability, i.e. consistency of user experience. Depending on the literature completeness can be a function of either accuracy or maturity. In this thesis completeness more logically aligns with maturity hence is discussed in the maturity discussion of this Chapter.

6.4.1.2 Relevance

Relevance is the second design choice under the quality headline design choice.

According to Sperber and Wilson (1987, p. 700) relevant information is *"information likely to bring about the greatest improvement of knowledge at the smallest processing cost"*. This process of communicating relevant information is inherently complex because it requires that the sender of information knows enough about the receiver to be able to improve the receiver's level of knowledge. Relevance not only requires a judgement of the receiver's level of knowledge but also a level of knowledge about how the receiver views and describes the world, this is called context. Finally this exchange must take place *"at the smallest processing cost"* which means that it must be precise and not require further consideration, or processing on behalf of the recipient, to maintain relevance. The assumptions that a sender of information must know the level of knowledge of a receiver, their context and deliver the message as precisely as possible makes relevance subjective and complex.

Based on the above definition, for a data product to be relevant it must be presented at the correct level of technical knowledge for the receiver, in their local vocabulary or context and finally be delivered as succinctly as possible. To achieve optimal relevance according to Sperber and Wilson (1987, p. 704) you must satisfy two related criteria:

> *(a) The set of assumptions / that the communicator intends to make manifest to the addressee is relevant enough to make it worth the addressee's while to process the ostensive stimulus.*
>
> *(b) The ostensive stimulus is the most relevant one the communicator could have used to communicate.*

What this means is that a data product must add more knowledge to an emergency manager than the effort it takes to understand that information. Furthermore the product must be delivered in the emergency manager's optimal circumstance. This means that all presentational design choices must be tailored to the emergency manager including but not limited to delivery format, delivery medium and level of processing.

Table 34 summaries the design choices for relevance and their related results from the various studies conducted in this thesis.

Table 34: Design choices and levers for relevance and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Relevance	3 (=9/67)					
Business model		159/171	4.8/5.3	1.6/1.4	Research sector 5.5 Private sector 5.6 NGO sector 4.0 < 5 yrs. experience 4.2 Location TAS 4.3	
Coverage	3 (=9/67)					
Detection without identification	1 (=67/67)					
Right information	1 (=67/67)					
Frequency	1 (=67/67)					
More monitoring	1 (=67/67)					
Tailored	1 (=67/67)					
Lack of situational awareness	1 (=67/67)					
Responsive	1 (=67/67)					
Right time	1 (=67/67)					
Flexibility	1 (=67/67)					
Common boundaries	1 (=67/67)					
Value-added						
Topic considered						
Precise and specific content						
Absence of other alternative resources						
Context and criticality of the need for information						

Since relevance is a function of the individual user's knowledge and context, the settings for each design choice vary with each user. The Table above provides examples of potential

design levers. These levers can be divided into fitness for purpose (reflecting the users knowledge) and context specific. Fitness for purpose means that the data product is pitched at the audience at the correct level, i.e. the product adds to the audience's knowledge. For example, in the border protection community rapid detection of a vessel is generally not enough information to increase a user's knowledge. They would require identification of the vessel to make it worth their while consulting a new source of data. Context specific means you must present the product in the manner in which it would be expected within that community. This means regardless of whether the product creator believes their product is superior if it is present out of the audience's context it takes more time to understand hence lowering its relevance and increasing the likelihood of not being used in a time sensitive decision.

Relevance and coverage are in the top ten most mentioned terms in the inquiries study. In the survey the highest score any design choices source is 4.8 for business model which is below the 5.3 mean for the survey. Relevance comes up consistently in multiple contexts.

The absence of other alternative resources is related to both relevance and mandate depending on meaning. When the safety of human life is involved it is important to have a justification of every choice made in the management of that emergency. To manage this requirement emergency managers often default towards "authoritative" data product or products which are official and made by an entity with a mandate to produce the data product. For this reason when there are multiple data products available for a given variable in a disaster, emergency managers often choose the authoritative data product even if there is significant evidence that there is a higher quality (or more relevant) data product available.

Relevance, specifically business model, has significant links with timeliness. For a data product to be relevant it must be available when required. Data products and many data collection platforms, mostly satellites, can operate in two main business models – ad hoc production or rolling production for data products and tasked capture or ongoing capture for data collection. Rolling production and ongoing capture is significantly more expensive. Ad hoc production and tasked capture generally require long lead times, sometimes of several days when scheduling a capture into an orbiting satellite. Disasters require information at short notice, this means that by the time a disaster has been declared it is often too late to commence ad hoc capture before the data loses its relevance.

This reality is shown in the inquiries study where the three products with the highest usage are all ongoing capture and rolling production products (weather warnings, weather forecast and positioning). This suggests a need to move from creating maps in response to a fire disaster to mapping all fires in case any of them become disasters. As described in the Council of Australian Governments' report *Natural disasters in Australia: Reforming mitigation, relief and recovery* there is a need for a "fundamental shift in focus towards cost-effective and evidence-

based disaster mitigation" and that this shift "represents an historic move beyond disaster response and reaction, towards anticipation and mitigation".

6.4.1.3 Timeliness

Timeliness is the third design choice under the quality headline design choice.

In the context of sensor data, timeliness relates to the time it takes to convert and transport an observation to the decision maker in a relevant format. Wang and Strong (1996) present timeliness as the age of a dataset. This definition is limited because it leaves some ambiguity about whether it refers to the age of a data set or the age of a data product, i.e. when the product became available to a user. This distinction is important in emergency management and so timeliness is taken to mean the time from capture to delivery of the data product to the user.

As discussed in Chapters two and three, making a product available involves moving the observation from the data collection platform to a processing facility, processing the observation into the variable desired by the decision maker, checking or validating that the calculated variable is accurate, representing that variable in the desired format and transporting that data to the decision maker. Each of these steps can take from milliseconds to months depending on the size of the dataset, the amount of automation and various other design choices.

One related term is currency. According to Loshin (2010) currency is:

> *"the degree to which data is current with the world that it models. Currency can measure how up-to-date data is, and whether it is correct despite the possibility of modifications or changes that impact time and date values. Currency rules may be defined to assert limits to the lifetime of a data value, indicating that it needs to be checked and possibly refreshed."*

Currency refers to shelf life while timeliness refers to delivery speed. Given currency is a function of how often data is captured, it will be incorporated in discussion of the technical selection of the data source, Section 6.4.3.2.

Table 35: Design choices and levers for timeliness and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Timeliness	12 (1/67)	177/171	6.5/5.3	0.7/1.4	Local Govt. Sector 7.0 Research sector 7.0	47 (2/6)
Efficiency of the system	1 (=67/67)					
Data used too late	1 (=67/67)					

Time of creation of the content						
Recency of factors under consideration						

Timeliness is a measure of time between data acquisition and product delivery, as it is generally measured in minutes or years. In Australia emergency management has been split into four phases for the past 20 years, these phases are Prevention, Preparedness, Response, Recovery or PPRR for short (Attorney-General's Department 2009; Emergency Management Australia 2004; Cronstedt 2002). Depending on what the data will be used for the requirement in terms of timeliness changes. Figure 22 illustrates "implied service levels" or timeliness metrics for different circumstances.

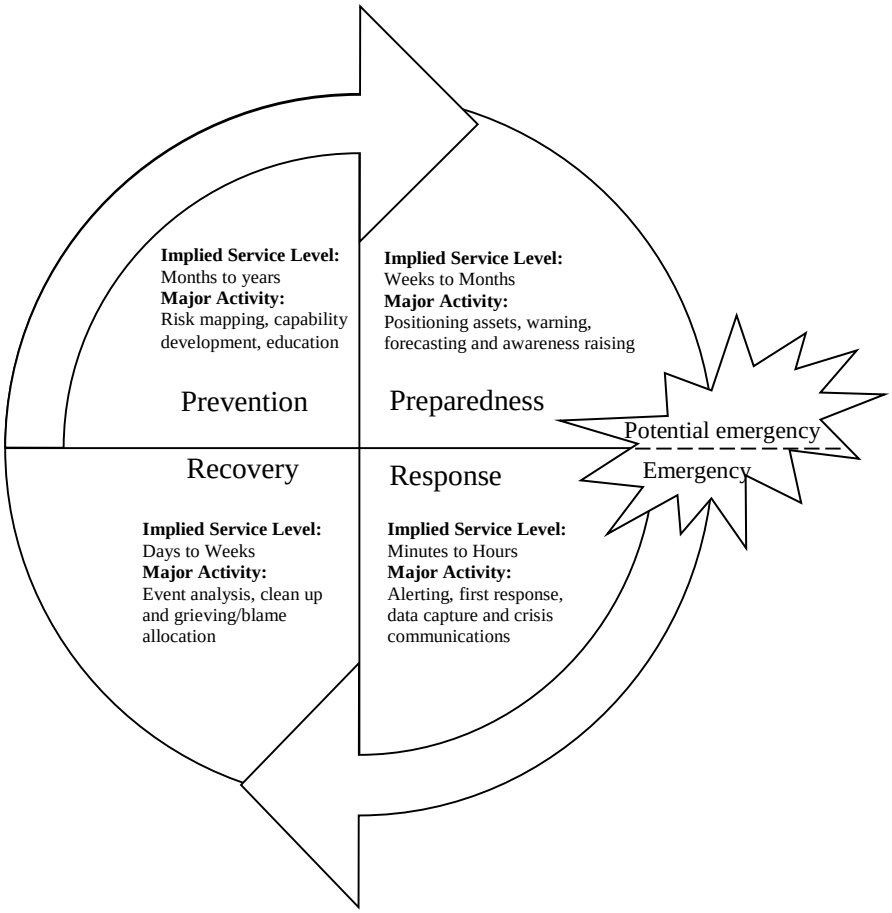


Figure 22: Prevention, Preparedness, Response, Recovery emergency management framework. Adapted from (National Governors' Association. Emergency Preparedness Project 1979; Cheyne 2011).

Harris (2014) argues that, timeliness is not only an important design choice in increasing the uptake of a data product in disaster decision making but could potentially be the most important design choice. Australian emergency managers rated timeliness as the second most likely design choices to affect decision making. It is important because if a product does not arrive before the decision it is supposed to inform then it cannot be used. The following two free text responses from the survey expand on this point:

> *"No matter how good the sensor data is - if the emergency has passed before the sensor information has arrived then it is tantamount to being irrelevant."*

> *"As an example from personal experience, a map produced by professional cartographer and available 6 hrs after the data is received is no use to a fire crew, (though it will be of great value to the subsequent Royal Commission) whereas a sketch map traced onto a photocopied sheet available 5 minutes after the helicopter lands is much more use in dealing with the incident."*

As discussed in Chapter three, there is an inverse relationship between accuracy and timeliness (Ballou and Pazer 1995; Cooper and Kleinschmidt 1994). Wright (2001) was the first to apply this to emergency management. He illustrated the inverse relationship held in the context of flash floods. Figure 23 shows the trade-off between warning time and flood forecast accuracy.

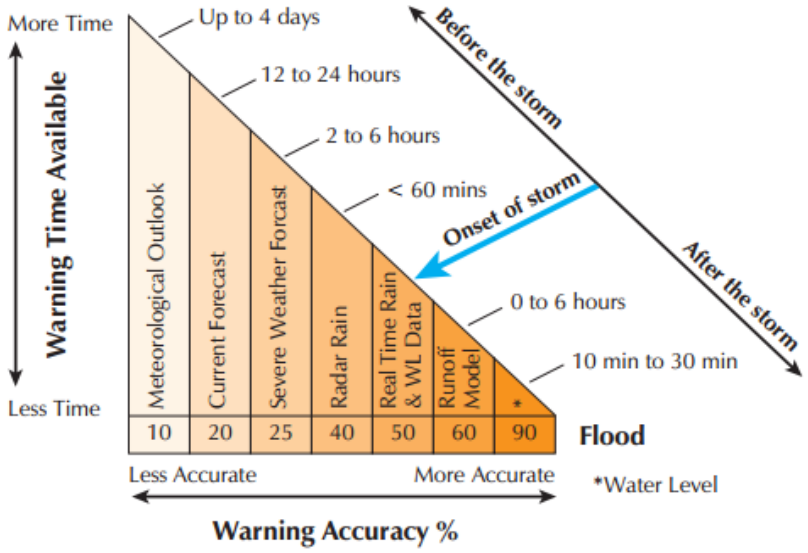


Figure 23: Trade-off between timeliness and accuracy for flash flood situations (Wright 2001).

Where Wright's (2001) analysis is limited is that timeliness and accuracies for data products are not always fixed quantities, they can be adjusted. Wright (2001) argues that if data products do not meet the user's requirements then you should try another data product. This misses the fact that data producers have a large number of design choices that can influence timeliness and accuracy. This area of influence is central to this thesis.

Through many post-event inquiries the following line is a reoccurring theme, 'we made the decision based upon the best available data at that time'. Noting the inverse relationship between timeliness and accuracy this raises the following three questions:

1. Do decision makers need to request the latest data before they make a decision or disclose when a decision is about to be made?
2. What quality of data product is required to make what decision particularly when the choices are poor quality or no data?
3. Can you dynamically update the quality of a dataset as time progresses before the next dataset becomes available?

Currently the status quo is such that decision makers expect data producers to generate products to an accuracy they define as high enough through trial and error. Then producers attempt to reduce the timeliness as fast as possible. This process is generally conducted with little consultation such as through annual conferences or during disaster responses. In some cases cooperative approaches between producers and users are used but this is still not focused on designing the optimal timeliness vs. accuracy. While the cooperative approach is preferable because other approaches involve a highly inefficient iteration process where the producer takes the product away then comes back with the next version. In addition all of these approaches are driven by the technology and are models where the producer is pushing the technology onto the user. A different approach which has become increasingly popular within the literature is that of coproduction (Ostrom 1996; Jasanoff et al. 2004). Applying this process to emergency management data product development would involve emergency managers taking a step back from technology and clearly stating what information they need, to what accuracy and how quickly. Following this the emergency manager would be involved available to the creators to clarify requirements as they arouse. What appears to be missing is a clear statement from the decision maker is how, in detail, they would decide to trade-off between information type, quality and timeliness. This concept is often known as opportunity cost.

Timeliness is also linked with blame in disaster inquiries. Data producers and value adders have noted the increasing risk to data custodians being blamed during and after disasters. In an effort to lower custodial risks, producers and value adders use three common choices. They can stop producing the product, add restrictions/indemnities to their data policy, or increase their accuracy thresholds for the product. Higher accuracy thresholds set by data suppliers mean that many data products will not meet the timeliness requirements to achieve relevance in a given disaster. The conclusion of this is that the blame culture developing around emergency management is leading to less sensor data evidence being considered in decision making. It would seem that disaster inquiries aim to increase evidence based decision making during disasters but in the area of sensor data may be having the opposite effect.

Finding 40: The balance between accuracy and timeliness is complex and must be actively managed. (Section 6.4.1.3)

According to the 2009 Victorian operational debrief report for the 2008/09 fire season, *"the flexibility of current mapping systems can compromise consistency and speed of production"* (Fox and Major 2009, 40). This assertion has serious consequences. As discussed in the relevance section, tailoring to the user community is essential to ensure a product is relevant. One design choice to increase the likelihood of a tailored solution is increasing the flexibility of the product or delivery system so users can customise the platform to suit their

needs. While the specific example is not clear, Fox and Major (2009) appear to have used a system where so much customisation has been offered that it has reduced the timeliness and hence relevance of a sensor data product.

6.4.1.4 Usability

Usability is the fourth and final design choice under the quality headline design choice.

Usability is a measure of the ease of use of a user interface. According to Nielsen (2012), usability can be broken into 5 contributing design choices:

1. *Learnability: How easy is it for users to accomplish basic tasks the first time they encounter the design?*
2. *Efficiency: Once users have learned the design, how quickly can they perform tasks?*
3. *Memorability: When users return to the design after a period of not using it, how easily can they re-establish proficiency?*
4. *Errors: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?*
5. *Satisfaction: How pleasant is it to use the design?*

Usability has historically focused on unquantifiable design choices such as presentation or simplicity but more recently the term has been used to describe regulatory requirements such as disability accessibility features of a website or data product. Usability also maintains the focus on the requirements of the specific user group differentiating it from simplicity which is a universal term.

Table 36: Design choices and levers for useability and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Usability		177/171	5.5/5.3	1.3/1.4	Private sector 5.4 < 5 yrs. experience 4.7 Location ACT 6.1 Location TAS 4.8 Location WA 6.2	
Simplicity		176/171	6.1/5.3	1.0/1.4	Research sector 6.7	
Consistency	8 (3/67)	176/171	6.1/5.3	1.0/1.4	Private sector 6.6	
Ease						10 (4/6)
Accessibility	2 (=12/67)					
Availability of maps in the field	1 (=67/67)					
Clarity of message	1 (=67/67)					
Cleaned of extraneous information	1 (=67/67)					
Consistent terminology	1 (=67/67)					
Extent of detail	1 (=67/67)					
Fitness for purpose	1 (=67/67)					
Dissemination	1 (=67/67)					
Over aggregation	1 (=67/67)					
Presentation	1 (=67/67)					
Right form	1 (=67/67)					
Technical means of filtering/triaging inputs	1 (=67/67)					
Omitted data	1 (=67/67)					
Appropriate amount of data						
Ease of understanding						
Representational consistency						
Concise representation						
Expertise of the user						
Interpretability						
Professional appearance						

Although efforts like the Web Content Accessibility Guidelines (WCAG) have tried to quantify usability (Caldwell et al. 2008), generally usability is considered to be a more subjective design choice. Usability does not exist as a binary usable or not usable. A data product can have poor usability, through a continuum of adequate usability then a threshold is crossed and a product could be highly usable. Many design choices such as availability of a product in a certain format are simple to identify but usability can also include highly subjective user requirements. As one survey respondent describes:

> *"Granularity of data - too much information can impede interpretation; vs. too little information makes it hard to make an informed decision."*

This example shows that usability is more than implementing more accessibility features in a data product or system but ensuring that the scale of problem and product are aligned. The subjectivity of usability is also related to the level of experience of the user. As discussed in the web survey, less experienced staff feel that the time it takes to become familiar with a dataset is less important than more experienced staff implying that they feel they can adapt or learn faster. Australian emergency managers rated simplicity and consistency as equal fourth most important design choice to improve uptake.

Finding 41: No product is too complex to be simple to use. (Section 6.4.1.4)

Usability has some links with accuracy and believability. As discussed previously and in Yang et al. (2013) some communities, including the GEOSS clearinghouse, consider consistency to be a measure of accuracy. This refers to logical consistency within the actual data but in the context of usability it can also refer to consistency of a user experience when using a system. Omitted data is sometimes required to make sure the data product is pitched at the correct audience in the context of the granularity of data but it can also be a negative when excluded to manipulate results. As such usability has a relationship with believability which is discussed later in the chapter.

6.4.2 Data policy

Data policy is a headline design choice with no contributing design choices but several design levers – this is due to its consistently low rating of importance in all studies.

Data policy is a legal policy area which focuses on the access and usage constraints placed on data and the codifying of these constraints into a legal instrument such as a licence. In von der Dunk (2008), "Legal aspects of using space-derived geospatial information for emergency response" summarises the main legal issues for data for emergency response as: copyright,

access, liabilities and dual use. The first three of these are data policy design choices and the last is a data source design choice.

Turning to what elements constitute data policy, Harris and Browning (2003) outline six data policy characteristics. They are: ownership, privacy and confidentiality; intellectual property rights and associated legal frameworks; standards and metadata; licensing, distribution and dissemination; pricing policy; and archiving policy. Of these six design choices four are considered data policy design levers, standards/metadata fall under maturity and ownership/privacy/confidentiality are a mix of data policy and reputational design choices.

Based on a synthesis of von der Dunk (2008) and Harris and Browning (2003) the following design levers contribute to data policy in the emergency management context. Note that archiving, which was identified by Von der Dunk, has been rolled into responsibilities:

1. Ownership
2. Intellectual property
3. Pricing policy
4. Responsibilities
5. Licencing

All of these issues are, however, tightly interconnected. For example, intellectual property rights are described in licences and implemented through pricing policies. For this reason all of the five data policy design choices are covered under the data policy section rather than as individual sub headings. This condensation is required to address the interconnectivity of the design choices and reduce duplication.

Ownership of a data product has been a moderate but continuing issue when using commercial data sources according to the survey responses. Historically ownership of data was generally maintained by the party who collected the data and this data was distributed using licencing agreements. In the situation where data was collected under a contract, such as the aerial photography sector, the purchaser retains ownership not the collector of the data. Questions about the risks of purchasing data from a third party could lead to groups, including emergency management agencies, to move to greater data collection within government.

Intellectual Property (IP) and copyright are restrictions placed on a user by the data supplier. These restrict the distribution of either a product or products derived from the original work. In many cases even after a distribution right has been negotiated copyright must be clearly displayed on the distributed product or subsequent derived product. All of these restrictions are described within the licence. While IP or distribution rights vary, the commercial sector has historically had restrictive distribution conditions. More recently shifts to allow the purchasing of open distribution rights as standard in the government and scientific community are becoming common place (Harris and Baumann 2015).

Pricing policies are a description of how much a product will cost based upon a number of different models. The two most common pricing models are usage based models where different pricing allows for a different number of users and distribution based models where how a product is distributed determines the product's cost.

Finally, responsibilities, and in particular liabilities, are a complex and contentious area often overlooked in most data polices. Responsibilities can take many forms. Archival responsibilities and liabilities are two common examples. Archival responsibilities are policies, often legislative, which prescribe how or for how long a data product must be stored. One example of national legislation is the Australian Archives Act of 1983 which prescribes that all government entities must keep all records for at least seven years from creation or acquisition. Therefore even if nobody is using a product it must be archived for that length of time. Archival responsibilities can also require deletion of a data product. For example satellite data is sometimes distributed through regional distributors whom after their distributorship has ended are required to purge their archive of the data product they were distributing. Liabilities are potential debts which could be associated with the use or misuse of a product by a value adder or user. For example, if data is sold to a military who uses the data to target a missile strike which then misses its target; does that make the data provider liable? Liabilities are of particular concern in emergency management where misuse of a data product could lead to loss of life which is a greater risk than many providers in the public and private sector are willing to accept.

Licencing is a legal tool or document which outlines or codifies all of the ownership, IP, copyright, distribution and usage constrains of a data product. Historically licences have been specific to each data product and are renegotiated with each new purchase of a data product, but more and more standard licences are being used to reduce the costly process of renegotiating a licence (Harris and Baumann 2015).

Table 37 summaries the design choices for data policy and their related results from the various studies conducted in this thesis.

Table 37: Design choices and levers for data policy and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Data policy						
Cost	2 (=12/67)	175/171	5.3/5.3	1.7/1.4	Fed Govt sector 4.7 Private sector 6.1 Age under 35 6.0 Location ACT 4.8 Location QLD 5.8 Location WA 5.9	
Copyright		166/171	4.8/5.3	1.8/1.4	Research sector 3.3 Location ACT 5.4 Location NSW 5.3 Location TAS 3.4	
Access to raw data		167/171	5.1/5.3	1.6/1.4	Local Govt sector 3.6 Research sector 4.3 Private sector 5.6 NGO sector 5.6 Location TAS 4.5	
Publicly release the raw data		170/171	4.2/5.3	1.8/1.4	Local Govt sector 3.6 Private sector 4.7 NGO sector 3.4 Provider role 4.9 Location NT 4.8 Location TAS 3.5	
Responsibilities and liabilities		164/171	5.1/5.3	1.5/1.4	Local Govt sector 5.6 NGO sector 4.6 Age under 35 5.6 Provider role 5.9 Location ACT 5.8 Location NSW 5.6 Location TAS 4.1	
Access						8 (5/6)
Ownership						
Intellectual property						
Licencing						
Pricing policy						
Archiving policy						

With the exception of pricing policy (referred to in the survey as cost), all data policy design choices had a lower than average response rate in the survey. This low response rate implies that there is a lower level of understanding about data policy design choices than about quality or reputational design choices. While this result could be interpreted as data policy not being an important design choice, Chapter three and academic studies showed the dramatic effects of data policy changes particularly with the Landsat case study (Wulder et al. 2012). In addition, data policy design choices have a larger number of outliers than quality or reputational design choices which implies that while overall data policy may be less important there are still specific issues which matter greatly to specific groups. These results are hence interpreted as data policy being a highly subjective design choice which is relevant but only to certain data products.

Finding 42: Data policy may not be understood by many but is a choice which can have large impacts on usage and uptake. (Section 6.4.2)

The design choice of whether or not ownership is necessary is a clear binary choice. The survey rated 'data collected within their own organisation' as the third most likely data design choice to increase uptake, implying that data collected or at least processed within your own organisation or government is preferable.

IP has a variety of different settings related to distribution, source data and copyright. Distribution rights can be unlimited or restricted to any combination of individuals, organisations or market sectors such as Australian researchers only. The source data which created a data product can also be restricted, while generally it is either known or not disclosed but it can also be falsely disclosed. While copyright is not required to make a licence it is almost always required to ensure data producers get credit for their product.

Pricing policies are generally specific to the licence for a given product. In general, different licences are aligned with different IP collections such as a single user licence for a price, an enterprise 500 user licence for a large price or an open licence for free.

Responsibilities are varied and can be placed upon any aspect of the data product, for example archiving, discovery or liabilities of misuse. Liabilities are held by the data owner and all parties seek to reduce their own liabilities by shifting them down the supply chain.

Data policy is not considered by many providers, value adders and users due to its legal nature being seen as out of their field. The survey showed the likelihood of trust decreases when licencing restrictions are added. For example, government agencies showed a 1.2 value drop and universities showed a 1 value decrease in trust when licencing restrictions were added. This suggests that licence restrictions not just on the data product but the source data can decrease the

trust in a dataset. Increases in usage (as shown in the Landsat example) and the survey results point towards a sector-wide trend of making data open.

Licencing is a tool which codifies the issues described above. In the majority of cases a licence is codified as a standard document but increasingly licences are also being written or codified as a machine readable document. For example, all versions of the creative commons licence are available as a standard document and a machine readable version.

Data policy design choices such as cost and licencing have strong links with maturity and believability. Both maturity and believability require an understanding of where a product has come from its provenance. If provenance is obstructed by a high cost or restrictive licence then these choices can lead to a reduced level of uptake. Knowledge of how a product is created is increasingly moving from being a desired feature to becoming a standard with many global transparency initiatives requiring open data (Rao and Sridhara Murthi 2006).

6.4.3 Reputation

Reputation is a headline design choice made up of six design choices: Believability, data source, mandate, popularity, reliability and security.

Reputation is the measure of how much a community trusts you (Botsman 2012). Given reputation is a view from a person or persons it is inherently subjective and highly context specific. For example you may have a good reputation for an accurate weather forecast but a poor reputation for a highly unusable website. In addition reputation can apply at different scales, as one survey respondent described it:

> *"Reputation is based on the first hand observation, hence when data providers are not the source of the data both must be considered."*

This means an organisation or individual has different reputations for different products and projects. Also noted by the respondent is that reputation is formed by historical experience. This reality means that reputation takes a long time to build but can be lost quickly.

Finding 43: Reputation takes a long time to build but can be lost very quickly. (Section 6.4.3)

There are numerous examples of attempts to establish reputation systems or trust measurement systems. For example, Kostoulas et al. (2008) developed a decentralized reputation based trust model for establishing trust between different groups of first responders or for information dissemination between first responders. The system focuses on measuring the trustworthiness of information which already exists within the network through referrals.

Referrals are one method of establishing reputation but this thesis contends that there are a large collection of design choices which contribute to reputation. A critical component of understanding reputation in the context of this thesis is that reputation is a measure of how an individual or organisation is perceived. While Botsman (2012) argues that reputation is a direct measure of trust this thesis takes reputation to mean a collection of design choices which contribute to trust. This is further explored in the trust section later in this Chapter.

Organisational culture, including the culture of including or excluding information from decision making, was also raised by one survey recipient who explained:

> *"Sometimes decisions are made at a high level based on a minimal scope of data steam rather than the wider picture ("Tunnel Vision"). This can be a negative to effective use of real time data."*

This thesis is focused on data product design choices that increase the likelihood of uptake of a product in decision making. As such culture is somewhat at the boundary of this thesis but it presents a potential future piece of work about how to change organisational culture to be more receptive to receiving data.

Table 38: Design choices and levers for reputation and related evidence.

Design choices and levers	**# mentions in inquiries (Chapter 4) # (rank/ # design choices)**	**Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average**				**# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)**
		Count	**Mean**	**SD**	**Outliers Group ≤ or ≥ 0.5 mean**	
Reputation		175/171	6.1/5.3	1.1/1.4	Local Govt sector 5.6 Research sector 6.7	
Culture	1 (=67/67)					
Competence						
Care						
Fairness						

Reputation is measured on a continuum from good reputation to poor reputation. The question of measuring reputation is discussed in Marsh (1994) and is discussed in more detail later in this Chapter. In the survey different groups varied in their weighting of reputation related design choices. For example, mandate was viewed as the key design choice contributing to a good reputation by respondents from Brisbane while the Federal government view mandate as far less important. Australian emergency managers believe reputation is the equal 4th most likely design choice to influence uptake. There are strong links between reputation and trust as well as reputation and quality.

6.4.3.1 Believability

Believability is the first design choice under the reputation headline design choice.

According to Hovland et al. (1953) believability is the credibility of a source or message. He argues that believability can be measured in two primary dimensions: trustworthiness and expertise. This implies that you can trust someone with no expertise, and you can be an untrustworthy expert, but to be believable you require a mix of both. Unpicking this further, credibility is a subjective perception so different people can judge different data products or data producers differently (Fogg and Tseng 1999).

Believability is a group of design choices which relate to the plausibility of a product. This could include the product being clear and simple but also that the source data has not been manipulated to change the result, conflicts of interest and producing an effective and efficient product.

Table 39: Design choices and levers for believability and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Believability						
Provider familiarity		173/171	5.6/5.3	1.3/1.4	Research sector 6.7 NGO sector 6.3 Location TAS 6.1 Location WA 4.9	
Coordination	1 (=67/67)					
Effective use	1 (=67/67)					
Effectiveness	1 (=67/67)					
Funding	1 (=67/67)					
National coordinated	1 (=67/67)					
Misinformation	1 (=67/67)					
Not relied upon	1 (=67/67)					
Rumours	1 (=67/67)					
Availability of experts	1 (=67/67)					
Experience	1 (=67/67)					
Lack of knowledge	1 (=67/67)					
Training	1 (=67/67)					
Omitted data	1 (=67/67)					
Credibility						
Integrity						
Objectivity						

Reputation by direct experience						
Referrals by other users						
Association by other trusted resources (e.g., citations)						
Perceived bias of source						
Perceived incentive in providing accurate information						
Likelihood of content being correct given what is known						
Likelihood of deceptive behaviour						

Believability is impacted by a wide variety of choices. In order to try and specify what some of these are, the web survey asked respondents to compare the likelihood that they would use different data products only altering the producer and data policy. Firstly, regardless of sector, advertising in a product adversely affects the believability of a data product potentially due to perceived bias from attempting to generate profit from a natural disaster. This profit bias extends not just to advertising but also to the private sector itself and so it is better for the private sector to provide data during a disaster to emergency services and the public through a public sector intermediary with a good reputation and mandate. One way to measure believability is referrals by other users. This attribute is strongly related to provider familiarity which was rated as above average importance but highly important within the smaller sectors such as the research sector and NGOs.

Usability and believability are both connected with accuracy as a measure of how well the product reflects the observed phenomenon. Usability reflects the user's ability to simply understand the product, and believability is the subjective measure of whether what is shown and how it is presented reflects the user's understanding of the phenomenon. One specific design choice where these differences become clear is omitted data. If too much data is removed from a product (in an effort to improve useability) then users may develop a perception that data is being hidden. For example, United States positioning and imaging satellites degrade their signal for national security reasons. This interference with the original signal is designed to reduce the quality of a signal but reduces the reputation of the data product as well.

6.4.3.2 Data source

Data source is the second design choice under the reputation headline design choice.

Data source describes the technical selection of the data source and matching of a data source to a given set of requirements. This is fundamental to the product but also taken as a given by most sensor data professionals. Data source can also refer to the selection of the sensor, this style of consideration is covered under relevance within the quality section.

In the instances where national security or defence sensor data can be acquired its quality is often higher than what is generally available to emergency managers or the private sector, but the decision to use a military source is a binary choice with the subsequent restrictions being described within the product's data policy.

Table 40 outlines the key choices that are impacted by data source.

Table 40: Design choices and levers for data source and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Data source						
Sovereignty		167/171	4.3/5.3	2.0/1.4	Local Govt sector 3.4 Private sector 5.1 NGO sector 3.8 Age under 35 5.3 Location ACT 3.2 Location NSW 4.8 Location NT 5.3	
Publicly disclose the source		167/171	4.6/5.3	1.8/1.4	Research sector 6.3 Location NT 5.4 Location SA 4.0 Location TAS 3.9	
Dual-use		162/171	3.9/5.3	1.9/1.4	Local Govt sector 2.5 Research sector 5.0 Private sector 4.7 NGO sector 2.9 Age under 35 4.4 Provider value adder 3.0 Location ACT 3.4 Location NT 5.4	
Third party source	1 (=67/67)					
Source						7 (6/6)
Privacy						
Confidentiality						

Using data from a military source can be restrictive because it often involves additional steps in the delivery of a data product such as masking the source of the data or only allowing distribution of the data within sovereign borders all reduce the usability of a data product and generally also reduce the timeliness.

On the other-hand the data suggests that respondents like data that is sourced domestically because importance is placed on sovereignty and national self-reliance.

All this said, the use of military sensor data within emergency management is small. It should be noted that in the unlikely occasion where a military data product is used, data providers care greatly about each of the above design choices. This was shown in the low response rate all data source design choices received in the web survey.

6.4.3.3 Mandate

Mandate is the third design choice under the reputation headline design choice.

Mandate refers to an official recognition that a given individual or organisation has been told to undertake a specific task. An example of this is that weather agencies, such as the Australian Bureau of Meteorology, have the only mandate in most countries to issue weather warnings to the public. There can be many different types of mandate including official mandates, historical mandates and informal mandates. An official mandate occurs where a role or responsibility is bestowed through a legal document, such as legislation, upon a given entity. A historic mandate occurs where an entity establishes a mandate through precedent. Finally an informal or implied mandate occurs where a group believes that an entity is the best placed to carry out a role or responsibility.

Table 41: Design choices and levers for mandate and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Mandate		171/171	5.6/5.3	1.4/1.4	Local Govt sector 6.3 Research sector 6.3 NGO sector 4.8 Location ACT 4.9 Location QLD 6.2	
Recognized authority of associations						
Absence of other						

alternative resources						

In the context of emergency management, whether an individual or organisation has an official mandate or not is a binary decision.

In most cases, official emergency management mandates are only found within government agencies. In Australia, the majority of these are in state government agencies. As discussed in Chapter five, official data or data from an organisation with an official mandate is more trusted than data from an organisation without a mandate.

Mandate has some links with relevance when you consider the absence of alternative resources. Often the most relevant data is the only data which exists and sometimes this comes from an organisation without any mandate to collect, value add or distribute that data such as crowd sourced content, particularly Volunteer Geographic Information (VGI). In the case of VGI the data can be highly relevant yet lack the mandate and hence not be used. This issue was explored in Section 6.2.3 regarding risk aversion.

6.4.3.4 Popularity

Popularity is the fourth design choice under the reputation headline design choice.

Popularity refers to the level of awareness of a product, i.e. how well known it is across the general population. It does not refer to provider popularity (how well known the producer is) or familiarity (how well known someone is with a product). These are covered by believability.

Table 42: Design choices and levers for popularity and related evidence.

Design choices and levers	**# mentions in inquiries (Chapter 4) # (rank/ # design choices)**	**Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average**				**# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)**
		Count	**Mean**	**SD**	**Outliers Group ≤ or ≥ 0.5 mean**	
Popularity						
Product popularity		174/171	4.2/5.3	1.6/1.4	Local Govt sector 3.5 Research sector 5.3 Age under 35 5.0 Provider role 5.1 Location ACT 3.7	
Awareness	1 (=67/67)					
Popularity of the resource						

How to measure popularity is highly sector specific when talking about online data products. The number of downloads, unique website hits and total website hits are all common

metrics. While all these metrics are useful for communicating relevance, popularity can be difficult to define because it can use many different specific measurements for example popularity can refer to awareness, usage or uptake. While most of the community do not value popularity it is of importance to the research sector, data providers and those under 35 years old.

6.4.3.5 Reliability

Reliability is the fifth design choice under the reputation headline design choice.

Reliability is a formal metric of the proportion of time a system is available and its ability to cope with rapid usage changes, related to scalability.

Table 43: Design choices and levers for reliability and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Reliability	3 (=9/67)	176/171	6.5/5.3	0.8/1.4		39 (3/6)
Availability	5 (4/67)					
24 hour availability	1 (=67/67)					
Availability of communications	1 (=67/67)					
Redundancy	1 (=67/67)					
Scalability	1 (=67/67)					

Reliability is generally measured as a percentage of the time which a system is available and not down due to failure or scheduled maintenance. For example, a standard system could have 95% uptime whereas a mission critical system, which is involved in safety of life application such as emergency management, may have an uptime of 99.999%. Reliability appears in all three of the numerical studies.

Reliability has links with usability because it is often unavailable due to an outage then it becomes less usable.

6.4.3.6 Security

Security is the sixth and final design choice under the reputation headline design choice.

Security is traditionally defined as being free from danger or threat. In the context of data products, security refers to the protection of data collection, process, distribution and storage of the product. Importantly this involves both physical aspects, such as locks on data centre doors, and digital aspects such as block shift alternation technology which alerts users when source data has been changed. Other potential security issues include authentication, authorisation, access control, confidentiality, integrity, non-repudiation, auditing and privacy (Havlik et al. 2011, 3889).

Table 44: Design choices and levers for security and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Security						
Access security		172/171	5.1/5.3	1.7/1.4	Local Govt sector 3.9 Private sector 5.6 NGO sector 4.6 Age under 35 5.6 Value adder role 4.4 Location ACT 3.9 Location NSW 5.6 Location NT 5.7 Location TAS 4.5	
Network security		170/171	5.0/5.3	1.7/1.4	NGO sector 4.3 Value adder role 4.2 Location ACT 4.1 Location NT 5.8	

Security is generally a compliance task which must be completed, rather than something which can be weaker or stronger. This perception can rapidly change following a security breach after which security is clearly viewed as an important reputational design choice.

6.4.4 Maturity

Maturity is a headline design choice with six design choices as defined by Bates and Privette (2012): software readiness, metadata, documentation, product validation, public access and utility.

While maturity is commonly discussed in the context of physiology or finance, probably the simplest and clearest definition of maturity comes from agriculture. Maturity is when the fruit is ripe or at a state where it is fit to be consumed. This concept of ripeness, or fitness, is often overlooked when trying to rush a product to customers or promote a new breakthrough.

Chapter two explored the maturity of various moderate resolution data systems using a simplified version of the NOAA Climate Data Record maturity model described by Bates and Privette (2012). In this system maturity is judged by a score of 1-6 in six different thematic areas including: software readiness (stability of code), metadata (amount and compliance with international standards), documentation (description of the processing steps and algorithms for scientific and general communities), product validation (quality and amount in time and space), public access (availability of data and code), and utility (uses by broader community). Scores of 1-2 are for new systems not yet ready for decision making, 3-4 are known as Initial Operating Capability (IOC) products which are tentatively ready for decision makers, and finally, scores of 5-6 are at Full Operating Capability (FOC) and available for use in decision making with confidence. This model was demonstrated in comparing four systems in Chapter three.

Table 45: Design choices and levers for maturity and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Maturity	1 (=67/67)					
Interoperability	1 (=67/67)	176/171	5.9/5.3	1.4/1.4	NGO sector 5.4 Provider role 5.4 Location QLD 5.4	
Standards & specifications		173/171	5.5/5.3	1.5/1.4	Fed Govt sector 4.8 Research sector 6.7 Provider role 4.6 Value adder role 4.8	
Documentation		174/171	5.1/5.3	1.4/1.4	Local Govt sector 4.5 Research sector 6.5 NGO sector 4.5 Value adder role 4.6 Location NT 5.7 Location QLD 4.6	
Completeness		175/171	5.7/5.3	1.0/1.4	Research sector 6.3 Private sector 6.4	
Provenance		159/171	5.0/5.3	1.6/1.4	Local Govt sector 4.4 Research sector 6.7 NGO sector 5.5 < 5 yrs. experience 4.5 Location NT 5.6 Location QLD 4.2	
Lack of a manual	1 (=67/67)					
Tightening of connections between staff	1 (=67/67)					
Optimisation	1 (=67/67)					
Authorising environment	1 (=67/67)					
Information flow to decision makers	1 (=67/67)					
Repeatability	1 (=67/67)					
Rigor	1 (=67/67)					
Provenance and pedigree						

More often than not the lowest score across the different elements of maturity is used to measure maturity. This means it is important to ensure that the entirety of a data product is mature.

According to the survey of Australian emergency managers, maturity is of moderate importance. There are countless examples of products being released to consumers before they were ready, such as buggy computer games or defective cars. These experiences show that releasing immature products can be costly financially but also costly to a product's reputation. When accounting for the large reputational risk of releasing a product before it is ready, maturity can be seen almost as an initial design choice which must be addressed before looking at improving other design choices.

Further supporting the importance of maturity are the findings of the inquiries study in Chapter four. During this study 18 sensor data products were found in the inquiries, of which only five, or 28%, were actual products. The rest were raw data feeds otherwise known as immature data products. The two data products which were mentioned the most, the weather forecast and warnings, are both well-established mature data products. In fact the weather forecast and warnings are so mature that their original source observations are completely invisible to the user with millions of observations from satellites, airborne platforms and ground based sensors contributing to the model of the forecast every hour. This suggests that an emergency manager is more likely to use a mature integrated data product as part of a decision than an immature raw data feed.

Maturity has strong links with data policy design choices specifically around provenance. One central concept of scientific maturity is being able to demonstrate the quality of a product and where it has come from. This is achieved through a systematic description of the steps used to create a product and is generally referred to as provenance. One large difference between public and private sector emergency management data systems right now is the disclosure of how a product was created by the public sector and the private sector not disclosing provenance in an effort to protect their intellectual property. This difference may partially account for the differing levels of trust of the public and private sectors found within the survey.

There are many examples of provenance systems which hope to address this challenge (Missier et al. 2010; Moreau et al. 2008; Yue, Gong, and Di 2010). A highly relevant and evolving discussion within the data community is around the idea of Sarbanes–Oxley for science. The Sarbanes-Oxley Act of 2002 is a United States law which required firms in the financial sector to improve disclosure of financial details in order to reduce fraud after the Enron and WorldCom scandals. The concept of full transparency could also be expanded to science as explained in Michaels (2006):

> *"At present, there is virtually no oversight or independent review of corporate decision making as it relates to the sequestration of scientific*

> *data… The importance of ensuring that data interpretation is independent of conflicts of interest is tragically illustrated by the debate on the cardiovascular effects of Merck's painkiller Vioxx (rofecoxib). In early 2000, the results of a clinical trial showed that participants who took Vioxx for an average of nine months had a significantly higher risk of heart attack than those taking the comparison painkiller, naproxen (sold under the brand name Aleve). Since the comparison was between two biologically active products, scientists could have interpreted these results to mean either that Vioxx increased heart-attack risk or that naproxen reduced it. Unfortunately, Merck's researchers chose to promote the latter interpretation, ignoring other evidence that supported the former. Fortunately, among the clinical trials Merck had initiated was one in which Vioxx was compared to a placebo. When participants who took the drug for more than eighteen months suffered twice as many heart attacks and strokes as those taking the placebo, the trial was halted, and Vioxx was removed from the market. FDA scientists subsequently estimated that Vioxx was responsible for between 88,000 and 139,000 heart attacks—thirty to forty percent of which were probably fatal—in the five years the drug was on the market."*

This escalating tension between open science and protection of intellectual property will continue for many years but will likely be less important for emergency managers than the public safety concern. It is this concern for public safety that could lead to greater transparency, rather than protection of intellectual property, in times of a disaster.

6.4.5 Trust

Trust is the overarching objective of all headline design choices and hence encompasses all design choices.

Trust therefore, is what increases the uptake of sensor data in emergency management decision making. As described by one of the free text responses: *"timeliness is more important that quality but data will only be trusted if quality is understood"*.

Trust according to the Oxford dictionary is a "firm belief in the reliability, truth, or ability of someone or something". This definition is a clear example of how the literature views trust – a series of factors (reliability, truth and ability) which all affect an entity's ability to trust something. (Mayer, Davis, and Schoorman 1995, 712) define trust as:

> *"The willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party."*

Put simply, trust is being certain in your expectation that something will happen in the way that you expect it to happen. Another common and more structured definition of trust comes from Olmedilla et al. (2005, p. 5) in the artificial intelligence and semantic web field:

> *"Trust of a party A to a party B for a service X is the measurable belief of A in that B behaves dependably for a specified period within a specified context (in relation to service X)."*

An everyday example of this is rubbish collection. A person can trust that the local council will collect their rubbish every Thursday based on that they have witnessed this for the past 12 years and their belief that the government has the ability and the willingness to continue to do so.

In a recent survey of more than 50 Australian CEOs from critical infrastructure related organisations (Kay and Goldspink 2012) trust was considered to be the most important cultural characteristic to organisational resilience by a factor of three. The study found that "trust is often discussed as a moral concept but that was not the case in these interviews. In relation to organisational resilience, trust was broadly described as a prediction by an individual about how others (including organisations) are likely to act" (Kay and Goldspink 2012, 21).

The complexity of the concept of trust arises in attempting to articulate and analyse the factors, or, as discussed in this thesis, the design choices, which lead to trust and their relative weighting in any given context. For example, the literature of the past fifty years raises the following aspects leading to trust:

- Confidence, reliance, expectation and hope (Giffin 1967);
- Ability, benevolence, integrity (Mayer, Davis, and Schoorman 1995);
- Competence, openness, caring, reliability (Mishra 1996);
- Predictability, congruity, reliability, integrity, openness, acceptance, sensitivity, (Acrement 2002); and
- Competence, care, fairness, openness, credibility, reliability and integrity (Poortinga and Pidgeon 2003).

Each of these eighteen terms has specific and intricate meaning which presents a bewildering diversity of definitions. They can however, be grouped into three common themes. Confidence, ability and competence all contribute to the ability of an entity party to do something. Reliance, reliability, predictability, congruity and credibility all contribute to evidence that an entity has done something in the past. Expectation, integrity, benevolence, openness, caring, acceptance, sensitivity and fairness all contribute to a belief that an entity will do something in the future. These themes present a simplified yet comprehensive, *trust is the belief that an entity can, has and will do something*. These themes all contribute towards an entity's measure of trustworthiness.

More recently the computer science field has increasingly become interested in understanding trust as it is a central concept in building the third version of the internet - Web 3.0. This concept is more commonly known as the semantic web which is described in Figure 24.

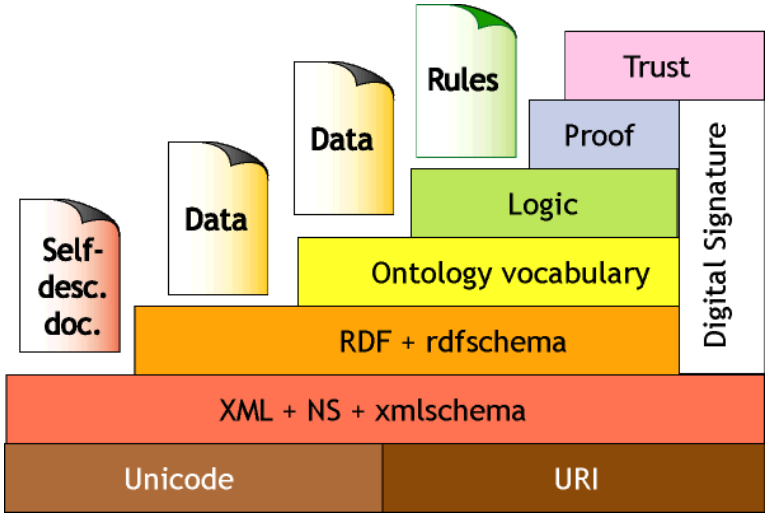


Figure 24: Positive Semantic web stack (Berners-Lee 2000).

The summary of Web 3.0 and the semantic web is that information must contain descriptive information or metadata about its location, audience, vocabulary, provenance, validation and security all of which collectively contribute to the trust in that piece of information. There are strong parallels between semantic web research and the use of sensor data products in emergency management suggesting potential future work in combining these two complimentary fields.

Context is critical when considering trust. For example, you could trust an Australian hydrogeologist to provide information about floods in Australia but you would not trust that same person to provide information about forest fires in rural China. Trust in one context will not necessarily guarantee trust of the same person or thing in a different context or situation (Bizer and Oldakowski 2004; Botsman 2012).

Trust can be found in fields as diverse as psychology (Giffin 1967), philosophy (Yamamoto 1990), medicine (Breakwell 2000), volcanology (Haynes, Barclay, and Pidgeon 2008), semantic web (Artz and Gil 2007; Dividino et al. 2009), risk analysis (Poortinga and Pidgeon 2003), management (Acrement 2002) and media (Seo et al. 2012). Hence, this implies that an entity could be trusted for their skills and actions in a given discipline or context but that trust does not directly translate into a different discipline.

Finding 44: Trust is the overarching term to encompass all design choices. (Section 6.4.5)

Earle and Cvetkovich (1995) discuss a further dimension concerning similarities in belief, or "value similarity". In this dimension trust is a social bond between the trustor and the trustee. Poortinga and Pidgeon (2004, p. 1476) expand on this concept of value similarity by discussing people who "share identities and/or have a similar understanding of a specific situation". While value is a valid dimension to understand trust, it should be noted that its effect on trust is considered by some studies such as Haynes et al. (2008) to be a less important factor.

Scale is another key dimension when considering trust. Trust can cover an entire organisation, a person, a product or a particular feature of a specific product: for that reason this thesis refers to entities to encompass all possible recipients of trust. Within the semantic web community scale is described through two terms: 'entity trust' covers an organisation or person, whilst 'content trust' covers a specific product or dataset (Gil and Artz 2007). Although some terms have been created in an attempt to specify scale, such as brand trust or organisational trust, these terms are not common or applied consistently across multiple domains (Mayer, Davis, and Schoorman 1995).

The final dimension to be discussed is consequence. Consequence, or the effect of a decision, plays a large role in determining trust, as shown for genetically modified foods in the UK (Poortinga and Pidgeon 2005). Consequence is particularly relevant when thinking about disasters because the consequences are high and regularly life threatening.

From these various definitions and dimensions of trust, there are a huge number of similarities between previously discussed design choices and trust. In fact in many cases, the design choices leading to trust have already been directly referenced in this Chapter. Trust is the key determinant of whether an emergency manager will consider a data product in decision making and is being taken as the overarching term which encompasses all of the design choices described in this Chapter.

Table 46: Design choices and levers for trust and related evidence.

Design choices and levers	# mentions in inquiries (Chapter 4) # (rank/ # design choices)	Rate between 1-7 the likelihood of affecting a decision survey questions 17-19 results (Chapter 5) Value/Average				# mentions in survey question 20 (Chapter 5) # (rank/ # design choices)
		Count	Mean	SD	Outliers Group ≤ or ≥ 0.5 mean	
Trust	3 (=9/67)					

Although trust is a subjective term it can be treated as a measurable quantity. Every day everyone makes numerous trade-offs or judgements which lead to a decision to trust an entity. This next section explores the various methods for measuring trust that have been applied to data management. This measure of trust is not a binary measurement; you do not simply trust or distrust an entity. Instead there is a continuum upon which something is highly distrusted, through to an area of uncertainty about trust where most people still choose to distrust an entity, then a threshold is crossed upon which trust is established (Marsh 1994). This continuum is shown in Figure 25.

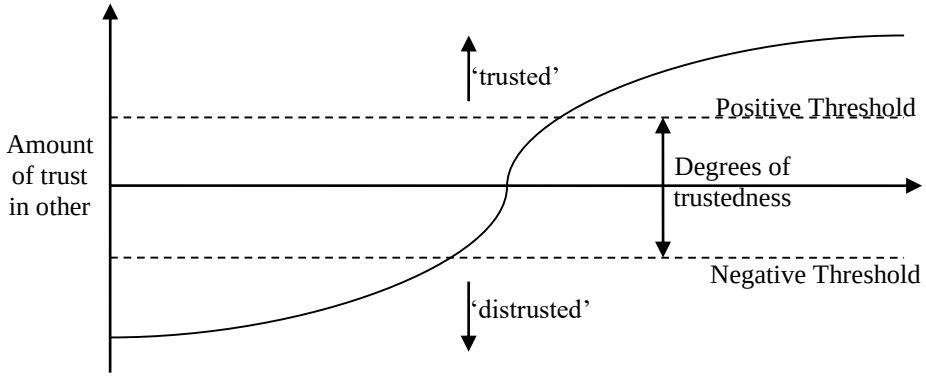


Figure 25: Positive and negative thresholds for trust adapted from Marsh (1994).

Finding 45: Trust is measured on a continuum from distrusted, through to an area of uncertainty about trust where most people still choose to distrust an entity, then a threshold is crossed upon which trust is established. (Section 6.4.5)

Artz and Gil (2007) describe four common methods for measuring trust: Policy-based trust, reputation-based trust, general models of trust, and trust in information resources. These areas have been researched in depth and are common across many fields (Marsh 1994). Policy based trust, also known as a universal trust model, is a method where a policy is used to establish or declare trust of a given group, for example users often tell their computers to trust content from a specific website. Reputation, referral or rating based trust is established by aggregating referrals to create a measure of trust. A tradition example of reputation based trust is referee checks in an interview process but it also used to check the quality of flood data using references from peers (Kussul et al. 2013). General models of trust refer to a variety of approaches which weight design choices that contribute to trust, for example using Bayesian logic to communicate decisions for managing volcanic eruptions (Aspinall et al. 2003). Finally, trust in information resources or trust in data is a subtype of general models of trust which include data specific concepts like quality, accuracy and provenance.

An example of trust in data is journalism, where information is tested using source checking, or acquiring information from multiple sources in order to determine if that information can be trusted. Trust in data, or content trust, is the same as trust with the added quality related dimensions of information resources such as accuracy and provenance (Gil and Artz 2007). One intricacy which becomes important when considering content trust is the role of the middleman. Often when using a dataset, the provider of the data is not the creator of that data and so when talking about content trust one must consider the trustworthiness of both groups.

6.5 Summary of findings

Finding 34: Sensor data is available to higher level decision makers but less available to front line incident management staff. (Section 6.2.1)
Finding 35: Technologies, often complimentary, participate in the Battle of the Samaritans to discredit other technologies and promote their own. (Section 6.2.2)
Finding 36: Integration of technologies and co-production can reduce the Battle of the Samaritans. (Section 6.2.2)
Finding 37: Rigid emergency management doctrine is not conducive to the acceptance of new technologies. (Section 6.2.3)
Finding 38: Lesson learning, doctrine, improvisation and innovation need to be balanced in disasters. (Section 6.2.3)
Finding 39: Sensor data when used as evidence to support decision making can reduce blame, particularly in post event inquiries. (Section 6.2.3)
Finding 40: The balance between accuracy and timeliness is complex and must be actively managed. (Section 6.4.1.3)
Finding 41: No product is too complex to be simple to use. (Section 6.4.1.4)
Finding 42: Data policy may not be understood by many but is a choice which can have large impacts on usage and uptake. (Section 6.4.2)
Finding 43: Reputation takes a long time to build but can be lost very quickly. (Section 6.4.3)
Finding 44: Trust is the overarching term to encompass all design choices. (Section 6.4.5)
Finding 45: Trust is measured on a continuum from distrusted, through to an area of uncertainty about trust where most people still choose to distrust an entity, then a threshold is crossed upon which trust is established. (Section 6.4.5)

Chapter 7: Emergency management sensor data product uptake framework

7.1 Aim and overview of this chapter

This Chapter presents an emergency management sensor data product uptake framework. This framework condenses the findings in this thesis and the lexicon for data products established in Chapter six.

The first section of this Chapter outlines the emergency management sensor data product uptake framework. The purpose of the framework is explained before presenting the framework itself. Advice is provided on how to implement the framework through the different stages of a product's development.

Case studies are then used to illustrate complex applications of the framework and provide examples of best practice. Topics include the relationship between timeliness and accuracy, building trust over time, relationships with end users and product simplicity.

The aims of this Chapter are to:

- Present the emergency management sensor data product uptake framework; and
- Highlight key aspects of the framework by using case studies to illustrate best practice of sensor data product uptake in emergency management.

The Chapter is structured as follows:

7.2 Emergency management sensor data product uptake framework

7.2.1 Purpose of the framework

In order to present the findings of this thesis, a framework has been developed to help guide product creators in understanding and addressing key design choices that affect uptake.

The framework draws on the concept of a 'data adoption framework' which has been used outside the emergency management field, for example QA4EO Secretariat (2007) and Vanden Borre et al. (2011). One example of a framework for satellite-derived fire products is Trigg and Roy (2005) study of resource managers in southern Africa. This thesis updates this concept to restrict the scope to sensor data products and focus on uptake rather than adoption. The framework proposed is thus called an *'emergency management sensor data product uptake framework'*. From this point on this will be referred to as 'the framework'.

The purpose of the framework is to guide those who are involved in sensor data product development towards choices they should actively consider in the design process. The framework is designed to be tailored, it is not a step by step process because what is prioritised will depend on the desired outcome or target user group. Users need to input more than just knowing the algorithm or accuracy. The purpose of this framework is to stimulate an informed conversation between sensor data product creators and end users about requirements.

It should be noted that the framework only applies once certain technical criteria have been met. Datasets can only become products if the measurements used have a high enough accuracy and precision to resolve the desired variable and if the models used to relate the physical processes to the measurements are effective. Section 2.3 provides further detail on this point. If data producers are working with datasets that are not high enough accuracy to produce useful observations or variables, the framework will not be able to assist in creating a useful product.

In addition, it should be noted that uptake takes longer and costs more to achieve than usage. Targeting design choices to improve uptake will generally increase development costs and timeframes. Employing this framework to achieve uptake should only be considered if it is clear that uptake is the desired objective of the product. Emergency management applications are often highly operational, subject to legal proceedings and involve decisions which could lead to the loss of a human life. For these reasons, consideration of whether a dataset is appropriate for emergency management uptake is critical before developing a sensor data product for this purpose.

7.2.2 The framework

The framework aims to increase the likelihood of a sensor data product being used in emergency management decision making by improving the way product creators engage with emergency management practitioners and design products to meet their needs. It is based on a synthesis of existing research, case study analysis, disaster inquiry analysis and surveys of emergency managers.

The central proposition of this framework is that every aspect of a sensor data product involves a decision made by the product's creator. These design choices are a mix of conscious decisions, such as presentational choices, and subconscious, often ignored, design choices, such as the source data's data policy, or the data delivery business model.

First and foremost, the framework aims to add more value to a product than the time spent understanding and implementing the framework. The framework is designed to be transparent so that creators and users can see why design choices have been made so trust is not eroded by unexplained decisions. Finally, it is designed to be reportable, so that discussing the implementation time and cost requirements of a product are practical.

Beyond this it aims to be simple. Simplicity does not just mean ease of use but also simplicity in the sense of design choice independence. The effort required to adjust a design choice can vary greatly and so the ability to pick and choose which design choices should be altered must be as independent of other design choices as possible.

The framework organises design choices into a hierarchical structure so that individuals building a new feature can directly track how design levers related to that feature contribute to the overarching design objectives. This traceability is also useful in the other direction where managers supervising the development of a product can gain a greater understanding of which features impact what design choices.

The framework is hierarchical and consists of four nested levels: an objective; headline design choices; design choices; and design levers. The headline design choices cluster all design choices into four main groups: quality, data policy, reputation and maturity. Under the design choices there are design levers which are the means of achieving the design choices. In short, design choices are what users want and design levers are how to achieve those choices. Data product design choices cover many fields, including traditional technical scientific and engineering fields, as well as non-technical areas such as the law, public policy and marketing. All of these fields must be considered to fully grasp the implications of uptake.

Design choices related to quality, data policy, reputation and maturity all contribute towards the likelihood of an emergency manager incorporating a data product in decision making. This likelihood can be summarised as a measure of *trust*. Trust is a measure of the belief that someone or something can, has and will do something: more specifically trust is a

collective measure of the design choices of a data product. This means if a data product aligns all design choices with a given user it is likely to be highly trusted, and therefore more likely to be considered in decision making. Conversely, the findings of this research suggest that if a data product ignores some design choices, and does not tailor design choices to a given user, users will be less likely to trust the product and unlikely to consider that product in decisions.

Table 47 shows the full suite of design choices collected in the course of this research. While this list is the most comprehensive list collected, technological developments will inevitably create new design choices and hence this list will evolve over time. This list is not supposed to be a comprehensive list of technical design levers but an illustration of options to affect the higher level choices. Less important but highly context specific design choices have been marked with an *.

Table 47: Emergency management sensor data product uptake framework.

Objective	**Trust**			
Headline design choice	**Maturity**	**Quality**	**Reputation**	**Data policy**
Design choices (Examples of design levers)	**Software readiness** (Software documentation i.e. readme/commenting, portability, numerical reproducibility, meets coding standards and code security) **Metadata** (File level, collection level and standards) **Documentation** (Algorithm Theoretical Basis document, Operational Algorithm Description, Process Flow Chart and peer reviewed documents of algorithm and product) **Product validation** (Independent validation, uncertainty, quality flag and operational monitoring) Public access (Archive, updates to record and version) **Utility** (Data usage, Societal Sector Decision Support Systems, citations in peer-reviewed literature and feedback)	**Accuracy** (Accuracy, consistency, completeness, errors of commission, errors of omission and human error) **Relevance** (Tailored, business model, coverage, frequency, specificity, absence of alternative resources, responsive, flexible, common boundary and level of value add or wrong product level i.e. detection without identification) **Timeliness** (Time from acquisition to delivery and efficiency of system) **Usability** (Presentation, simplicity, consistency, accessibility including maps in the field, ease of use, consistency of terms, consistency of representation, fitness for purpose no omitted data and right amount of data i.e. cleaned of extraneous information while not over aggregation)	**Believability** (Credibility, integrity, objectivity, provider familiarity, quantity of rumours, availability of experts, experience, referrals by other users, association with other trusted resources, bias/perceived incentives, likelihood of deceptive behaviour and appears efficient/effective/coordination) **Mandate** (Officially recognised authority and absence of other alternative resources) **Reliability** (Percentage uptime, availability of system, availability of communications, redundancy and scalability) **Security** (Physical security, network security, authentication, authorisation) **Data source*** (Source, defence dual-use, third party source, sovereignty, ability to disclose source, confidentiality and privacy) Popularity* (Product popularity and awareness)	**Data policy*** (Ownership, Intellectual property, pricing policy, archiving policy and licencing describing access to raw data, rights to distribute data, responsibilities and liabilities)

7.2.3 Implementation of the framework

This framework is aimed at creating an informed conversation between sensor data product creators and emergency management decision makers before a product is developed. It articulates which design levers should be pulled to create a product that meets the user's needs. This conversation in itself will build buy-in, trust and understanding of a product which will lead to greater uptake.

This framework can be implemented in three iterative steps. Firstly, establish a joint understanding between creators and users about the potential design choices of a product. Secondly, prioritise design choices for a given product based on user requirements and resources available. Finally, with a clearly defined set of requirements, identify a technical product specification or development path to a product.

Reflecting on the technology curves outlined in section 2.5, and in figure 26 below, it can be seen that the decisions outlined in the framework are not one off choices but should be developed, built on and revisited over the life of a product.

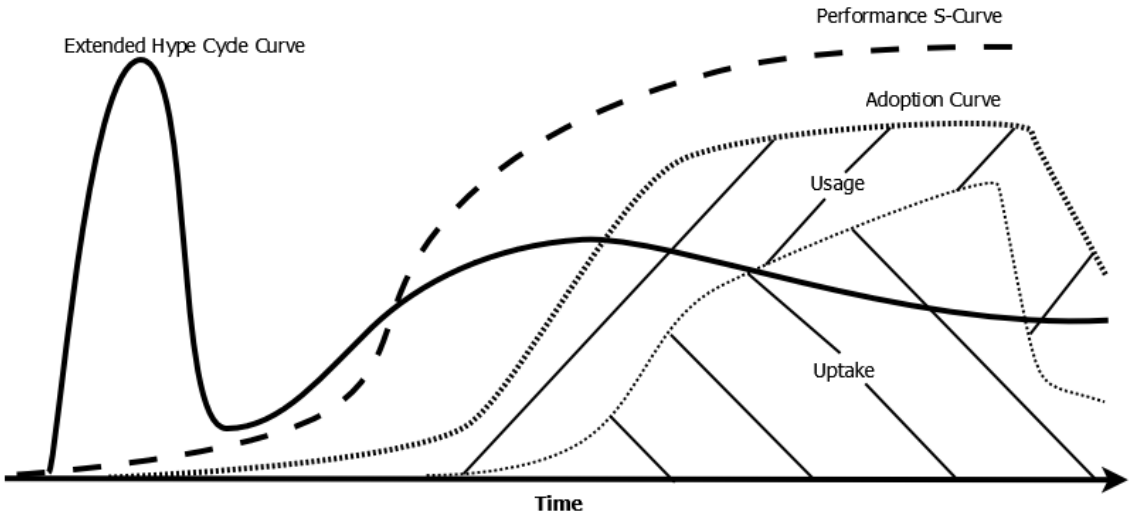


Figure 26: Technology lifecycle models adapted and expanded from Linden and Fenn (2003).

The framework can be implemented across two stages of the product cycle: before product launch and after product launch. While products traditionally launch as hype begins to recover and quality on the performance S-curve climbs, this is not always the case as the case studies will show. The focus of the pre product launch stage is to ensure that the product is ready before release and to provide clear guidance as to what "ready" means so that product creators can prioritise competing technical and financial barriers and deadlines.

The second stage is about continuous improvement. After a product has been launched, both internal and external feedback is received which allows for the rapid increase in product

quality. This is reflected in the performance S-curve. Unfortunately, many data products are not improved after launch and miss this opportunity for rapid, and often cheap yet dramatic, improvements in product quality. Continuous improvement of products also offers a useful method of building tighter links between product creators and users leading to a greater sense of buy-in to the data product.

Bates and Privette (2012) divide the time after product launch into the Initial Operating Capability (IOC), where products have not climbed the performance S-curve, and Full Operating Capability (FOC) where products are mature and available for use in decision making with confidence. To illustrate the point that building maturity is an iterative process, Table 48 summarises the authors observations about the indicative levels of maturity, investment, usage and uptake during the life cycle of a product.

Table 48: Indicative levels of maturity, investment, usage and uptake across a data product's lifecycle.

	Bates and Privette (2012) maturity rating	Amount of investment	Usage (excluding uptake)	Uptake
Research to Proof of Concept	0	Low	Nil	Nil
Proof of Concept to Development	0	Low/medium	Nil	Nil
Development to Initial Operating Capability	1-2	High	Low	Nil
Initial Operating Capability to Full Operating Capability	3-4	Medium/high	Medium	Low
Full Operating Capability	5-6	Low/medium	Low	High

The hierarchical nature of the framework illuminates what levers data producers have at their disposal. Through understanding the typical progression of hype, quality, usage and uptake in a data product the typical maturity and investment levels can be described.

7.3 Case studies

The framework is broad and high level and can be applied in a variety of different ways. For this reason rather than putting forward an inflexible step by step approach, this thesis uses case studies to explore how to utilise different aspects of the framework.

A broad cross section of data products have been selected in order to provide a breath of advice on how to apply the framework. Within each case study, the findings from the literature, from all the three studies (Chapters three to five) and from the subsequent discussion (Chapter six) will also be expanded upon.

Each case study will begin with a broad overview of the product or organisation. Following this the case study's approach to quality, data policy, reputation and maturity will be briefly discussed. The maturity of each case study product will also be assessed using the NOAA maturity model described in Bates and Privette (2012), except for the first case study which is based upon Chapter three. The focus of each case study will be to explore a specific implication of using the framework.

7.3.1 Moderate resolution optical data systems

In the framework, quality consists of both accuracy and timeliness. However, as Wright (2001) has demonstrated, there is an inverse relationship between the two. In implementing the framework, active decisions about how to balance the two, based on user requirements will need to be made.

Chapter three presented a case study comparing the USGS's Earth Explorer system, the South Dakota State University's Web Enabled Landsat Data (WELD) system, Geoscience Australia's Australian Geoscience Data Cube (AGDC) and the Institute of Remote Sensing and Digital Earth in the Chinese Academy of Science's (RADI-CAS) Satsee system. The case study showed that even with the same input data, choices can be made that affect timeliness and accuracy.

Figure 27 provides a visual depiction of the extent to which each system prioritised timeliness and accuracy. The plot is based on the author's interpretation of the four system's specifications, while not quantitative, the plot provides a visual demonstration of the inverse trend.

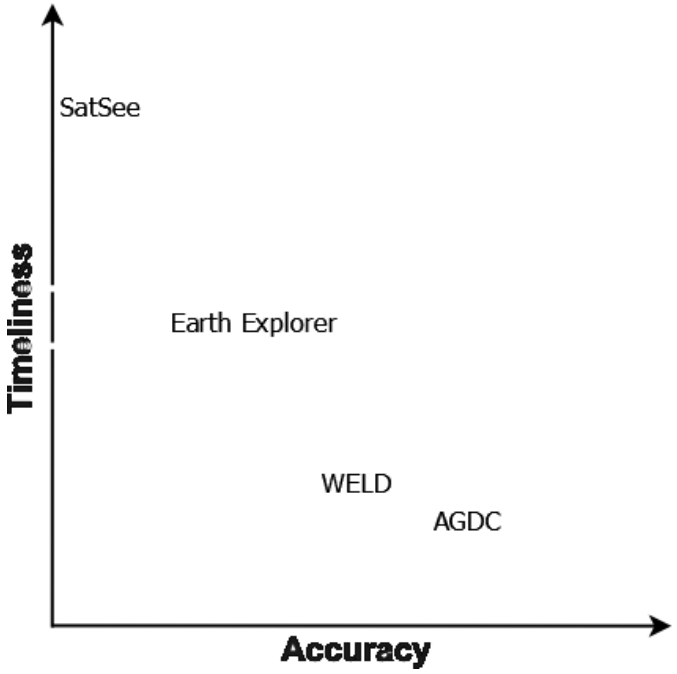


Figure 27: Chart showing the relationship between timeliness of each system and the accuracy of each system.

From this graph SatSee is clearly the fastest system and AGDC has the highest accuracy products. These were active choices made by those designing these products. The AGDC employs every possible correction including two types of cloud/cloud shadow masking, two types of atmospheric correction, sun sensor geometry corrections and topographic corrections all to maximise accuracy. On the other hand SatSee does not even wait for the entire dataset to be transferred from the ground station, before it sends out compressed quicklook images with no corrections.

Design choices can contribute towards accuracy and timeliness in direct and indirect ways. For example data policy is an often overlooked design choice whose complexity often contributes towards reduced timeliness of a product.

There is a misperception by users that a product's timeliness and quality is fixed by the sensor choice. But the SatSee and AGDC example shows that timeliness and quality can be adapted. The same data source can even be reproduced a number of times in different ways to suit different purposes. For example, on receipt, a product could be processed rapidly with poor accuracy, meeting emergency response timeliness requirements. Immediately following, or even in parallel with the release of this product, the data could be processed again to a higher accuracy but with reduced timeliness. Finally, after all ancillary datasets are available, perhaps after several days, a definitive product could be processed to the highest quality the product can achieve but with poor timeliness. This staged approach is shown by the SatSee system generating a poor accuracy preview product in minutes, the United States Earth Explorer system producing a medium accuracy rapid product in hours and the Australian Geoscience Data Cube

producing a high accuracy final product in days. This approach of reprocessing allows for greater usage and uptake of already acquired data while still allowing for high timeliness products to be generated.

Product refinement with users currently only takes place through ad hoc trial and error. Consultation often only takes place at annual conferences or during disaster responses. This leads to a highly inefficient iteration process where the creator takes the product away then comes back with the next version. In most cases the creator is pushing the technology onto the user at times of heightened tension. Such choices, however, require clear guidance from users on what they require. It is the user that should carefully prioritise the trade-offs involved.

A different approach which has become increasingly popular within the literature is that of coproduction (Ostrom 1996; Jasanoff et al. 2004). Applying this process to emergency management data product development would involve emergency managers taking a step back from the technology and clearly stating what information they need, to what accuracy and how quickly. Following this, the emergency manager would be available to the creators to clarify requirements as they arise.

Timeliness is also linked with blame in disaster inquiries. Data creators have noted the increasing risk to data custodians of being blamed during and after disasters. In an effort to lower custodial risks, producers and value adders use three common choices. They can stop producing the product, add restrictions/indemnities to their data policy, or increase their accuracy thresholds for the product. Higher accuracy thresholds set by data creators mean that many data products will not meet the timeliness requirements to achieve relevance in a given disaster. It would seem that while disaster inquiries aim to increase evidence based decision making during disasters in the area of sensor data it may be having the opposite effect.

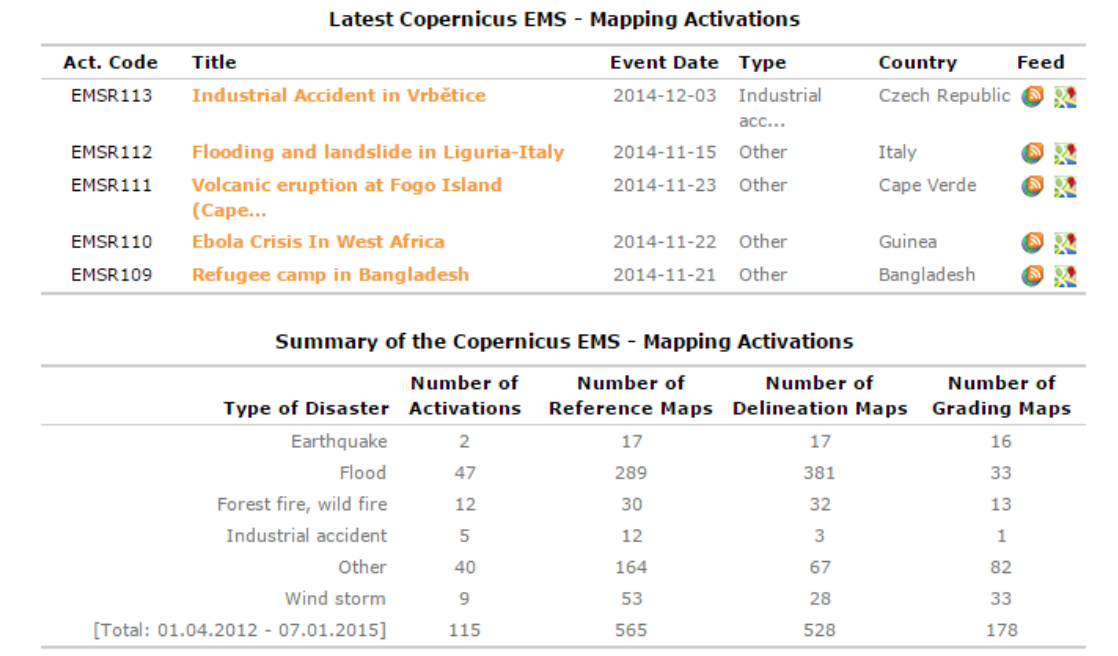
The balance between accuracy and timeliness is a critical relationship to be managed when generating sensor data products for emergency management. Through careful consideration of the design levers leading to the accuracy and timeliness design choices shown in Table 47 this relationship can be managed and tailored to a specific sensor data product.

7.3.2 European Commission's Emergency Management Service Mapping

This case study examines how long trust can take to build. In 2015, the product which could have the largest impact on emergency management is Europe's Copernicus initiative, formally the Global Monitoring for Environment and Security initiative. The Copernicus initiative is launching a fleet of satellites and associated downstream services to improve decision making in all types of applications including emergency management.

The emergency management service of Copernicus, known as Emergency Management Service Mapping (EMS-M), undertook development and testing in a highly transparent and staged manner. The results of this has been high levels of buy-in and trust. Individual disaster type products were developed from 2003 to 2009, after which a preoperational system was launched and operated between 2009 to 2012 (European Space Agency 2015).

In 2015, the EMS-M is an operational monitoring system using cutting edge science and technology to make disaster products. This project continues to promote transparency and build trust in its products by presenting not only active disasters but also statistics on historical operations on the front of their website (see Figure 28). This simple step means potential users know instantly that this organisation has a proven track record in the field.



Latest Copernicus EMS - Mapping Activations

Act. Code	Title	Event Date	Type	Country	Feed
EMSR113	Industrial Accident in Vrbětice	2014-12-03	Industrial acc...	Czech Republic	
EMSR112	Flooding and landslide in Liguria-Italy	2014-11-15	Other	Italy	
EMSR111	Volcanic eruption at Fogo Island (Cape...	2014-11-23	Other	Cape Verde	
EMSR110	Ebola Crisis In West Africa	2014-11-22	Other	Guinea	
EMSR109	Refugee camp in Bangladesh	2014-11-21	Other	Bangladesh	

Summary of the Copernicus EMS - Mapping Activations

Type of Disaster	Number of Activations	Number of Reference Maps	Number of Delineation Maps	Number of Grading Maps
Earthquake	2	17	17	16
Flood	47	289	381	33
Forest fire, wild fire	12	30	32	13
Industrial accident	5	12	3	1
Other	40	164	67	82
Wind storm	9	53	28	33
[Total: 01.04.2012 - 07.01.2015]	115	565	528	178

In the above table, only non-obsolete components are considered.

The Copernicus Emergency Management Service (EMS) is the first Copernicus (previously GMES) service to become operational.

EMS started operations on April 1st, 2012 and consists of a set of services funded by the European Commission.

These are aimed at providing actors in the management of natural and man-made disasters, in particular Civil Protection Authorities and Humanitarian Aid actors with mapping products based on satellite imagery (EMS - Mapping).

Other EMS activities support Early Warning Systems.

Figure 28: European Commission's Copernicus Emergency Management Service Mapping Tool.

EMS-M has a strong focus on product quality with accuracy and timeliness standards defined and published (European Space Agency 2015). The facility approaches the previously discussed accuracy/timeliness trade off by generating products in three different modes: mapping in rush mode, mapping in non-rush mode and external validation. Product relevance and usability have been addressed during the extensive and iterative development times taken before the facility went operational. The EMS-M's data policy is as open as could be expected from a private sector operated facility with primarily private sector data sources. Products are openly licenced with data sources and algorithms acknowledged within the product. Source data can be requested on a case by case basis. EMS-M has a good reputation built over many years of development. It has a clear government mandate and generates products from only well-known sources increasing believability. Reliability targets are defined and published with compliance targets against these standards published for each product. Finally, using the NOAA maturity model described in (Bates and Privette 2012), EMS-M has an average maturity of 4.8 and minimum value of three, these results are described further in Table 49.

Table 49: Maturity of the European Commission's Emergency Management Service Mapping capability using an adapted (Bates and Privette 2012) maturity framework.

Characteristic	European Commission's Emergency Management Service Mapping capability
Software Readiness	5, Minimal code changes expected; Stable, portable and reproducible
Metadata	5, Complete at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets international standards for dataset
Documentation	6, Public C-ATBD and OAD; Multiple peer-reviewed publications on algorithm and product
Product Validation	4, Uncertainty estimated over widely distributed times/location by multiple investigators; Differences understood.
Public Access	3, Data and source code archived and available; caveats required for use.
Utility	6, Used in published applications; may be used by industry; assessments demonstrating positive value
Average	4.8
Min	3

While EMS-M's development, which commenced in 2003, may seem lengthy it demonstrates that it takes time to build the high levels of trust and buy-in required to create an emergency mapping system which covers all of Europe. Marsh (1994) showed that trust is not binary but is built over time. EMS-M is an example of a product that has been iterated over such a length of time that it has moved from the initial negative to the positive trust threshold before becoming operational.

Moving on to a different product, the weather forecast, we can also see how time has built trust. The oldest and most trusted emergency management sensor data product, the weather forecast, still focuses on building trust. The 2013 Australian Federal inquiry *Recent trends in and preparedness for extreme weather events* contained a strong example of the role of trust, "*while weather forecasting is much more accurate than in the past, the committee heard that people still need convincing to trust and act on this information"*. Almost 33 years after quality tracking of the weather forecast began, even the weather forecast must continuously improve its products in order to maintain and improve its uptake and increase its trust. Figure 29 shows the increases in accuracy of the 10, 7, 5 and 3 day weather forecasts, demonstrating the concerted effort which has gone into long term continuous improvement.

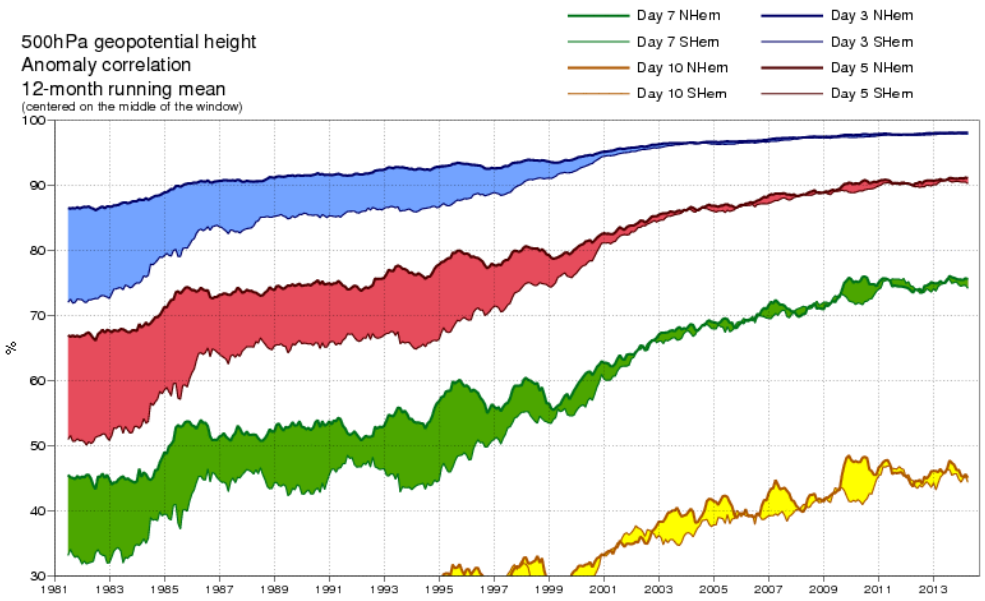


Figure 29: Long term increase in the 3, 5, 7 and 10 day weather forecast accuracy for the North and South hemispheres (ECMWF 2014).

This further shows that continuous development and improvement is important in building trust. Trust takes time to build but is easily lost. Using the curves described in Figure 26 the traditional progression of a data product can be tracked. An awareness of the positive and negative trust thresholds allows producers to know a product is trusted and ready for operational applications.

7.3.3 Bushfire and Natural Hazards CRC and the Phoenix fire spread model

This case study examines best practice for engaging with a user community. The Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) is an Australian research organisation which connects researchers, public sector emergency managers and the private sector. With input from BNHCRC and its predecessors, Australia has developed AS/NZS 4360:2004 or the Australian/New Zealand Standard of Risk Management. This standard provides an overarching framework for how to view and manage all types of disasters.

Under AS/NZS 4360:2004, BNHCRC has developed the Bushfire Risk Management Model (BRMM) which outlines the impact of various management strategies on fire characteristics across the landscape. One component of BRMM is the Pheonix fire spread model, developed by the University of Melbourne, which allows for analysis of impact on assets and the landscape. The Pheonix fire spread model is one component within the BNHCRC's Bushfire Risk Management Model which is one application of the Australian/New Zealand Standard of Risk Management (Tolhurst, Shields, and Chong 2008).

As the Bushfire Risk Management Model is not a publically accessible system, there is limited documentation outside the literature on the Pheonix fire spread model. Data quality and policy cannot be assessed due to the lack of definitive information on the model. Even so, Pheonix's reputation is high given the stage of development of the product. It is tested within academic journals (Saeedian et al. 2010) and used within the previously mentioned industry standard Bushfire Risk Management Model. In addition, it overcomes previous issues with GIS approaches increasing the believability of spread models (Tolhurst, Shields, and Chong 2008). Pheonix's maturity can be determined based upon the publically available data as an average value of 3.5 and a minimum value of two.

Table 50: Maturity of the University of Melbourne's Pheonix fire spread model using an adapted (Bates and Privette 2012) maturity framework.

Characteristic	University of Melbourne's Pheonix fire spread model
Software Readiness	4, Some code changes expected
Metadata	3, Research grade; meets international standards; ISO or FGDC for collection; netCDF for file
Documentation	2, C-ATBD Version 1+; paper on algorithm reviewed
Product Validation	3, Uncertainty estimated for select locations/times
Public Access	3, Data and source code archived and available; caveats required for use.
Utility	6, Used in published applications; may be used by industry; assessments demonstrating positive value
Average	3.5
Min	2

The Pheonix fire spread modelling tool is relevant because it situated itself within the user community during development. This led to an unusually high reputation for a system of this level of development. Specifically, it has a high level of engagement with users, not just producers and value adders. This is made possible through the existence of BNHCRC, whose membership brings together researchers, government agencies and the private sector into a single organisation which allows for this style of inclusive research.

This thesis has discovered numerous examples of sensor data product creators having the goal of improving emergency management and then maintaining consultation with the emergency management value adders rather than end users (Lowell et al. 2011; Sustineo 2011), tailoring a product to emergency managers without consulting users (Ji and Zhu 2012) or stating a technology will benefit emergency managers with zero consultation or tailoring (Gray et al. 2011; Yue, Gong, and Di 2010).

Consulting with the decision makers who will consider the evidence from a sensor data product in a decision, is critical because their standards and requirements will be different to these of the data producers and value adders. The survey conducted in Chapter five found that, the further up the supply chain, the higher the product quality standards, meaning data

producers and value adders are likely to block products which could prove useful to emergency management users.

This finding has profound implications, suggesting that the value adders advising emergency managers on capability development when preparing for disaster season may in fact be blocking access to products which could be of use to decision makers. This case study shows that, this bias of producers and value adders to hold a product until it is perfect, is easily detected and solved when the actual end user is present through the development of a sensor data product.

What makes the Pheonix fire spread model impressive is that it's entire technical development occurred within the user community through the BNHCRC. This inclusive approach has meant that technical staff developed products in partnership with end users. As a result, Pheonix has a higher reputation as a product under development than most products which have been completed. Developing data products in partnership with the true end user is critical.

7.3.4 United States Geological Survey (USGS) Earthquake Hazard Program's onePager or Prompt Assessment of Global Earthquakes for Response system (PAGER)

This case study examines how even highly complex products can be packaged in a simple manner to build quality and reputation. The United States Geological Survey (USGS) Earthquake Hazard Program's Prompt Assessment of Global Earthquakes for Response system (PAGER) analyses sensor data related to earthquakes and tsunami and generates a single page brief outlining the potential risks of that event. The product is generated less than 15 minutes after each event and the system generates around five briefs each day. Figure 30 is an example of the single page output summarising the entire suite of USGS earthquake related products onto one page after the 2011 Japan Earthquake.

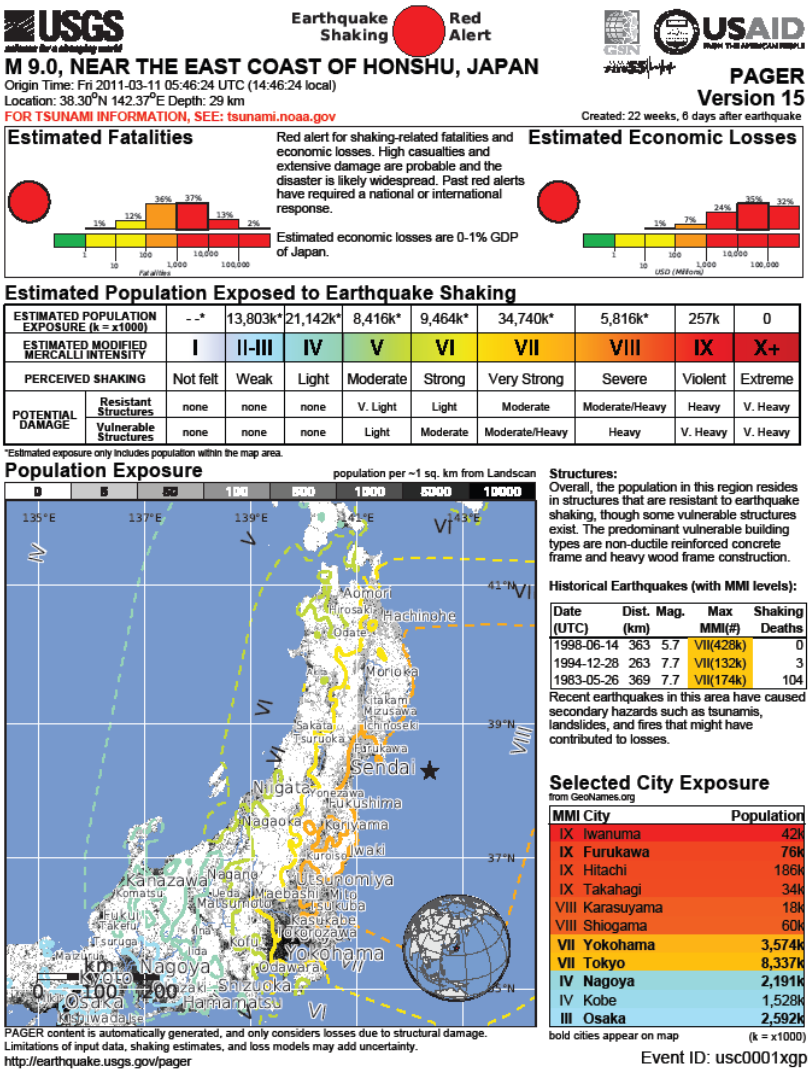


Figure 30: USGS Earthquake Hazard Program's onePager brief of the 2011 Japan Earthquake (USGS 2011).

The PAGER system's high accuracy is recognised in over forty peer reviewed papers which it publishes on its website. It generates an automated brief in less than 15 minutes which cannot be generated manually by most countries. The data policy of PAGER is completely open including data, algorithms and code. All data sources are civilian and open source suggesting high levels of believability. The USGS is the mandated US agency for earthquakes and tsunami. Using the adapted Bates and Privette (2012) maturity framework the average maturity is six and minimum value is six.

Table 51: Maturity of the United States Geological Survey (USGS) Earthquake Hazard Program's Prompt Assessment of Global Earthquakes for Response system (PAGER) capability using an adapted (Bates and Privette 2012) maturity framework.

Characteristic	European Commission's Emergency Management Service Mapping capability
Software Readiness	6, No code changes expected; Stable and reproducible; portable and operationally efficient
Metadata	6, Updated and complete at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets current international standards for dataset
Documentation	6, Public C-ATBD and OAD; Multiple peer-reviewed publications on algorithm and product
Product Validation	6, Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation; quantified errors
Public Access	6, Record is publically available for Long-Term archive; Regularly updated
Utility	6, Used in published applications; may be used by industry; assessments demonstrating positive value
Average	6
Min	6

> *"Granularity of data - too much information can impede interpretation; vs. too little information makes it hard to make an informed decision."*

The above quote from a survey respondent as part of this thesis captures the difficult balance of how much data should be presented in a sensor data product. This concept is a central theme in many of the design choices identified in this thesis particularly: utility, relevance, usability and believability. These design choices can increase or decrease the headline design choices of maturity, quality and reputation. Simplicity therefore covers a wide variety of design choices, not just presentational choices.

Simplicity of brand contributes directly towards a product's believability. This means that as much as possible products should be amalgamated into a consistent and familiar brand. This concept was discussed in the case study in Chapter three. The PAGER system even keeps its data policy simple, maintaining consistency across data, algorithms and code.

The inquiries study reinforced that simplicity increases a product's likelihood of uptake. This study also found that the relationship between different types of data, uptake and usage is heavily dependent on the level of maturity and integration with users. While many raw or upstream datasets are used in emergency management, to become widely used, highly mature and integrated downstream products, such as the weather forecast are required. According to the

studies conducted in this thesis, the three most used products in emergency management are all highly integrated downstream products: weather warnings, weather forecast and positioning. Conversely the three least known products are all upstream raw or less processed data feeds: stream gauge, seismogram and multispectral imagery.

Probably the greatest achievement of the PAGER system is how such a technical system has been distilled into a succinct, one page product. Table 52 shows the number of observations, measurements and variables used to generate this product.

Table 52: Observations, measurements and variables used in USGS PAGER, influence by Cheyne (2011).

Product stage and type	Example products used to generate the USGS PAGER product
Data/observations	Raw seismic waves, historical earthquake records, city population records, historical economic loss records, historical earthquake damage records, individual topographic records
Information/measurements	Earthquake detection, historical earthquake database, global exposure database, historical economic and engineering impact database, global topographic map, fatality estimation model, economic loss estimation model.
Knowledge/variables	onePAGER brief, earthquake detection and alerting system,

USGS's PAGER system is a powerful example of an immensely complex series of products being seamlessly integrated into a simple product, whose result is greater than the sum of its parts. One common problem in integrating products is the technological "Battle of the Samaritans" where engineers and scientists conduct critical peer review of products in front of users in order to gain advantage over solutions which may compete with their own (Boin et al. 2005). One impressive feature of the USGS PAGER is that it has overcome tensions between different sources of data, between numerical modellers and pure observers and between operational personnel and researchers.

No product is too complex to be simple and simplicity increases uptake.

7.4 Summary of uptake framework

Uptake is the highest form of contact with a data product i.e. when a product is used within decision making. Uptake of sensor data products within emergency management is a function of trust. The emergency management sensor data product uptake framework can be used to inform decisions leading to uptake.

Trust is determined by four headline design choices: quality, data policy, reputation and maturity. Quality is a function of the following design choices: accuracy, relevance, timeliness and usability. Data policy is a less important headline design choice but highly context specific. Reputation is a function of the following design choices: believability, mandate, reliability, security and data source. Maturity is a function of the following design choices: software readiness, metadata, documentation, product validation and utility. All of these design choices can be affected by a diverse range of technical and non-technical design levers.

To apply this framework, tailoring to the specific user community is key. Each case study highlighted a specific implication of using the framework. Firstly, the balance between accuracy and timeliness is a critical relationship to be managed when generating sensor data products for emergency management. Secondly, trust takes time to build. Thirdly, developing data products in partnership with the true end user is critical. Finally, no product is too complex to be simple and simplicity increases uptake.

Sensor data products can be designed to improve the likelihood that they will be used in decision making. This framework increases the likelihood of an informed conversation between sensor data product creators and emergency management decision makers before a product is developed. It articulates which design levers should be pulled to create a product that meets the user’s needs. This conversation in itself will build buy-in, trust and understanding of a product which will lead to greater uptake.

Chapter 8: Conclusion

8.1 Summary of thesis findings

The overarching research question of this thesis was, “How can sensor data products be designed to maximise their uptake in emergency management decision making processes in Australia?” To answer the core research question several sub questions were posed:

1. How is sensor data being used in the Australian emergency management sector?
2. What do emergency managers believe are the impediments and opportunities to greater inclusion of sensor data products in emergency management decision making processes?
3. What choices can sensor data product creators make to change how a product is received by emergency managers?
4. What recommendations can be made to sensor data product creators targeting emergency management uptake?

This thesis used a range of approaches to answer the overarching research question and sub questions. Firstly, it drew together disparate literature from a range of technical and non-technical disciplines. This work was both an original synthesis of existing knowledge and a foundation upon which the rest of the thesis is based.

Building upon the existing literature, three studies were designed and conducted in order to answer the core research question. Firstly, a comparative case study of four data delivery systems, which use the same input data source, revealed the impact various design choices can have on the resulting product. Secondly, a study of 257 disaster inquiries identified how sensor data is used in Australian emergency management, and what issues currently exist in the sector, as evident in post-event analysis. Finally, a survey of 230 emergency managers created a dataset which allowed detailed comparison about the relative importance of different design choices and provided valuable insights into how practitioners view uptake.

The findings from the literature and the three studies were then synthesised into a comprehensive lexicon to describe sector-wide barriers, as well as data product specific barriers, to the uptake of sensor data in emergency management decision making. As a new field, merging a range of disciplines, this is the first time a common lexicon has been established. This allows for ongoing discussion and research on the topic. This synthesis then provided the foundation for the emergency management sensor data product uptake framework. Throughout this work, the critical but previously poorly understood role design choices play in sensor data product development was brought to the fore.

This thesis has developed and presented a new synthesis and a number of specific findings that advance our understanding of product uptake, thus increasing the likelihood of uptake of sensor data in emergency management decision making.

This thesis yielded 45 findings which contribute to answering the overarching research question. The findings were highlighted in the section in which they were made, using call out boxes. Findings originate from key points in the literature, study findings and through the original synthesis of content.

This thesis answered sub question 1 (How is sensor data being used in the Australian emergency management sector?) through a discussion of historical and current usage with a focus on how sensor data has been reported in Australian disaster inquiries.

The thesis found that sensor data has been used in all stages of the emergency management spectrum including prevention, preparedness, response and recovery. It identified examples of sensor data being used in at least 68% of all disaster types. In addition, Australia has a long history of using platforms like sensors to improve emergency management decision making, with the first example in 1939. This thesis identified nine operational facilities dedicated to using satellite information for emergency mapping in Europe and Asia, showing just how important and common sensor data is within modern emergency management.

The inquiries study showed, however, that little formal attention has been paid to the role of sensor data in emergency management in Australia. This means it is at least underreported and under analysed, if not underutilised. Of the 61 Australian disaster inquiries which this thesis analysed in detail, only 32 inquiries, or 53%, had examples of data usage. Data quality, a key component of sensor data, has been a minor topic in Australian bushfire inquiries with 53 or 3.1% of the 1728 recommendations made between 1939 and 2013 related to mapping or data quality. Where usage was discussed, only 18 data types were raised across all forms of sensor data.

In summary, the potential of sensor data is clear and it has been used effectively in emergency management. It is therefore noteworthy that inquiries, which are formal assessments of the sector, gave such little consideration to this source of information. This low level of coverage in inquiries demonstrates that while present, sensor data has not penetrated the activities of the sector to a large degree. This suggests that the real problem is uptake rather than technical issues.

Not enough evidence was available to draw extensive lessons on how sensor data has been used in decision making, let alone identify problems and successes. The lack of systematic consideration shows that there is more work to be done in understanding the absence of sensor data in post disaster inquiries.

Furthermore, there was almost no formal consideration of new technologies to improve decision making in Australian disaster inquiries. All technologies referenced were well established and legacy technologies rather than new technologies.

Finally, this thesis found that the more political the structure of an inquiry the less technical the content of the inquiry, meaning sensor data was rarely discussed in royal commission style inquiries.

In answer to sub question 2 (What do emergency managers believe are the impediments and opportunities to greater inclusion of sensor data products in emergency management decision making processes?) this thesis discovered many relevant impediments and opportunities.

Chapter two demonstrated that within the academic community there is an active and diverse debate around improving the technical or implementation issues of using sensors for emergency management. Unfortunately, the way this translates into usefulness in the emergency management field is often unclear. Fundamentally, Chapter two revealed a lack of research and understanding into how to optimise sensor data products for emergency managers.

The survey in Chapter five highlighted that there are many opportunities for sensor data within Australia, with 97% of Australian emergency managers believing sensor data should be used in emergency management decision making. These opportunities were found to be particularly relevant to the public sector, with emergency managers preferring data products to be delivered to them by a public institution even if the data was collected by the private sector. The evidence suggested that current trends towards open licencing for public sector data increase the trust in a dataset, and that the more mature and integrated a sensor data product is the greater its usage and uptake. Finally, official data or data from an organisation with an official mandate was seen to be more trusted than data from an organisation without a formal mandate. All of these findings showed that there are many opportunities for the public sector to better leverage sensor data for emergency management.

This thesis also identified several common impediments to using sensor data. Availability of data, timeliness of data products, and skills to use the data, were the most common issues facing the emergency management sector. This thesis found that sensor data is available to higher level decision makers but less available to front line incident management staff. In addition, advertising concurrent with data displays or portals was shown to negatively affect trust by emergency managers. The survey found that the further up the supply chain you are, the higher your product quality standards. This suggests that data producers and value adders could themselves be blocking products useful to emergency managers.

This thesis focused on the exploration of design choices, addressing the question posed in sub question 3 (What choices can sensor data product creators make to change how a product is received by emergency managers?)

This thesis found that product creators have a myriad of design choices which can be altered in order to affect the use and uptake of a sensor data product. This myriad of choices covers fields as diverse as traditional technical scientific and engineering fields as well as non-

technical areas such as the law, public policy and marketing. Furthermore, the number of choices is increasing due to open data, technological and scientific developments.

These design choices were systematically formed into a framework which consists of four hierarchical levels: an objective; headline design choices; design choices; and design levers. The headline design choices cluster all design choices into four main groups: quality, data policy, reputation and maturity. Under each headline design choice there is a larger number of design choices which are controlled themselves by design levers. In short, design choices are what users want and design levers are how to achieve those choices. The overarching objective of the framework is trust.

Finally, this thesis made diverse findings related to sub question 4 (What recommendations can be made to sensor data product creators targeting emergency management uptake?).

This thesis used a triangulation of literature, inquiries and survey data to identify choices in designing a product that can be expected to impact uptake. These choices were grouped into a framework the purpose of which is to prompt a thorough and informed conversation between users and product creators to ensure they make the right design choices for the product at hand. The framework includes levers under each design choice which for the first time connects in a coherent manner the product creator's technical decisions, with the higher level product design choices that the user cares about. Product creators can see immediately how their design choices may affect uptake of a product. This thesis argues that there is no one size fits all way to apply the framework, but each of its elements must be actively considered in product development.

There are several complex trade-offs in using the framework. The balance between accuracy and timeliness is complex and must be actively managed. Next, no product is too complex to be simple to use. Finally, reputation and trust take a long time to build but can be lost very quickly.

It is, however, a two-way street. Emergency managers must be imaginative because if they underestimate a creator's capability to tailor the design choices of a sensor data product they dramatically limit the potential usage and uptake of that product. Product creators in turn must work with true end users, decision makers, to understand the requirements and limitations of the product they are developing.

Not all products are suitable for emergency management uptake. If data producers are working with datasets that are not high enough accuracy to produce useful observations, or variables then uptake is not likely. In addition, targeting design choices to improve uptake will generally increase development costs and timeframes.

In addition to addressing the sub research questions, the following 45 findings have been grouped by topic to reflect patterns to the findings. These groupings have yielded seven key

findings which show the key foci for the thesis and simplify the 45 findings into a simpler brief list of messages from this thesis.

Key finding 1: Rapidly growing problems like the increasing threat of disasters can only be effectively matched by an exponentially growing technological solution such as intelligence extracted from sensors

- Finding 1: Impacts of natural disasters are a rapidly growing problem (Section 2.2)
- Finding 3: Sensor numbers, quality and delivery speed are exponentially growing (Section 2.3)
- Finding 5: The Stretton Royal Commission in 1939 shows how long Australia has used spatial intelligence to improve emergency management decision making (Section 2.4)

Key finding 2: Sensor data can operationally, effectively and efficiently provide intelligence to improve decision making and reduce complexity in disasters

- Finding 6: Scientific literature has shown that sensor data has been used in at least 68% of disaster types (Section 2.4)
- Finding 7: Sensor data can be used in all stages of the emergency management framework: prevention, preparedness, response and recovery (Section 2.4)
- Finding 8: Dedicated operational satellite mapping facilities for disasters are common in Europe and Asia (Section 2.4)

Key finding 3: Public sector sensor data agencies must lead the long term sector-wide development of sensor data products for disaster management both inside and outside their agencies

- Finding 9: While there is an active and diverse academic debate around improving the technical or implementation issues of using sensor data for emergency management, the utility to emergency managers is often unclear (Section 2.4)
- Finding 11: There is a lack of research and understanding into how to optimise sensor data products for emergency managers (Section 2.4)
- Finding 12: There is a gap in the literature and a need to research what changes to sensor products will increase the likelihood that an emergency manager will incorporate a sensor product in their decision making (Section 2.4)
- Finding 27: Stakeholders higher up the supply chain have higher quality thresholds, meaning data producers and value adders often block products which are still useful to emergency managers. (Section 5.5.2)
- Finding 28: Official data or data from an organisation with an official mandate is more trusted than data from an organisation without a mandate. (Section 5.5.3)
- Finding 29: Advertising concurrent with data displays or portals negatively affects trust by emergency managers. (Section 5.5.3)
- Finding 30: Emergency managers prefer data products to be delivered to them by a public institution even if the data was collected by the private sector. (Section 5.5.3)
- Finding 31: Licence restrictions on the data product or the original source data can decrease the trust in a dataset. (Section 5.5.3)
- Finding 35: Technologies, often complimentary, participate in the Battle of the Samaritans to discredit other technologies and promote their own. (Section 6.2.2)
- Finding 36: Integration of technologies and co-production can reduce the Battle of the Samaritans. (Section 6.2.2)

- Finding 37: Rigid emergency management doctrine is not conducive to the acceptance of new technologies. (Section 6.2.3)

Key finding 4: Sensor data products can be tailored to a far greater degree than most emergency managers, sensor data value adders and sensor data product creators realise

- Finding 13: Consumers who underestimate a creator's capability to tailor the design choices of a sensor data product dramatically limit the potential usage and uptake of that product (Section 3.3)
- Finding 14: Product creators have a myriad of design choices which can be altered in order to affect the uptake of a product (Section 3.3)
- Finding 15: Open data, technological and scientific developments have meant that product creators can now increasingly change and tailor sensor data products (Section 3.3.3)
- Finding 16: In most cases no system is better than another. They are simply choosing a different collection of design choices to target a different groups of users, therefore different agencies and countries interpret user's needs in different ways (Section 3.4.3)
- Finding 20: Based upon Australian disaster inquiries, the circumstance around data usage and/or uptake are governed by at least 15 design choices: Maturity, accuracy, timeliness, relevant, effectiveness, reliability, availability, presentation, trust, experience, culture, accessibility, uptake, flexibility and third party source. (Section 4.4.4)
- Finding 33: Australian emergency managers believe the most likely design choices to inform decision making are accuracy, timeliness, reliability, simplicity, consistency and reputation. (Section 5.5.4)

Key finding 5: Australia is not learning lessons about how to use technology for the management of disasters

- Finding 17: The more political the structure of an inquiry the less technical the content of the inquiry. (Section 4.4.2)
- Finding 18: Data quality has been a minor topic in Australian bushfire inquiries with only 53 or 3.1% of the 1728 recommendations made between 1939 and 2013 related to mapping or data quality. (Section 4.4.3)
- Finding 19: Of the 61 Australian disaster inquiries which were analysed in detail 32 inquiries, or 53%, had examples of data usage across at least 18 different types of data. (Section 4.4.4)
- Finding 21: Inquiries tend to discuss more traditional technologies but do not discuss emerging technologies such as the use of social media as a data source for emergency managers. (Section 4.5)
- Finding 23: The discussion of data in inquiries is not new or complex with discussions in the 1939 bushfire royal commission often more complex than recent inquiries. (Section 4.5)
- Finding 38: Lesson learning, doctrine, improvisation and innovation need to be balanced in disasters. (Section 6.2.3)
- Finding 39: Sensor data when used as evidence to support decision making can reduce blame, particularly in post event inquiries. (Section 6.2.3)

Key finding 6: Sensor data for disaster management is not meeting its hype in Australia

- Finding 10: The distinction between awareness, usage and uptake is critical in assessing the effectiveness of a sensor data product (Section 3.2)
- Finding 24: 97% of emergency management survey respondents believe sensor data should be used in emergency management decision making. (Section 5.4.2)
- Finding 26: Availability of data, timeliness of data products and skills to use the data are the most common issues facing the emergency management sector. (Section 5.5.2)
- Finding 34: Sensor data is available to higher level decision makers but less available to front line incident management staff. (Section 6.2.1)

Key finding 7: Building a trusted sensor data product takes long term consistent strategy and support

- Finding 4: Not all data is high enough quality to become an observation, variable or product (Section 2.3)
- Finding 22: The more mature and integrated a sensor data product is the greater its usage and uptake. (Section 4.5)
- Finding 25: The higher the level of product integration the higher the usage. (Section 5.5.1)
- Finding 40: The balance between accuracy and timeliness is complex and must be actively managed. (Section 6.4.1.3)
- Finding 41: No product is too complex to be simple to use. (Section 6.4.1.4)
- Finding 42: Data policy may not be understood by many but is a choice which can have large impacts on usage and uptake. (Section 6.4.2)
- Finding 43: Reputation takes a long time to build but can be lost very quickly. (Section 6.4.3)
- Finding 44: Trust is the overarching term to encompass all design choices. (Section 6.4.5)
- Finding 45: Trust is measured on a continuum from distrusted, through to an area of uncertainty about trust where most people still choose to distrust an entity, then a threshold is crossed upon which trust is established. (Section 6.4.5)

8.2 Summary of contribution

This research has made an original synthesis of existing literature in several key areas. Firstly, it clarified terminology around assessing the impact of a product by distinguishing between awareness, usage and uptake in a digital supply chain. It further coined not just the term design choices, but also the definitions of each of the design choices identified within this thesis. This thesis fused together scholarly knowledge from the emergency management, sensor data and management of digital products fields to generate a new cross-disciplinary topic. Finally, several of the findings listed in this thesis were an original synthesis of existing knowledge. These syntheses have established a clear foundation upon which original contributions have been made, while ensuring that this work builds on previous research.

This thesis undertook three independent and varied studies in order to approach the research question from all relevant angles. This thesis generated two new research datasets: the Australian disaster inquiries database and the survey of sensor data in emergency management decision making dataset. The thesis established a emergency management sensor data product uptake framework. The framework presents the findings of the thesis in a succinct and usable format. The majority of findings presented in this thesis have been original contributions.

While there are limitations to the thesis, the approach taken is valid and the contributions usable in both research and practical contexts. The design choice lexicon for data products in emergency management builds on existing data adoption frameworks allowing product creators to better target sensor data products to emergency manager's needs. Furthermore, the methodical and broad range of approaches used to define this data adoption framework allows for lessons to be learned in how to create data adoption frameworks and tailor data products to audiences more generally.

8.3 Policy implications

With increasing population, urbanisation and climate change the frequency, intensity, spatial extent, duration and complexity of natural and human induced disasters are set to increase during the 21st century (Handmer and Dovers 2013; Intergovernmental Panel on Climate Change 2012). Sensor data is one of the few means of reducing complexity and determining what is happening at any point in time, to inform what should be done next within these complex situations (Boin et al. 2005).

Consumers who underestimate a creator's capability to tailor the design choices of a sensor data product dramatically limit the potential usage and uptake of that product. Product creators in turn must work with true end users, decision makers, to understand the requirements and limitations of the product they are developing. In a policy sense this requires emergency

management practitioners to clarify what they need as requirements and not jump straight to product specifications.

As shown with the evolution of the weather forecast, it can take decades of long term vision and development to climb the adoption curve and to reach the potential accuracies described in a performance S-curve. This long term consistent support is difficult to achieve given that most projects are required to achieve results within a relatively brief project or funding period and then are considered finished.

As part of the survey of Australian emergency managers the trust of identical datasets produced by organisations with and without mandates to generate disaster products, specifically universities compared with government agencies, were compared. The results showed the highest level of trust in products from government agencies with clear mandates. Sensor data development must be undertaken by, or in collaboration with, groups who have an accepted, public good emergency management mandate.

One area this thesis has significant implications for is the post disaster inquiry field. Contrary to the view that using sensor data products increases complexity, the likelihood of greater blame during post disaster inquiries is in fact reduced. Sensor data products can be used to explain and justify decision making in disasters during an inquiry. Furthermore, it is common place for sensor data products, specifically maps, to be used to assist post disaster inquiries. Often in a post disaster inquiry, emergency managers are asked to explain why a decision prioritised one option over another. Sensor data is a solid, official piece of evidence which can be used to help defend emergency management decision making.

Data producers and value adders have noted the increasing risk to data custodians being blamed during and after disasters. The blame culture developing around emergency management may lead to less sensor data evidence being considered in decision making. Data custodians may reduce their offerings to emergency managers unless clear policy and legal guidance is given to those running inquiries around the use of sensor data as evidence in post disaster inquiries.

This research suggests that the more political an inquiry the less technical the content of the inquiry. For example, agency led inquiries are more likely to discover technical issues than royal commissions. For this reason sensor data can be used to support all inquiries as an evidence source for describing what happened, but if technical issues are involved more targeted and less political inquiries are more likely to provide useful lessons.

Inquiries tend to discuss traditional technologies rather than emerging technologies. One example of this is the use of social media as a data source for emergency managers. Although of critical importance, data quality has been missed by almost all Australian disaster inquiries. Steps are required to reform inquiries to ensure they learn the most useful lessons from disasters in order to improve future policy and practice. It could be argued that reform is required to the

criteria for holding, governance and powers of inquiries in order to deal with this rapidly changing field.

This research could have large implications for the insurance industry and policy makers. Greater access to nationally consistent risk information such as long term hazard history maps can be used to more accurately price insurance policies at a time when disaster insurance is growing rapidly. This area requires further research.

8.4 Research implications, limitations and future work

This thesis focused on improving data creator's understanding of what design choices increase the likelihood of product uptake in decision making. Organisational culture was out of scope for this research but it presents an important future area of work about how to change organisational culture to be more receptive to receiving evidence from external or technological sources. The by-product of this research would be an increase in the complexity of decision making through the consideration of new data sources, but with the ultimate goal of decreasing the complexity of a decision and reducing complexity in the disaster.

Today, trust and reputation on the web are generally only assessed through referral based metrics. One example of referral based metrics are ratings, reviews and amalgamations on sites like Amazon and eBay. Web 3.0 will be implementing many forms of automated reputation assessment systems. There are strong parallels between the research in the semantic web and data adoption frameworks. Exploring the synergies could lead to automated methods of measuring agency specific trust in a data product, through a customised calculation of a product's metadata. These systems could be useful to emergency managers who regularly need to assess the trustworthiness of new data products which are only created during disasters.

With data fusion becoming more common, more sophisticated approaches are required to assess the accuracy of products with multiple sources of data. In addition, consistent accuracy measurement techniques need to be developed. While adding complexity to quality assessment techniques, Bayesian style quality assessment approaches may be required in the future across all evidence in emergency management decision making. This could include human intelligence sources such as triple zero emergency calls. This style of assessment would ensure a consistent measure of quality is applied across all types of data.

The Australian disaster inquiries database developed in this thesis was used for a very specific purpose. This dataset is worthy of further analysis, specifically around jurisdictional trends and the correlation between jurisdiction, inquiry type and risk.

This thesis uses a small number of technological lifecycle models like the Hype curve and performance S-curve. Future studies could expand on the framework to include more

quantitative models like the Technology Task Fit (TTF), Technology Acceptance Model (TAM) and the Unified Theory of Acceptance of Technology (UTAUT).

Detailed jurisdictional analysis was not undertaken for the survey data as this style of geographic analysis was not the focus of the study. That said, further analysis would be useful as individual jurisdictions have varied population, risks, requirements and interests.

This thesis is targeted at Australian emergency managers but has lessons which could apply to the global emergency management sector. Furthermore, the research into data uptake frameworks could be broadened to applications outside of emergency management.

Uptake has not been directly observed in this thesis it has only been indirectly reported in survey results and was not specifically mentioned in inquiries. Direct uptake would require an emergency manager stating that they changed a decision based upon data. This limitation is well understood and has been largely addressed through the constant iteration of findings. That aside, future studies could look to apply this framework in real life case studies over time to quantifiably measure the impact on uptake.

The framework presented in this thesis was not able to prioritise levers for specific user requirements due to the time limitations of this research. This prioritisation could be considered as future work.

8.5 Concluding remarks

Rapidly growing problems are most effectively addressed by rapidly growing, if not exponentially growing, solutions. With disasters becoming larger, more complex and more frequent, greater situational awareness is required to reduce complexity. Sensor data has only just begun to be used in mainstream society and many emergency manager's imaginations have not yet caught up with what will soon be yesterday's technologies.

The Australian continent is the least dense of the populated continents on the planet and yet it has far less sophisticated monitoring systems than many other nations. Australia uses only 18 different types of satellite data to measure all public policy challenges, at a time when the World Meteorological Organisation uses 28 types of satellite data to monitor climate and weather alone. This lack of uptake is troubling.

Low sensor uptake in Australia can be solved and used to help improve the quality of disaster response. 97% of Australian emergency management professionals surveyed believe sensor data should be used in emergency management decision making. Through long term and consistent vision, including funding, highly trusted sensor data products can be established which can inform all Australians where disasters are likely to occur, detect new disasters, track active disasters and estimate the impact of disasters in real time from anywhere on the planet. This information, in turn, could give emergency managers the force multiplier required to deal with the impending rise of the frequency, intensity, spatial extent, duration and complexity of natural and human induced disasters.

The sensor data product uptake framework for Australian emergency management has the potential to increase the usage of sensor data in Australia and uptake of sensor data in emergency management decision making.

If one message is to be taken away from this research it is that: sensor data products can be designed in order to improve uptake and they are not simply a function of the sensor. Full consideration should be given to the range of design levers available.

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Appendix A: Disaster inquiries in Australia

Table 53: Australian disaster inquiries between 1886 and 2014 and status within Chapter four study.

Note: "Not online" means that the inquiry could not be acquired digitally. "Analysed" means the inquiry was acquired and analysed. "Acquired, text not accessible" means the inquiry was acquired but could not be analysed within the word frequency analysis because the PDF file was not accessible or was read protected.

Year	State	Inquiry type	Disaster type	Title	Status
1886	NSW	Royal Commission	Technical accident	Royal Commission on Collieries	Not online
1887	NSW	Royal Commission	Technical accident	Royal Commission on the Bulli Colliery Accident	Not online
1901	NSW	Royal Commission	Technical accident	Royal Commission to Inquire Into the Fatal Accident which Took Place at the Broken Hill South Mine, Broken Hill on the 24th May, 1901	Not online
1902	VIC	Royal Commission	Technical accident	Royal commission to investigate the subject of locomotive spark arresters as a means of preventing the occurrence of destructive fires in the working of the Victorian railways	Analysed
1903	NSW	Royal Commission	Technical accident	Royal Commission of Inquiry Respecting the Mount Kembla Colliery Disaster	Analysed
1903	NSW	Royal Commission	Technical accident	Royal Commission appointed to inquire into the cause of the fatal accident at the mine of the sulphide corporation company (limited), commonly known as the "Central Mine" Broken Hill, on the 8th October, 1902	Not online
1909	VIC	Coronial	Technical accident	Coroner's enquiry into the Sunshine railway disaster	Not online
1913	Tas	Royal Commission	Technical accident	Royal Commission on the North Mount Lyell Mining Disaster	Analysed
1922	QLD	Royal Commission	Technical accident	Royal Commission on Mount Mulligan Colliery Disaster	Not online
1923	Federal	Royal Commission	Technical accident	Royal Commission on the circumstances attending the supposed loss at sea of the steamship "Sumatra"	Not online
1925	QLD	Royal Commission	Technical accident	Royal Commission of Inquiry into the Traveston railway accident	Not online
1926	NSW	Royal Commission	Technical accident	Report of Royal Commission on Coal and Shale Mines	Not online
1927	NSW	Royal Commission	Bushfire	Royal Commission of Inquiry on Bush Fires in the State of New South Wales	Not online
1937	VIC	Royal Commission	Technical accident	Royal commission on certain matters relating to the state coal mine Wonthaggi. Interim and Second Report	Analysed
1939	VIC	Royal Commission	Bushfire	Royal commission to inquire into the causes of and measures taken to prevent the bush fires of January 1939 and to protect life and property and the measures to be taken to prevent bush fires in Victoria and to protect life and property in the event of future bush fires	Analysed
1944	VIC	Royal Commission	Bushfire	Royal commission to inquire into the place of origin and the causes of the fires which commenced at Yallourn on the 14th day of February 1944; the adequacy of the measures which had been taken to prevent damage; and the measures to be taken to protect the	Analysed
1956	QLD	Royal Commission	Technical accident	Royal Commission Appointed to Enquire Into Certain Matters Relating to the State Coal Mine, Collinsville	Not online
1957	NSW	Independent	Flood	Report on the River Murray flood problem : (with particular reference to the 1956 flood)	Not online
1961	WA	Royal Commission	Bushfire	Royal Commission appointed to enquire into and report upon the bush fires of December, 1960 and January, February and March, 1961 in Western Australia. The measures necessary or desirable to prevent and control such fires and to protect life and property	Acquired, text not accessible
1964	Federal	Royal Commission	Technical accident	Royal Commission on Loss of H.M.A.S. Voyager	Not online

1967	Tas	Governments	Bushfire	Fire Prevention and Suppression—Report of Committee appointed by His Excellency the Administrator-in-Council to make recommendations with respect to future measures in consequences of the Bush Fire Disaster of 7th February, 1967	Not online
1968	VIC	Parliamentary	Fire	Metropolitan Fire Brigades Board. Committee of Enquiry	Not online
1971	VIC	Royal Commission	Technical accident	Royal commission into the failure of West Gate Bridge	Acquired, text not accessible
1971	NSW	Agency	Flood	Inter-Departmental Committee of Inquiry into Nepean-Hawkesbury Flood Problems. Interim and Final report	Not online
1973	VIC	Parliamentary	Flood	Northern River flooding inquiry, 1973 : evidence presented to Victorian Parliamentary Public Works Committee	Not online
1974	NT	Independent	Bushfire	A report arising from an enquiry into the Northern Territory fire service	Not online
1977	VIC	Parliamentary	Bushfire	Report of the Board of Inquiry into the occurrence of bush and grass fires in Victoria – Inquiries following 2002–2003 bushfires	Analysed
1977	Federal	Independent	Fire	Board of Inquiry into the Fire at the Naval Air Station, Nowra, New South Wales	Not online
1978	NSW	Independent	Fire	Committee of Inquiry into the NSW Fire Brigades (Parkinson Committee)	Not online
1979	Federal	Parliamentary	Biological	The Adequacy of Quarantine	Not online
1979	SA	Parliamentary	Fire	Committee of Inquiry into South Australian Fire Services	Not online
1983	VIC	Agency	Bushfire	A Study of Civilian Deaths in the 1983 Ash Wednesday Bushfires Victoria, Australia.	Analysed
1983	NSW	Coronial	Bushfire	Inquiry into a fire at Royal National Park, Grays Point	Not online
1983	VIC	Agency	Bushfire	Fire protection and fuel-reduction burning in Victoria	Not online
1983	SA	Independent	Bushfire	Report of the Review Team on the South Australian bushfires	Not online
1983	SA	Agency	All hazard	Final report and recommendations of the State Disaster Plan (Welfare) Review Committee	Not online
1984	VIC	Independent	Bushfire	Report of the Bushfire Review Committee on bushfire preparedness in Victoria, Australia, following the Ash Wednesday fires 16 February 1983 – Inquiries following 2002–2003 bushfires	Analysed
1984	Federal	Parliamentary	Bushfire	Bushfires and the Australian Environment	Not online
1984	Federal	Parliamentary	Bushfire	The 1982/83 Bushfires: Implications for national cooperation and coordination based on direct State and Territory forest service experience – major conflagrations report	Not online
1985	SA	Independent	Bushfire	Review of electricity distribution policies in bushfire prone and environmentally sensitive areas	Not online
1985	WA	Independent	All hazard	Review of emergency services	Not online
1986	Federal	Parliamentary	Technical accident	Passenger coach safety	Analysed
1986	ACT	Parliamentary	Fire	Committee of Enquiry into the A.C.T. Fire Brigade	Not online
1987	Federal	Independent	Technical accident	Report of the committee of inquiry into a fire which occurred on 18 March 1987 in a radioisotope processing cell, Building 54 at the Lucas Heights Research Laboratories.	Not online
1988	ACT	Independent	All hazard	Purdue Report on management training	Not online
1989	Federal	Parliamentary	Technical accident	Visits to Australia by Nuclear Powered or Armed Vessels: Contingency Planning for the Accidental Release of Ionising Radiation	Acquired, text not accessible
1989	NSW	Parliamentary	All hazard	Coastal development in NSW: Public concerns and government processes	Not online
1989	QLD	Independent	Fire	Commission of Review of Fire Services in Queensland	Not online

1991	NSW	Parliamentary	All hazard	Coastal planning and management in NSW: A framework for the future, Volume 1	Not online
1991	ACT	Independent	All hazard	Hannan Group review of the effectiveness of fire and emergency service organisations	Not online
1992	NSW	Parliamentary	All hazard	Coastal planning and management in NSW: The process for the future, Volume 2	Not online
1992	ACT	Independent	All hazard	Purdon Report	Not online
1993	QLD	Independent	All hazard	Review of the Bureau of Emergency Services	Not online
1993	ACT	Independent	All hazard	MacDonald review of emergency services	Not online
1993	Tas	Independent	Bushfire	Bushfire management in Tasmania's forests : an audit of the fire management activities of the Forestry Commission	Not online
1994	VIC	Parliamentary	Fire	Report of the Public Bodies Review Committee into the Metropolitan Fire Brigades Board	Analysed
1994	Federal	Parliamentary	All hazard	Disaster Management	Not online
1994	NSW	Parliamentary	Bushfire	the report of the Select Committee on Bushfires – COAG Bushfire Inquiry	Not online
1994	QLD	Independent	Bushfire	Audit of bushfire strategies:Queensland Emergency Services	Not online
1994	ACT	Independent	Bushfire	McBeth review of bushfire hazard–reduction practices	Not online
1994	Tas	Independent	Bushfire	Review of Vegetation-Based Fire in Tasmania – major conflagrations report	Not online
1994	WA	Independent	Bushfire	Report of the Fire Review Panel Conducting a Review of the Department of Conservation and Land Management's (CALM) prescribed burning policy and practices and 'Wildfire Threat Analysis – major conflagrations report	Not online
1995	ACT	Independent	Bushfire	Glenn Bushfire Taskforce	Not online
1996	NSW	Coronial	Bushfire	New South Wales Bushfire Inquiry : findings. Inquiry into the cause and origin of the bushfires occurring in New South Wales between 31st December, 1993 and 14th January, 1994 and Inquests into the manner and cause of death of Norman John Anthes, Robert Eglinton Page, William John Roach and Pauline Mary O'Neil	Not online
1996	NSW	Audit	Fire	New South Wales Fire Brigades : fire prevention	Not online
1997	VIC	Coronial	Fire	Inquest findings, comments and recommendations into fire and nine deaths at Kew Residential Services on 8 April 1996	Not online
1998	Federal	Independent	Technical accident	Board of Inquiry Into the Fire in HMAS Westralia	Analysed
1998	NSW	Audit	Bushfire	The Coordination of Bushfire Fighting Activities	Analysed
1998	Federal	Parliamentary	Biological	The Incidence and Management of the Ovine Johnes Disease in the Australian Sheep Flock	Not online
1999	VIC	Agency	Bushfire	Reducing the Risk of Entrapment in Wildfires: A Case Study of the Linton Fire	Analysed
1999	Federal	Parliamentary	Technical accident	Report 87: Loss of HMAS Sydney	Analysed
1999	VIC	Royal Commission	Technical accident	The Esso Longford Gas Plant Accident: Report of the Longford Royal Commission	Analysed
2000	Federal	Agency	Flood	Consumer Understanding of Flood Insurance	Analysed
2000	Federal	Audit	All hazard	Commonwealth Emergency Management Arrangements	Analysed

2000	NSW	Parliamentary	Bushfire	NSW Rural Fire Service	Analysed
2000	NSW	Coronial	Technical accident	Inquest into the deaths arising from the Thredbo landslide	Analysed
2000	QLD	Independent	Bushfire	Fire Safety and Budget Accommodation: The Building and Other Legislation Amendment Bill 2001	Analysed
2000	VIC	Parliamentary	Biological	Inquiry into the Control of Ovine Johne's Disease in Victoria	Analysed
2000	NSW	Coronial	Technical accident	Inquest into the event of the 1998 Sydney to Hobart Yacht Race	Analysed
2000	Federal	Independent	Maritime	Australian Offshore Petroleum Safety Case Review	Not online
2001	NSW	Parliamentary	Oil Spill	Oil Spills in Sydney Harbour (Inquiry)	Analysed
2001	NSW	Independent	Technical accident	Special Commission of Inquiry into the Glenbrook Rail Accident,Final Report	Analysed
2001	NSW	Coronial	Bushfire	Inquiry into the Fire at Mt Ku-Ring-Gai Chase National Park	Analysed
2001	NSW	Audit	All hazard	Readiness to Respond - 2001 Reports (Inquiry into the Ambulance Service)	Analysed
2001	NSW	Audit	Bushfire	Follow up of Performance Audits: Police response to calls for assistance, The levying and collection of land tax, Coordination of bushfire fighting activities	Analysed
2001	WA	Parliamentary	Fire	Bellevue Hazardous Waste Fire Inquiry	Analysed
2002	Federal	Governments	All hazard	Natural Disasters in Australia: Reforming mitigation, relief and recovery arrangements	Analysed
2002	NSW	Parliamentary	Bushfire	Inquiry into the 2001/2002 Bushfires	Analysed
2002	NSW	Audit	Biological	Managing Animal Disease Emergencies	Analysed
2002	VIC	Coronial	Technical accident	Inquest into the deaths of Peter Brubeck Wilson and John Francis Lowery and the fire at Longford Gas Plant Number 1	Analysed
2002	VIC	Coronial	Bushfire	Inquest into the Linton Wildfire	Analysed
2003	Federal	Parliamentary	Bushfire	A Nation Charred: Inquiry into the Recent Australian Bushfires	Analysed
2003	Federal	Audit	Biological	Pest and Disease Emergency Management Follow-on Audit	Analysed
2003	Federal	Audit	All hazard	Business Continuity Management Follow-on Audit	Analysed
2003	Federal	Audit	All hazard	Business Continuity Management and Emergency Management in Centrelink	Analysed
2003	NSW	Audit	Biological	Implementing the Ovine Johne's Disease Program - 2003 Reports	Analysed
2003	ACT	Independent	Bushfire	The Inquiry into the Operational Response to the January 2003 Bushfires	Analysed
2003	ACT	Independent	Bushfire	The Report of the Bushfire Recovery Taskforce	Analysed
2003	ACT	Audit	All hazard	Emergency Services	Analysed
2003	VIC	Agency	Bushfire	Inquiry into the 2002-2003 Victorian Bushfires	Analysed
2003	VIC	Audit	Bushfire	Fire Prevention and Preparedness	Analysed

2003	Tas	Parliamentary	All hazard	Report on Ambulance Services in Tasmania	Analysed
2003	SA	Independent	All hazard	Review of the Emergency Services Sector (Dawkins Review)	Acquired, text not accessible
2003	WA	Coronial	Maritime	Record of Investigation into Death HMAS Westralia	Acquired, text not accessible
2003	Federal	Independent	Maritime	National Offshore Petroleum Safety Authority: Review of Implementation Activities	Not online
2003	NSW	Coronial	Bushfire	Inquiry into the Circumstances of the Fire(s) in the Brindabella Range in January 2003	Not online
2004	NSW	Parliamentary	All hazard	Ambulance Service of NSW: Readiness to respond (Inquiry)	Analysed
2004	NSW	Parliamentary	Bushfire	Fire Services Funding (Inquiry)	Analysed
2004	NSW	Agency	Biological	NSW Taskforce on SARS (TSARS)	Analysed
2004	QLD	Audit	All hazard	Audit of the Queensland Disaster Management System	Analysed
2004	VIC	Audit	Biological	Beating the Bugs: Protecting Victoria's Economically Significant Crops from Pests and Diseases	Analysed
2004	WA	Coronial	Bushfire	Tenterden and Mt Barker Fires Coronial Inquiry	Analysed
2004	WA	Audit	Bushfire	Responding to Major Bushfires	Analysed
2004	WA	Coronial	Bushfire	Ocean Farm Fires Coronial Inquiry	Not online
2005	Federal	Governments	Bushfire	National Inquiry on Bushfire Mitigation and Management.	Analysed
2005	Federal	Governments	All hazard	Review of Australia's Ability to Respond to and Recover From Catastrophic Disasters	Analysed
2005	Federal	Independent	Tsunami	Tsunamis – Does anyone have to die?	Analysed
2005	Federal	Audit	Manmade	Review of the Evaluation Methods and Continuous Improvement Processes for Australia's National Counter-Terrorism Coordination Arrangements	Analysed
2005	NSW	Independent	Technical accident	Special Commission of Inquiry into the Waterfall Rail Accident,Volume 1 & Volume 2.	Analysed
2005	NSW	Audit	All hazard	Coordination of State Rescue Services	Analysed
2005	VIC	Agency	Bushfire	Examination of Prescribed Burning Practices	Analysed
2005	VIC	Agency	All hazard	Improving Emergency Response at Melbourne Airport	Analysed
2005	VIC	Audit	Flood	Managing Stormwater Flooding Risks in Melbourne	Analysed
2005	SA	Parliamentary	Bushfire	Eyre Peninsula Bushfire and Native Vegetation	Analysed
2005	NSW	Independent	Bushfire	Statutory Review of the Rural Fires Act 1997	Not online
2006	Federal	Parliamentary	Tsunami	Inquiry into Australia's response to the Indian Ocean Tsunami	Analysed
2006	NSW	Parliamentary	Biological	Inquiry into Managing Animal and Plant Diseases	Analysed
2006	NSW	Audit	Biological	Major Infectious Disease Outbreaks: Readiness to Respond	Analysed

2006	QLD	Coronial	Fire	Palace Backpackers Hostel Fire	Analysed
2006	ACT	Coronial	Bushfire	The Canberra Firestorm: Inquests and Inquiry into Four Deaths and Four Fires between 8 and 18 January 2003 Volume 1 & Volume 2	Analysed
2006	VIC	Independent	Bushfire	Fire Season Debrief Outcomes Report 2005/06	Analysed
2006	WA	Parliamentary	All hazard	Inquiry into Fire and Emergency Services Legislation	Analysed
2006	VIC	Agency	All hazard	Emergency Management Discussion Paper. Department of Justice.	Not online
2007	SA	Coronial	Bushfire	Inquests into the deaths of [9 named people] (2005 Eyre Peninsula, Wangarry fires).	Analysed
2007	VIC	Coronial	Bushfire	Record of Investigation into Death (Ararat Road Block).	Acquired, text not accessible
2007	Federal	Audit	Biological	Australia's Preparedness for a Human Influenza Pandemic	Analysed
2007	QLD	Independent	Cyclone	The Final Report of the Operation Recovery Task Force: Severe Tropical Cyclone Larry	Analysed
2007	QLD	Coronial	Technical accident	Inquest into the Lockhart River air crash	Analysed
2007	VIC	Independent	Bushfire	Operational Review of Major Fires in Victoria 2006/07 – Ross Smith Report	Analysed
2007	Tas	Independent	All hazard	Tasmanian Medical Retrieval Services External Review	Analysed
2007	SA	Governments	Bushfire	Ministerial Review of Bushfire Management in South Australia	Analysed
2007	WA	Parliamentary	All hazard	Inquiry into Western Australia's Natural Disaster Relief Arrangements	Analysed
2007	Federal		Terrorism	Lessons from London and considerations for Australia: London Terrorist Attacks 7 July 2005	Not online
2008	Federal	Parliamentary	All hazard	Inquiry into climate change and environmental impacts on coastal communities	Analysed
2008	Federal	Parliamentary	All hazard	Inquiry into the Administration of the Civil Aviation Safety Authority (CASA) and related matters	Analysed
2008	Federal	Royal Commission	Biological	Equine Influenza Inquiry	Analysed
2008	Federal	Audit	All hazard	Emergency Management Australia	Analysed
2008	QLD	Audit	Bushfire	Management of Rural Fire Services in Queensland	Analysed
2008	ACT	Parliamentary	All hazard	ACT Fire and Emergency Services Arrangements	Analysed
2008	VIC	Parliamentary	Bushfire	Inquiry into the Impact of Public Land Management Practices on Bushfires in Victoria	Analysed
2008	VIC	Agency	Windstorm	Review of the April 2008 Windstorm	Analysed
2008	VIC	Agency	Fire	Westpoint Chemical Fire Community Report	Analysed
2008	VIC	Audit	Biological	Biosecurity Incidents: Planning and Risk Management for Livestock Diseases	Analysed
2008	SA	Independent	All hazard	Review of the Fire and Emergency Services Act 2005	Analysed
2008	SA	Coronial	Bushfire	Wangary Fires Inquest	Analysed

2008	SA	Agency	All hazard	Volunteer Administrative Workload Review	Analysed
2008	Federal	Independent	Maritime	National Offshore Petroleum Safety Authority Operational Review	Not online
2008	VIC	Agency	Maritime	Marine Emergency Framework Review Final Report	Not online
2009	WA	Coronial	Bushfire	Record of Investigation into Death (2007 Boorabin fires).	Analysed
2009	Tas	Coronial	Fire	Record of Investigation into a Fire at the Myer Store at 98-108 Liverpool Street, Hobart, on 22 September 2007	Analysed
2009	Federal	Governments	All hazard	Recommendations on the Role of AEMO and the Effectiveness of Current Gas and Electricity Emergency Arrangements	Analysed
2009	Federal	Independent	All hazard	Offshore Petroleum Safety Regulation – this inquiry produced two reports "Marine Issues" and "Better practice and the effectiveness of the National Offshore Petroleum Safety Authority"	Analysed
2009	Federal	Audit	All hazard	Business Continuity Management and Emergency Management in Centrelink	Analysed
2009	NSW	Independent	Flood	Recovery Coordinator's Report of the Mid North and Far North Coast Flood Recovery – May 2009	Analysed
2009	NSW	Agency	Bushfire	Review of Bushfire Arson Laws	Analysed
2009	QLD	Independent	All hazard	Report on a Review of Disaster Management Legislation and Policy in Queensland	Analysed
2009	ACT	Audit	All hazard	Delivery of Ambulance Services to the ACT Community	Analysed
2009	VIC	Agency	Bushfire	Operational debrief report 2008/09 fire season	Analysed
2009	VIC	Audit	Manmade	Preparedness to Respond to Terrorism Incidents Essential Services and Critical Infrastructure	Analysed
2009	Tas	Coronial	Technical accident	Beaconsfield Mine Disaster Coronial Inquest	Analysed
2009	WA	Agency	Bushfire	Review of Western Australia's Bushfire Preparedness	Analysed
2009	WA	Agency	Bushfire	Bridgetown Complex Post Incident Analysis	Analysed
2009	WA	Audit	All hazard	Coming Ready or Not: Preparing for Large-scale Emergencies	Analysed
2010	Federal	Parliamentary	Bushfire	The incidence of bushfires across Australia. Senate Select Committee on Agriculture and Related Industries.	Analysed
2010	WA	Independent	Bushfire	Major Incident Review of Toodyay Fire December 2009	Analysed
2010	Federal	Independent	Oil spill	Montara Commission of Inquiry	Analysed
2010	Federal	Audit	All hazard	Emergency Management and Community Recovery Assistance in Centrelink	Analysed
2010	VIC	Royal Commission	Bushfire	Victorian Bushfires Royal Commission. Interim Report 1, Interim Report 2 and Final Report	Analysed
2010	VIC	Audit	All hazard	The Department of Human Services' Role in Emergency Recovery	Analysed
2010	VIC	Audit	All hazard	Business Continuity Management in Local Government	Analysed
2010	NT	Coronial	Maritime	Ashmore Reef Boat Explosion – SEIV 36	Analysed

2010	WA	Independent	Bushfire	A Review of the Ability of the Department of Environment and Conservation Western Australia to Manage Major Fires	Analysed
2010	Federal	Agency	All hazard	Working Better Together: An NGO perspective on improving Australia's coordination in disaster response	Not online
2011	WA	Independent	Bushfire	Major Incident Review: Lake Clifton, Red Hill and Roleystone Fires June 2011.	Analysed
2011	WA	Independent	Bushfire	Shared Responsibility: The Report of the Perth Hills Bushfire February 2011 Review.	Analysed
2011	Federal	Agency	Flood	Inquiry into flood insurance and related matters. Natural Disaster Insurance Review.	Analysed
2011	VIC	Agency	All hazard	Towards a More Disaster Resilient Victoria: Green Paper Options and Issues. Government of Victoria.	Analysed
2011	WA	Parliamentary	Fire	Inquiry into the 2011 Kimberley Ultramarathon. Parliament of Western Australia	Analysed
2011	Federal	Parliamentary	All hazard	The capacity of communication networks and emergency warning systems to deal with emergencies and natural disasters	Analysed
2011	Federal	Parliamentary	All hazard	The asset insurance arrangements of Australian state governments	Analysed
2011	Federal	Parliamentary	Maritime	Joint Select Committee on the Christmas Island Tragedy of 15 December 2010	Analysed
2011	Federal	Independent	All hazard	Natural Disaster Insurance Review	Analysed
2011	Federal	Independent	Maritime	National Offshore Petroleum Safety Authority Operational Review	Analysed
2011	NSW	Parliamentary	Technical accident	Kooragang Island Orica chemical leak	Analysed
2011	QLD	Parliamentary	Bushfire	Management of Rural Fire Services in Queensland	Analysed
2011	QLD	Audit	All hazard	National Partnership Agreement for Natural Disaster Reconstruction and Recovery	Analysed
2011	VIC	Independent	Flood	The review of the 2010-11 Flood Warnings and Response. Interim and Final reports	Analysed
2011	VIC	Independent	Fire	Independent Inquiry into the effect of arrangements on Country Fire Authority Volunteers	Analysed
2011	VIC	Agency	Bushfire	Review of the February 2011 Tostaree Fire	Analysed
2011	VIC	Agency	Fire	TriTech Lubricants factory fire	Analysed
2011	VIC	Agency	Bushfire	2011 Review of Community Bushfire Warnings	Analysed
2011	Tas	Audit	Bushfire	Bushfire Management	Analysed
2011	SA	Parliamentary	Bushfire	Natural Resources Committee Bushfire Inquiry	Analysed
2011	WA	Parliamentary	Bushfire	Examination of the State's Preparedness for this Year's Coming Fire Season	Analysed
2012	WA	Independent	Bushfire	Appreciating the Risk: Report of the Special Inquiry into the November 2011 Margaret River Bushfire	Analysed
2012	Federal	Parliamentary	All hazard	Inquiry into the operation of the insurance industry during disaster events	Analysed
2012	Federal	Independent	All hazard	Review of the Bureau of Meteorology's extreme weather and seasonal forecasting capacity	Analysed

2012	Federal	Independent	All hazard	Barriers to Effective Climate Change Adaptation	Analysed
2012	QLD	Independent	Flood	Queensland Floods Commission of Inquiry Interim and Final reports	Analysed
2012	QLD	Coronial	Flood	Inquest into the deaths caused by the South-East Queensland floods of January 2011	Analysed
2012	VIC	Parliamentary	Flood	Inquiry into Flood Mitigation Infrastructure in Victoria	Analysed
2012	VIC	Agency	Flood	North East Victoria Flood Review	Analysed
2012	VIC	Agency	Flood	Gippsland Flood Event – Review of Flood Warnings and Information Systems	Analysed
2012	VIC	Agency	Fire	Fire at Yarra Valley Grammar School	Analysed
2012	VIC	Agency	Bushfire	Westmeadows Grassfire	Analysed
2012	VIC	Agency	Fire	Fire Management at Landfill Sites	Analysed
2012	VIC	Agency	Technical accident	Port of Portland Emergency	Analysed
2012	VIC	Agency	Technical accident	NuPlex Chemical Incident	Acquired, text not accessible
2012	VIC	Agency	Bushfire	2011/12 Post Bushfire Season Review Report	Analysed
2012	NT	Agency	Bushfire	Review of the Operations of Bushfires NT	Analysed
2012	WA	Parliamentary	Bushfire	Inquiry into the State's preparedness for this year's fire season	Acquired, text not accessible
2012	WA	Parliamentary	All hazard	The Toll of Trauma on Western Australian Emergency Staff and Volunteers	Analysed
2012	WA	Coronial	Maritime	Coronial inquest into 2010 Christmas Island boat disaster or SIEV 221	Analysed
2012	WA	Agency	Bushfire	Post Incident Analysis for Blackwood Fire 8	Analysed
2012	WA	Agency	Bushfire	Post Incident Analysis for Blackwood Fire 11	Analysed
2012	WA	Audit	All hazard	Second Public Sector Performance Report 2012	Analysed
2013	Federal	Parliamentary	All hazard	Recent trends in and preparedness for extreme weather events	Analysed
2013	Federal	Parliamentary	Technical accident	Aviation Accident Investigations (Pel-air)	Analysed
2013	Federal	Parliamentary	Biological	Inquiry into health issues across international borders	Analysed
2013	Federal	Parliamentary	All hazard	Spectrum for public safety mobile broadband	Analysed
2013	Federal	Agency	Fire	Inquiry to learn lessons from Warrnambool exchange fire	Analysed
2013	Federal	Audit	All hazard	The Preparation and Delivery of the Natural Disaster Recovery Work Plans for Queensland and Victoria	Analysed
2013	Federal	Audit	Flood	The Australian Government Reconstruction Inspectorate's Conduct of Value for Money Reviews of Flood Reconstruction Projects in Victoria	Analysed

2013	Federal	Audit	Flood	The Australian Government Reconstruction Inspectorate's Conduct of Value for Money Reviews of Flood Reconstruction Projects in Queensland	Analysed
2013	NSW	Independent	All hazard	Independent Hazard Reduction Audit Panel	Analysed
2013	QLD	Independent	All hazard	Police and Community Safety Review	Analysed
2013	QLD	Governments	Bushfire	The Malone Review into the Rural Fire Service	Analysed
2013	ACT	Audit	Bushfire	Bushfire Preparedness	Analysed
2013	VIC	Coronial	Technical accident	Kerang Train Crash Inquest	Acquired, text not accessible
2013	VIC	Agency	Bushfire	Report into the Harrietville Fire	Analysed
2013	VIC	Audit	All hazard	Management of Unplanned Leave in Emergency Services	Analysed
2013	VIC	Audit	Flood	Flood Relief and Recovery	Analysed
2013	Tas	Independent	Bushfire	Tasmanian Bushfires Inquiry	Analysed
2013	SA	Parliamentary	All hazard	Community Safety and Emergency Services in South Australia	Analysed
2013	SA	Independent	All hazard	Review of the Fire and Emergency Services Act 2005	Analysed
2013	WA	Audit	All hazard	Delivering WA's Ambulance Services	Analysed
2013	Tas	Audit	All hazard	Radio Communications (yet to be completed)	Not online
2013	WA	Coronial	Bushfire	Coroner's inquest into the fatal bushfire at Albany (yet to report)	Not online
2013	WA	Agency	Bushfire	Report into the fatal bushfire at Albany (completed report will be released following the coronial inquiry)	Not online
2013	NSW	Agency	Flood	Hawkesbury-Nepean Valley Flood Management Review (report due late 2013)	Not online
2013	QLD	Audit	All hazard	Ambulance Service Performance (report due December 2013)	Not online
2014	Federal	Independent	Technical accident	Aviation Safety Regulation Review – (report due May 2014)	Not online
2014	Federal	Independent	Bushfire	Commission of Inquiry appointed into the fire at Marrangaroo Training Area (report expected 2014)	Not online
2014	Federal	Independent	All hazard	Productivity Commission Inquiry Into National Disaster Funding Arrangements (inquiry expected 2014)	Not online
2014	NSW	Parliamentary	Bushfire	Wambelong fire (Inquiry) (report expected late 2014)	Not online
2014	NSW	Coronial	Bushfire	Coronial Inquest into the Warrumbungle Bushfire (expected late 2014)	Not online
2014	VIC	Audit	All hazard	Managing Emergency Service Volunteers (report due February 2014)	Not online

Appendix B: Disaster inquiries in Australia by jurisdiction, hazard and inquiry type

Table 54: Australian disaster inquiry types by jurisdiction

	Agency	Audit	Coronial	Governments	Independent	Parliamentary	Royal Commission	Total
ACT		3	1		8	2		14
Federal	4	12		4	16	21	3	60
NSW	4	8	6		7	12	7	44
NT	1		1		1			3
QLD		4	3	1	8	1	3	20
SA	2		2	1	5	4		14
Tas		2	2	1	4	1	1	11
VIC	24	10	6		5	7	7	59
WA	5	4	7		7	7	1	31
Total	**40**	**43**	**28**	**7**	**61**	**55**	**22**	**256**

Table 55: Australian disaster inquiry hazard type by jurisdiction

	Federal	ACT	NSW	NT	QLD	SA	Tas	VIC	WA	Total
All hazard	24	7	7		6	6	3	7	7	67
Biological	6		5					3		14
Bushfire	6	6	15	2	5	7	5	22	19	87
Cyclone					1					1
Fire	2	1	2		2	1	1	8	2	19
Flood	4		4		2			7		17
Manmade	1							1		2
Maritime	5			1				1	3	10
Oil Spill	1		1							2
Technical accident	9		10		4		2	9		34
Terrorism	1									1
Tsunami	2									2
Windstorm								1		1
Total	**61**	**14**	**44**	**3**	**20**	**14**	**11**	**59**	**31**	**257**

Table 56: Australian disaster inquiry by jurisdictions over time

	Federal	ACT	NSW	NT	QLD	SA	Tas	VIC	WA	Total
1886			1							1
1887			1							1
1901			1							1
1902								1		1
1903			2							2
1909								1		1
1913							1			1
1922					1					1
1923	1									1
1925					1					1
1926			1							1
1927			1							1
1937								1		1
1939								1		1
1944								1		1
1956					1					1
1957			1							1
1961									1	1
1964	1									1
1967							1			1
1968								1		1
1971			1					1		2
1973								1		1
1974				1						1
1977	1							1		2
1978			1							1
1979	1					1				2
1983			1			2		2		5
1984	2							1		3
1985						1			1	2
1986	1	1								2
1987	1									1
1988		1								1
1989	1		1		1					3
1991		1	1							2
1992		1	1							2
1993		1			1		1			3
1994	1	1	1		1		1	1	1	7
1995		1								1
1996			2							2
1997								1		1
1998	2		1							3
1999	1							2		3
2000	3		2		1			1		7
2001			5						1	6
2002	1		2					2		5
2003	5	3	2			1	1	2	1	15
2004			3		1			1	3	8
2005	4		3			1		3		11
2006	1	1	2		1			2	1	8
2007	2				2	2	1	2	1	10
2008	5	1			1	3		5		15
2009	3	1	2		1		2	2	4	15
2010	4			1				3	3	11
2011	6		1		2	1	1	6	4	21
2012	3			1	2			9	7	22
2013	8	1	2		3	2	2	4	3	25
2014	3		2					1		6
Total	**61**	**14**	**44**	**3**	**20**	**14**	**11**	**59**	**31**	**257**

Table 57: Australian disaster inquiry by inquiry type over time

	Agency	Audit	Coronial	Governments	Independent	Parliamentary	Royal Commission	Total
1886							1	1
1887							1	1
1901							1	1
1902							1	1
1903							2	2
1909			1					1
1913							1	1
1922							1	1
1923							1	1
1925							1	1
1926							1	1
1927							1	1
1937							1	1
1939							1	1
1944							1	1
1956							1	1
1957					1			1
1961							1	1
1964							1	1
1967				1				1
1968						1		1
1971	1						1	2
1973						1		1
1974					1			1
1977					1	1		2
1978					1			1
1979						2		2
1983	3		1		1			5
1984					1	2		3
1985					2			2
1986						2		2
1987					1			1
1988					1			1
1989					1	2		3
1991					1	1		2
1992					1	1		2
1993					3			3
1994					4	3		7
1995					1			1
1996		1	1					2
1997			1					1
1998		1			1	1		3
1999	1					1	1	3
2000	1	1	1		2	2		7
2001		2	1		1	2		6
2002		1	2	1		1		5
2003	1	6	2		4	2		15
2004	1	3	2			2		8
2005	2	3		2	3	1		11
2006	1	1	2		1	3		8
2007		1	3	1	3	1		9
2008	4	3	1		2	4	1	15
2009	4	4	3	1	3			15
2010	1	3	2		3	1	1	11
2011	5	2			6	8		21
2012	11	1	2		4	4		22
2013	4	9	2	1	4	5		25
2014		1	1		3	1		6
Total	**40**	**43**	**28**	**7**	**61**	**55**	**22**	**256**

Table 58: Australian disaster inquiry by hazard type over time

	All hazard	Biological	Bushfire	Cyclone	Fire	Flood	Manmade	Maritime	Oil Spill	Technical accident	Terrorism	Tsunami	Windstorm	Total
1886										1				1
1887										1				1
1901										1				1
1902										1				1
1903										2				2
1909										1				1
1913										1				1
1922										1				1
1923										1				1
1925										1				1
1926										1				1
1927			1											1
1937										1				1
1939			1											1
1944			1											1
1956										1				1
1957						1								1
1961			1											1
1964										1				1
1967			1											1
1968					1									1
1971						1				1				2
1973						1								1
1974			1											1
1977			1		1									2
1978					1									1
1979		1			1									2
1983	1		4											5
1984			3											3
1985	1		1											2
1986					1					1				2
1987										1				1
1988	1													1
1989	1				1					1				3
1991	2													2
1992	2													2
1993	2		1											3
1994	1		5		1									7
1995			1											1
1996			1		1									2
1997					1									1
1998		1	1							1				3
1999			1							2				3
2000	1	1	2			1		1		1				7
2001	1		2		1				1	1				6
2002	1	1	2							1				5
2003	5	2	6					2						15
2004	2	2	4											8
2005	3		4			1	1			1		1		11
2006	2	2	2		1							1		8
2007	2	1	4	1						1	1			10
2008	6	2	3		1			2					1	15
2009	6		5		1	1	1			1				15
2010	4		4					2	1					11
2011	5		8		3	2		2		1				21
2012	5		7		2	5		1		2				22
2013	11	1	6		1	4				2				25
2014	2		3							1				6
Total	**67**	**14**	**87**	**1**	**19**	**17**	**2**	**10**	**2**	**34**	**1**	**2**	**1**	**257**

Appendix C: Top 5 most frequently mentioned data related keyword Australian disaster inquiries

Table 59: Data related keyword mention count for Australian disaster inquiries flagged by word frequency analysis.

	data	information	observation	satellite	plane	aircraft	camera	sens	instrument	measure	radar	forecast	predict	project	model	surveillance	reconnaissance	intelligence	map	meteorol
1939 (Victoria) Royal Commission to inquire into the causes of and measures taken to prevent the bush fires of January, 1939 and to protect life and property and the measures to be taken to prevent bush fires in Victoria and to protect life and property in the event of future bush fires, L.E.B. Stretton.					4															
1944 (Victoria) Royal Commission to Inquire into the Place of Origin and the Causes of the Fires which Commenced at Yallourn on the 14th day of February, 1944, the Adequacy of the Measures which had been taken to Prevent Damage and the Measures to be taken to Protect the Undertaking and Township at Yallourn, L.E.B. Stretton.										4										
1984 (Victoria) Report of the Bushfire Review Committee on bushfire preparedness in Victoria, Australia, following the Ash Wednesday fires 16 February 1983 – Inquiries following 2002–2003 bushfires, S.I. Miller et al.										2										
1999 (Victoria) The Esso Longford Gas Plant Accident: Report of the Longford Royal Commission, D. Dawson and B. J. Brooks							5		3											
2000 (Federal) Commonwealth Emergency Management Arrangements, Australian National Audit Office								4												5
2001 (New South Wales) Inquiry into the Fire at Mt Ku-Ring-Gai Chase National Park, J. Stevenson, NSW State Coroner's Office																			2	
2001 (New South Wales) Readiness to Respond - 2001 Reports (Inquiry into the Ambulance Service), New South Wales Audit Office	3																			
2002 (Federal) Natural Disasters in Australia: Reforming mitigation, relief and recovery arrangements, Council of Australian Governments										1										
2002 (New South Wales) Managing Animal Disease Emergencies, New South Wales Audit Office																3				
2003 (New South Wales) Implementing the Ovine Johne's Disease Program - 2003 Reports, New South Wales Audit Office																4				
2003 (ACT) Emergency Services, J.L. Benton, ACT Auditor Generals office										3										

2005 (Federal) National Inquiry on Bushfire Mitigation and Management. , S. Ellis et al.								3											
2004 (New South Wales) Fire Services Funding (Inquiry), M. Brown et al. NSW Legislative Assembly															3				
2004 (Victoria) Beating the Bugs: Protecting Victoria's Economically Significant Crops from Pests and Diseases , J.W. Cameron Auditor General of Victoria																5			
2005 (Federal) Review of Australia's Ability to Respond to and Recover From Catastrophic Disasters, Australian Emergency Management Committee													5		4				
2005 (Federal) Tsunamis – Does anyone have to die?, Prime Minister's Science, Engineering and Innovation Council									5						5				3
2006 (New South Wales) Inquiry into Managing Animal and Plant Diseases, N. Hay et al. NSW Legislative Assembly																2			
2006 (ACT) The Canberra Firestorm: Inquests and Inquiry into Four Deaths and Four Fires between 8 and 18 January 2003 Volume 1 & Volume 2, M. Doogan, ACT Coroner's Court																	2		
2007 (Queensland) Inquest into the Lockhart River air crash, M. Barnes, Queensland State Coroner					2	1			1										
2007 (Tasmania) Tasmanian Medical Retrieval Services External Review, P. Sharley					1														
2008 (Federal) Inquiry into climate change and environmental impacts on coastal communities, J. George et al. Parliament of the Commonwealth of Australia														3					
2008 (Federal) Inquiry into the Administration of the Civil Aviation Safety Authority (CASA) and related matters, G. Sterle, Senate Rural and Regional Affairs and Transport References Committee					3	5													
2008 (Victoria) Inquiry into the Impact of Public Land Management Practices on Bushfires in Victoria, J. Pandazopoulos, et al. Victorian Parliamentary Environment and Natural Resources Committee								2											
2008 (Victoria) Westpoint Chemical Fire Community Report, Office of the Emergency Services Commissioner		3																	
2008 (Victoria) Biosecurity Incidents: Planning and Risk Management for Livestock Diseases, D.D.R. Pearson Auditor General Victoria																1			
2009 (Western Australia) Record of Investigation into Death (2007 Boorabin fires), A.N. Hope, State Coroner							2					2	4						
2009 (Tasmania) Record of Investigation into a Fire at the Myer Store at 98-108 Liverpool Street, Hobart, on 22 September 2007, C.P. Webster, Coroner							1												
2009 (Federal) Recommendations on the Role of AEMO and the Effectiveness of Current Gas and Electricity Emergency Arrangements, Energy Security Working Group of the Ministerial Council on Energy									2					5					
2009 (Federal) Business Continuity Management and Emergency Management in Centrelink, Australian National Audit Office	1																		
2009 (ACT) Delivery of Ambulance Services to the ACT Community, T. Pham ACT Auditor-General	5									5									
2009 (Victoria) Operational debrief report 2008/09 fire season, J. Fox and W. Major																		3	
2009 (Tasmania) Beaconsfield Mine Disaster Coronial Inquest, R. Chandler, Tasmania Coroner					5														

2009 (Western Australia) Bridgetown Complex Post Incident Analysis, Department of Environment and Conservation																3		5	
2010 (Western Australia) Major Incident Review of Toodyay Fire December 2009, P. Murphy			1					1								1	4		
2010 (Western Australia) A Review of the Ability of the Department of Environment and Conservation Western Australia to Manage Major Fires, E. Ferguson			2					5											
2011 (Western Australia) Shared Responsibility: The Report of the Perth Hills Bushfire February 2011 Review. , M.J. Keelty													4						
2011 (Victoria) Towards a More Disaster Resilient Victoria: Green Paper Options and Issues, Government of Victoria				5															
2011 (Western Australia) Inquiry into the 2011 Kimberley Ultramarathon. Parliament of Western Australia, M.D. Nahan et al.				2															
2011 (Federal) Joint Select Committee on the Christmas Island Tragedy of 15 December 2010, G. Marshall et al.										2									
2011 (Victoria) Review of the February 2011 Tostaree Fire, Office of the Emergency Services Commissioner		5																	
2011 (Victoria) TriTech Lubricants factory fire, Office of the Emergency Services Commissioner		4																	
2011 (Victoria) 2011 Review of Community Bushfire Warnings, Molino Stewart Pty Ltd		2															5		
2011 (Tasmania) Bushfire Management, H.M. Blake, Tasmania Auditor General																		4	
2012 (Federal) Review of the Bureau of Meteorology's extreme weather and seasonal forecasting capacity, C. Munro			3	4						3	1	3		2					1
2012 (Federal) Barriers to Effective Climate Change Adaptation, W. Craik et al. Productivity Commission									4				2						
2012 (Queensland) Inquest into the deaths caused by the South-East Queensland floods of January 2011, M. Barnes, Queensland State Coroner										4									
2012 (Victoria) North East Victoria Flood Review, Molino Stewart Pty Ltd												1					2		
2012 (Victoria) Gippsland Flood Event – Review of Flood Warnings and Information Systems, Office of the Emergency Services Commissioner		1										2					1		4
2012 (Victoria) Westmeadows Grassfire, J. Dalton Department of Sustainability and Environment						4										4	3	1	
2012 (Victoria) Fire Management at Landfill Sites, I.R.S. Services							3												
2012 (Victoria) 2011/12 Post Bushfire Season Review Report, Fire Services Commissioner Victoria et al.			4																
2010 (Western Australia) Coronial inquest into 2010 Christmas Island boat disaster or SIEV 221, A. N. Hope, Western Australia State Coroner										1									
2000 (NSW) Inquest into the event of the 1998 Sydney to Hobart Yacht Race, J. Abernethy											4								
2012 (Western Australia) Post Incident Analysis for Blackwood Fire 11, P. Heazlewood et al.			5								5								
2013 (Federal) Recent trends in and preparedness for extreme weather events, S. Birmingham et al.										5			1						2

2013 (Federal) Aviation Accident Investigations (Pel-air), B. Heffernan et al.							4													
2013 (Federal) Spectrum for public safety mobile broadband, R. McClelland	2			1		3						3								
2013 (Federal) Inquiry to learn lessons from Warrnambool exchange fire, Department of Broadband, Communications and the Digital Economy				3																
2013 (Federal) The Preparation and Delivery of the Natural Disaster Recovery Work Plans for Queensland and Victoria, I. McPhee ACT Auditor-General	4																			
2013 (Victoria) Report into the Harrietville Fire, M. Hallowes Victoria Emergency Services Commissioner						2											5			
2013 (South Australia) Review of the Fire and Emergency Services Act 2005, P. Holloway															1					

Appendix D: Key examples of data uptake and concerns from Australian disaster inquiries

1939 (Victoria) Royal Commission to inquire into the causes of and measures taken to prevent the bush fires of January, 1939 and to protect life and property and the measures to be taken to prevent bush fires in V ictoria and to protect life and property in the event of future bush fires, L.E.B. Stretton

- Examples of data uptake, usage or awareness include aerial visual surveillance and ground based fire look-out towers.
- Examples of data concerns include availability, repeatability, redundancy and timeliness
    - p.30 The use of the aeroplane in Victoria, there being an entirely insufficient installation of look-out towers, has been general… But it is suggested that the use has been too restricted and could be valuable only if fires were to break out according to time-table. In the immediate past, on days of fire danger, the aeroplane has made a circuit of very wide range. It has, in its circuit, passed over location "A" at 10 a.m., has quickly passed out of vision range of "A," and has not returned until next day or the fire danger day. If firebreaks out at "A" at 10.10 a.m., it may he detected by some other means ; it will not be detected by the aeroplane observer. The system of aeroplane observation should consist of a network operation by one or more machines. The aeroplane should carry a transmitting wireless set and the ground patrol or other ground body a receiving set.

1984 (Victoria) Report of the Bushfire Review Committee on bushfire preparedness in Victoria, Australia, following the Ash Wednesday fires 16 February 1983 – Inquiries following 2002–2003 bushfires, S.I. Miller et al.

- Examples of data uptake, usage or awareness include weather forecast, weather warnings and satellite vegetation mapping.
- Examples of data concerns include optimisation, more monitoring, dissemination and reliability
    - P. 133 Optimisation of existing meteorological capability to provide most effective warning.
    - P.133 Monitoring of seasonal fire danger developments. Utilisation of Landsat (satellite) monitoring, and similar systems, to provide progressive fire—related information on state of vegetation.
    - P.75 There needs to be a marked improvement generally in the systems and procedures used for gathering and disseminating information, particularly during disaster operations and during recovery.
    - P.75 As far as possible, warning and information systems need to be independent of normal power supplies, since the latter are prone to failure in fire situations. Thus, for example, sirens or similar devices driven by batteries or compressed air should be used to convey warning messages.

2000 (NSW) Inquest into the event of the 1998 Sydney to Hobart Yacht Race, J. Abernethy

- Examples of data uptake, usage or awareness include weather forecast and weather warnings
- Examples of data concerns include awareness and lack of knowledge
    - P214 like many other crews in the fleet, did not know the BOM's rule that gusts may be 40% stronger than the forecast wind speeds and wave heights may be 86% or more higher than forecast(ie, rogue waves).

2001 (New South Wales) Inquiry into the Fire at Mt Ku-Ring-Gai Chase National Park, J. Stevenson, NSW State Coroner's Office

- Examples of data concerns include availability of maps in the field
    - Rec 6 That a full briefing be carried out with all persons who are to undertake a prescribed burn.

2001 (New South Wales) Readiness to Respond - 2001 Reports (Inquiry into the Ambulance Service), New South Wales Audit Office

- Examples of data concerns include uptake, reliability, effective use and culture
    - P11 overall response time improvement will only be realised when the information available from the AmbCAD system is used
    - P25 …hurdles yet to be overcome concerning data reliability and effective use of information, once produced.
    - P64 information-driven culture does not depend solely on the availability of suitable information. It also requires a commitment by managers at all levels to use information to improve the business, and to be pro-active in improving the quality and application of the management information itself.

2005 (Federal) National Inquiry on Bushfire Mitigation and Management. , S. Ellis et al.

- Examples of data uptake, usage or awareness include satellite hotspots, fire scar mapping.
- Examples of data concerns include consistency and funding
    - Pxiii There has been good progress towards nationally consistent, widely available data and information in some arenas, but anomalies and gaps remain. These include a national program of fire regime mapping
    - Rec 5.2 - The Inquiry recommends that the Australian Government and the state and territory governments jointly provide additional resources and work in partnership to establish and refine a national program of fire regime mapping.

2004 (Victoria) Beating the Bugs: Protecting Victoria's Economically Significant Crops from Pests and Diseases , J.W. Cameron Auditor General of Victoria

- Examples of data concerns include flexibility and availability
    - P6 surveillance activity for threats not known to occur in Victoria is very limited

2005 (Federal) Tsunamis – Does anyone have to die?, Prime Minister's Science, Engineering and Innovation Council

- Examples of data uptake, usage or awareness include seismometers and satellite positioning
- Examples of data concerns include timeliness
    - P21 Because this information was not available sooner, news reports were the first confirmation seismologists had that the earthquake was massive enough to generate a tsunami

2006 (ACT) The Canberra Firestorm: Inquests and Inquiry into Four Deaths and Four Fires between 8 and 18 January 2003 Volume 1 & Volume 2, M. Doogan, ACT Coroner's Court

- Examples of data uptake, usage or awareness include aerial linescan, aerial photography, multispectral imagery
    - V1 P189 This data was collected by an aircraft with appropriate instruments, and effectively combined an aerial photograph with a digital image taken with an infra-red camera. This imagery provided Mr McRae with information as to the size, location and perimeter of the various ACT fires
- Examples of data concerns include accuracy, scalability and consistency
    - V1 P108 fire at Mount Gingera was not accurately plotted

- V2 352 ...as fire activity intensified in the early afternoon, it became increasingly difficult to get reliable information about the position of the various fire fronts. Although information was radioed in by firefighters in the field, he said that it was difficult to build a coherent view of the fire front

2008 (Victoria) Inquiry into the Impact of Public Land Management Practices on Bushfires in Victoria, J. Pandazopoulos, et al. Victorian Parliamentary Environment and Natural Resources Committee

- Examples of data uptake, usage or awareness include satellite imagery
- Examples of data concerns include maturity and cost
  - P158 while remote sensing technology has significant potential, it had yet to be fully proven
  - P159 the technology is not yet cost-effective

2009 (Western Australia) Record of Investigation into Death (2007 Boorabin fires), A.N. Hope, State Coroner

- Examples of data uptake, usage or awareness include weather forecast
- Examples of data concerns include not relied upon
  - P9 In the context of the nature and reliability of the information provided by the Bureau of Meteorology, the fact that the significant wind change information contained in these spot forecasts appears not to have been relied upon at all by the DEC Incident Management Team responsible for fire safety on 30 December 2007 is remarkable.
  - P56 RI recommend that to the extent it has not already done so, DEC take action to ensure that in future cases relevant weather forecast information, particularly information as to significant wind changes, is promptly transmitted through the Incident Management Team and made available to persons with field operation responsibility.

2009 (Tasmania) Record of Investigation into a Fire at the Myer Store at 98-108 Liverpool Street, Hobart, on 22 September 2007, C.P. Webster, Coroner

- Examples of data uptake, usage or awareness include thermal camera
- Examples of data concerns include data used too late and training
  - P32 …failed to use the thermal imaging camera in a timely manner.
  - P32 …inadequate training with the use of thermal imagining cameras.

2009 (Victoria) Operational debrief report 2008/09 fire season, J. Fox and W. Major

- Examples of data concerns include availability, quality, extent of detail
  - P23 many complaints about the availability and quality of maps, as well as the extent of detail (too much or too little)
  - P23 no operating manual to guide external mappers / GIS operators

2009 (Western Australia) Bridgetown Complex Post Incident Analysis, Department of Environment and Conservation

- Examples of data concerns include cleaned of extraneous information
  - P37 An aviation map that is ‘cleaned’ or extraneous information would be of benefit to air crew.

2010 (Western Australia) Major Incident Review of Toodyay Fire December 2009, P. Murphy

- Examples of data uptake, usage or awareness include weather forecast and fire weather warnings
  - P3 BoM provided the emergency services briefing (ESB) with predicted severe to catastrophic conditions across a number of fire weather districts. All relevant regions were placed on high alert and local arrangements were assessed for readiness.
- Examples of data concerns include information flow to decision makers, accurate, timeliness, lack of situational awareness

  - Piv … the poor passage of information through the chain of command, particularly from the fire ground to the IMT, is endemic to all rural fire services in Australia. Similarly in Toodyay, there was a lack of appreciation of the importance of information and the integrity of the chain of command. This meant that decision makers did not always have accurate and up-to-date information.
  - P17 a general lack of situational awareness in the IMT and higher levels of command

2011 (Victoria) Towards a More Disaster Resilient Victoria: Green Paper Options and Issues, Government of Victoria

- Examples of data uptake, usage or awareness include satellite flood perimeters
- Examples of data concerns include right information, right form, right time, consistency, rigor, accuracy, timeliness, fitness for purpose, common boundaries, tust, uptake, rumours and misinformation
  - P34 Access to the right information, in the right form, at the right time is critical to coordinated operations and effective decision-making. Currently, a wide variety of assessment material is produced across government and through different control and coordination centres that lacks consistency and rigor, reducing its value to decision-makers. Government also needs accurate and timely impact assessments to plan both short- and long-term recovery. At present, the way in which this information is collected and collated makes it difficult for State and local government to respond effectively to community needs.
  - P34 Common boundaries have the benefit of bringing agency representatives together at various forums, which enables networking, and building important relationships and trust required for effective joint-agency planning, response and recovery.
  - P43 New technologies – online and mobile media are now well established as significant tools for public communication among communities and emergency response agencies. Agencies need to harness technology, including social media effectively, to provide official warnings. They also need to manage the challenge of information being disseminated ahead of or in conflict with authorised information. In other words, governments need to keep people informed while avoiding the spread of misinformation.

2011 (Western Australia) Inquiry into the 2011 Kimberley Ultramarathon. Parliament of Western Australia, M.D. Nahan et al.

- Examples of data uptake, usage or awareness include satellite hotspots
  - P66 Hotspots used by Park Managers 4-5 times per days Mr Michael Bass “One of the best means available for us for monitoring the outbreak and movement of fires on the property is by satellite imagery which I monitor regularly, on average every few hours
- Examples of data concerns include cost, errors of omission and errors of commission
  - P283 The Terra MODIS instrument was one of the first satellites to constantly broadcast data for anyone with the right equipment and software to download, free of charge.
  - P285 Accuracy is a two sided question between errors of omission and errors of commission. SRSS are unable to make a categorical statement that SRSS fire hotspots are more “accurate” than M14, even in the north of Australia. Given the increased sensitivity, SRSS’s proprietary algorithm will report more fire
  - hotspots than M14.

2011 (Federal) Joint Select Committee on the Christmas Island Tragedy of 15 December 2010, G. Marshall et al.

- Examples of data uptake, usage or awareness include ground based RADAR and satellite RADAR
- Examples of data concerns include detection without identification and accuracy
    - P9 Simply detecting an object with the radar is not sufficient to identify it as a small boat.
    - P71 it became evident that the current surveillance and monitoring protocols for detecting and intercepting Suspected Illegal Entry Vessels (SIEVs) is not fool proof.

2011 (Victoria) Review of the February 2011 Tostaree Fire, Office of the Emergency Services Commissioner

- Examples of data uptake, usage or awareness include fire modelling
- Examples of data concerns include timeliness, relevance, clarity of message, consistency, interoperability accuracy, responsive, lack of a manual, technical means of filtering/triaging inputs and tailored.
    - P6 review found some issues with the timeliness, relevance and clarity of messages across all warning systems
    - P31 R11. The Fire Services introduce systems, procedures and operational training that promote information sharing and consistent situational awareness at every level, including to and from the fireground. This should include agencies such as police members on duty at roadblocks.
    - P31 The interoperability of different technologies continues to be problematic. The suite of technologies available at the state level need to be better integrated across agency functions to improve the way they are accessed and used (for example, fire mapping and modelling). Difficulties associated with different technologies also need to be resolved so that they are accurate and responsive to the potential needs of users.
    - P31 The capacity of the Phoenix Rapidfire tool and other systems to produce intelligence and modelling accurately and quickly is compromised by the lack of a manual or technical means of filtering and triaging inputs.
    - p38 Information Officers need to be highly skilled in those areas, and in the development of relevant, timely and tailored information
    - P41 Rec 17. The Fire Services evaluate the new information and warning systems to identify ways to integrate them and improve their capacity to issue timely, relevant and tailored messages. This should include the use of social media.

2011 (Tasmania) Bushfire Management, H.M. Blake, Tasmania Auditor General

- Examples of data uptake, usage or awareness include fire regime mapping
- Examples of data concerns include national coordinated
    - Progress on previous recommendations:
        - COAG 2004 recommendation 5.2 ... that the Australian Government and the state and territory governments jointly provide additional resources and work in partnership to establish and refine a national program of fire regime mapping.
        - State entities were not aware of any nationally coordinated program or of any national progress against this criterion.
        - Our assessment: 25 per cent implementation.

2012 (Federal) Review of the Bureau of Meteorology's extreme weather and seasonal forecasting capacity, C. Munro

- Examples of data uptake, usage or awareness include weather forecast and weather warnings.
- Examples of data concerns include quality, timeliness, frequency, accessibility, presentation and trust
    - P11 Bureau's extreme weather services met their needs in terms of quality, timeliness, frequency, accessibility and presentation

    - P30 Senior regional staff have developed trusted relationships with their counterparts in the state emergency services and have built up extensive local knowledge over many years. Their contextual knowledge is seen as critical to contribute to effective decision-making.

2012 (Victoria) North East Victoria Flood Review, Molino Stewart Pty Ltd

- Examples of data uptake, usage or awareness include gauges
- Examples of data concerns include accuracy, timeliness, coverage and reliablility.
    - P7 The Numurkah Hospital flooded before any warning had been received or preventative action taken. This was due largely to a combination of the following factors: a flood warning system that was unable to provide accurate and timely data - a lack of river gauges that could have enabled more reliable prediction

2012 (Victoria) Gippsland Flood Event – Review of Flood Warnings and Information Systems, Office of the Emergency Services Commissioner

- Examples of data uptake, usage or awareness include weather warnings and gauges
- Examples of data concerns include third party source, quality and timeliness, coverage and accessibility.
    - P15 BoM's capacity to monitor or model floods and provide predictive warnings varies across Gippsland. This is because they rely on other parties for some information, and the nature of flood predictions or warnings depends on the quality and timeliness of that information. For instance, there remain a number of locations where BoM is unable to provide more than qualitative flood information, due to the low coverage or accessibility of gauges (for example in East Gippsland).

2010 (Western Australia) Coronial inquest into 2010 Christmas Island boat disaster or SIEV 221, A. N. Hope, Western Australia State Coroner

- Examples of data uptake, usage or awareness include ground based RADAR and space based RADAR.
- Examples of data concerns include availability and effectiveness
    - Piv On the early morning of 15 December 2010 there was almost no surveillance being conducted of the ocean to the north and northwest of Christmas Island.
    - Pxiii There was no effective radar surveillance being conducted north of Christmas Island at the time when SIEV 221 arrived.

2012 (Western Australia) Post Incident Analysis for Blackwood Fire 11, P. Heazlewood et al.

- Examples of data uptake, usage or awareness include weather forecast
- Examples of data concerns include tightening of connections between staff, experience and availability of experts.
    - P10 Tightening the connection between weather forecasting and decision making would offer opportunities for improved risk management.
    - P10 Modern forecasting models offer the prospects of more informed decisions but need to be interpreted by experienced meteorologists.
    - P12 Lesson 9. DEC embed an experienced forecaster in the state operations centre.

2013 (Federal) Recent trends in and preparedness for extreme weather events, S. Birmingham et al.

- Examples of data uptake, usage or awareness include weather forecast and weather warnings.
- Examples of data concerns include coverage, availability and trust.

- P56 The Bureau of Meteorology have expanded their radar network considerably in recent years and are still expanding the network, but along the coastlines there are still gaps in coverage.
- P58 Recommendation 1 Para 2.115 The committee recommends that the Commonwealth government, through the Bureau of Meteorology and CSIRO, continues to support data collection and research to improve forecasting of extreme weather events, especially early warning capabilities.
- P109 However, while weather forecasting is much more accurate than in the past, the committee heard that people still need convincing to trust and act on this information.68

2013 (Federal) Spectrum for public safety mobile broadband, R. McClelland

- Examples of data concerns include availability of communications
  - P40 Even a modest sustained growth rate in data demand would impact on the adequacy of the ACMA's PSMB spectrum decision for PSAs' future needs.

2013 (Federal) The Preparation and Delivery of the Natural Disaster Recovery Work Plans for Queensland and Victoria, I. McPhee ACT Auditor-General

- Examples of data concerns include timeliness, quality, omitted data, over aggregation and consistency.
  - P16 There was early recognition that Australian Government oversight of the recovery and reconstruction efforts in Queensland and Victoria was reliant on timely and high quality data.
  - There is also limited evidence of the Taskforce analysing the information that has been reported by the states or raising questions about: omitted data (in relation to agreed reporting metrics); overly-aggregated data that provided limited transparency of actual reconstruction progress in relation to the events covered by the NPAs; and the consistency of the data that was provided over time.

2013 (Victoria) Report into the Harrietville Fire, M. Hallowes Victoria Emergency Services Commissioner

- Examples of data uptake, usage or awareness include aerial reconnaissance

As noted there are many similarities between the provision of data to a fire agency which can be used and the data which a fire agency provides in the context of a warning. For this reason the following reports which are all making comments related to warnings have also been included.

2008 (Victoria) Westpoint Chemical Fire Community Report, Office of the Emergency Services Commissioner

- In the context of alerts, examples of data concerns include coordination, consistency, accuracy and timeliness
  - P6 coordination and consistency of information between/from agencies
  - P7 assist community accessing accurate and timely emergency information

2011 (Victoria) TriTech Lubricants factory fire, Office of the Emergency Services Commissioner

- In the context of warnings, examples of data concerns include consistency, relevant, timely, 24 hour availability, human error and accuracy.
  - P7 Rec 1, The Fire Services Commissioner ensures that policy, operational procedures, systems and training relating to information and warnings that have been applied to bushfires are now also applied to other emergencies. In particular: information and warning messages are consistent as well as relevant, timely and accurate; a formal arrangement is established to ensure twenty-four hour availability of information officers…

  - P14 The review team estimates that the response of the correct brigades to the correct location was delayed by four minutes and 56 seconds. This was primarily due to a combination of incorrect information provided by the first caller and the road name (Venture Court, Dandenong South) not being included in the Vicmap data used by ESTA to build the ESTA CAD Map.

2011 (Victoria) 2011 Review of Community Bushfire Warnings, Molino Stewart Pty Ltd

- In the context of warnings, examples of data concerns include timeliness, accuracy, consistent terminology, relevant, consistent, efficiency of the system and authorising environment.
  - P1 The timeliness of community warnings was found to be an issue in recent fires. It was largely dependent on the speed and accuracy of fire intelligence received by ICCs. (Incident Control Centres)
  - P1 There were a few issues identified in relation to the terminology used including the lack of consistency of fire language between OSOM and FireWeb.
  - P19 speed of information received by the IMT from the fire, the efficiency of the warning systems (technical and non-technical) and the authorising environment were major determinants in the poor timing of warning messages during the Tostaree fire.

Appendix E: Consolidated concerns from Australian disaster inquiries

Table 60: Consolidated list of concerns in Australian disaster inquiries flagged by word frequency analysis.

Inquiry	Concern(s) raised in inquiry	Consolidated concerns														
		Maturity	Accuracy	Timeliness	Relevant	Effectiveness	Reliability	Availability	Presentation	Trust	Experience	Culture	Accessibility	Uptake	Flexibility	Third party source
1939 (Victoria) Royal Commission to inquire into the causes of and measures taken to prevent the bush fires of January, 1939 and to protect life and property and the measures to be taken to prevent bush fires in Victoria and to protect life and property in the event of future bush fires, L.E.B. Stretton.	availability, repeatability, redundancy and timeliness	1		1			1	1								
1984 (Victoria) Report of the Bushfire Review Committee on bushfire preparedness in Victoria, Australia, following the Ash Wednesday fires 16 February 1983 – Inquiries following 2002–2003 bushfires, S.I. Miller et al.	optimisation, more monitoring, dissemination and reliability					1	1	1	1							
2001 (New South Wales) Inquiry into the Fire at Mt Ku-Ring-Gai Chase National Park, J. Stevenson, NSW State Coroner's Office	availability of maps in the field												1			
2001 (New South Wales) Readiness to Respond - 2001 Reports (Inquiry into the Ambulance Service), New South Wales Audit Office	uptake, reliability, effective use and culture					1	1					1		1		
2005 (Federal) National Inquiry on Bushfire Mitigation and Management. , S. Ellis et al.	consistency and funding	1				1										
2004 (Victoria) Beating the Bugs: Protecting Victoria's Economically Significant Crops from Pests and Diseases , J.W. Cameron Auditor General of Victoria	flexibility and availability							1							1	
2005 (Federal) Tsunamis – Does anyone have to die?, Prime Minister's Science, Engineering and Innovation Council	timeliness			1												

2006 (ACT) The Canberra Firestorm: Inquests and Inquiry into Four Deaths and Four Fires between 8 and 18 January 2003 Volume 1 & Volume 2, M. Doogan, ACT Coroner's Court	accuracy, scalability and consistency	1	1				1									
2008 (Victoria) Inquiry into the Impact of Public Land Management Practices on Bushfires in Victoria, J. Pandazopoulos, et al. Victorian Parliamentary Environment and Natural Resources Committee	maturity and cost	1				1										
2008 (Victoria) Westpoint Chemical Fire Community Report, Office of the Emergency Services Commissioner	coordination, consistency, accuracy and timeliness	1	1	1		1										
2009 (Western Australia) Record of Investigation into Death (2007 Boorabin fires), A.N. Hope, State Coroner	not relied upon									1						
2009 (Tasmania) Record of Investigation into a Fire at the Myer Store at 98-108 Liverpool Street, Hobart, on 22 September 2007, C.P. Webster, Coroner	data used too late and training										1	1				
2009 (Victoria) Operational debrief report 2008/09 fire season, J. Fox and W. Major	availability, quality, extent of detail		1		1			1								
2009 (Western Australia) Bridgetown Complex Post Incident Analysis, Department of Environment and Conservation	cleaned of extraneous information	1														
2010 (Western Australia) Major Incident Review of Toodyay Fire December 2009, P. Murphy	information flow to decision makers, accurate, timeliness, lack of situational awareness	1	1	1								1				
2011 (Victoria) Towards a More Disaster Resilient Victoria: Green Paper Options and Issues, Government of Victoria	right information, right form, right time, consistency, rigor, accuracy, timeliness, fitness for purpose, common boundaries, trust, uptake, rumours and misinformation	3	1	2	2				1	3				1		
2011 (Western Australia) Inquiry into the 2011 Kimberley Ultramarathon. Parliament of Western Australia, M.D. Nahan et al.	cost, errors of omission and errors of commission		2			1										

2011 (Federal) Joint Select Committee on the Christmas Island Tragedy of 15 December 2010, G. Marshall et al.	detection without identification and accuracy		1		1											
2011 (Victoria) Review of the February 2011 Tostaree Fire, Office of the Emergency Services Commissioner	timeliness, relevance, clarity of message, consistency, interoperability, accuracy, responsive, lack of a manual, technical means of filtering/triaging inputs and tailored	3	1	2	2				1						1	
2011 (Victoria) TriTech Lubricants factory fire, Office of the Emergency Services Commissioner	consistency, relevant, timely, 24 hour availability, human error and accuracy	1	2	1	1		1									
2011 (Victoria) 2011 Review of Community Bushfire Warnings, Molino Stewart Pty Ltd	timeliness, accuracy, consistent terminology, relevant, consistent, efficiency of the system and authorising environment	3	1	1	1							1				
2011 (Tasmania) Bushfire Management, H.M. Blake, Tasmania Auditor General	national coordinated					1										
2012 (Federal) Review of the Bureau of Meteorology's extreme weather and seasonal forecasting capacity, C. Munro	quality, timeliness, frequency, accessibility, presentation and trust		1	1				1	1	1			1			
2012 (Victoria) North East Victoria Flood Review, Molino Stewart Pty Ltd	accuracy, timeliness, coverage and reliability		1	1	1		1									
2012 (Victoria) Gippsland Flood Event – Review of Flood Warnings and Information Systems, Office of the Emergency Services Commissioner	third party source, quality and timeliness, coverage and accessibility		1	1	1								1			1
2010 (Western Australia) Coronial inquest into 2010 Christmas Island boat disaster or SIEV 221, A. N. Hope, Western Australia State Coroner	availability and effectiveness					1		1								
2000 (NSW) Inquest into the event of the 1998 Sydney to Hobart Yacht Race, J. Abernethy	awareness and lack of knowledge	1									1					

2012 (Western Australia) Post Incident Analysis for Blackwood Fire 11, P. Heazlewood et al.	tightening of connections between staff, experience and availability of experts	1									2					
2013 (Federal) Recent trends in and preparedness for extreme weather events, S. Birmingham et al.	coverage, availability and trust				1			1		1						
2013 (Federal) Spectrum for public safety mobile broadband, R. McClelland	availability of communications						1									
2013 (Federal) The Preparation and Delivery of the Natural Disaster Recovery Work Plans for Queensland and Victoria, I. McPhee ACT Auditor-General	timeliness, quality, omitted data, over aggregation and consistency	1	1	1					2							

Appendix F: Sensor data in disaster decision making web survey

Information sheet

Interest in the use of **sensor data** from space-based, airborne and ground platforms to support emergency management decisions has increased substantially in recent years. This includes information such as the weather forecast, satellite derived fire hotspots, thermal line scans and geolocated photos from social media. At the same time, there remains limited understanding of how much data producers and value adders can tailor data products for emergency management and what information would be of most value to end-users. The *Fenner School of Environment and Society from the Australian National University in collaboration with Geoscience Australia, the Cooperative Research Centre for Spatial Information and the Bushfire & Natural Hazards Cooperative Research Centre* are currently conducting and funding research to address such gaps in understanding.

The relevance and validity of the research will be improved by the participation of those involved in the emergency management, policy and data sectors. We invite you to contribute to this research through completion of the on-line survey which will ask you to share your opinions and experiences regarding the use and usefulness of sensor data from satellites, planes and ground based sensors, including social media, for supporting emergency management decision-making. A formal background in or understanding of data is not required to participate in the survey.

It is expected that the survey will take around **15 minutes** to complete. **All responses will remain strictly confidential**. Summary survey results will be made available to all interested respondents.

Your participation

Your participation in the survey is voluntary. Submission of the completed web-survey will indicate your consent to participate. Once you have commenced the survey you are entitled to skip any questions you would prefer not to answer, or you can withdraw simply by not clicking on the ‘submit survey’ Tab on the final page of the survey. You will be able to withdraw from participation once the survey is submitted by contacting the primary researcher. To maintain your confidentiality, as far as the law allows, all survey responses will be coded and any identifying material will be stored separately from survey responses.

Use of the data

Information gathered during this research will be analysed by the researchers and presented in the scientific literature to inform those interested in the use and value of data products to the emergency management sector. In addition this ANU research will contribute towards the PhD of the primary researcher and will be published as part of a PhD thesis. All publications arising from the survey will be subject to peer review and openly published. Individual participants will not be identified in any publication. After publication, the data is required to be kept securely for 5 years.

Researchers and organisation contacts

Professor Stephen Dovers, Dr Michael Eburn and Mr. David Hudson from the Fenner School of Environment and Society, Australian National University; and Dr Adam Lewis from Geoscience Australia.

If you have any questions about this study, please contact the primary researcher David Hudson at david.hudson@anu.edu.au

The ethical aspects of the research have been approved by the Australian National University Human Ethics Committee. If you have any issues or concerns about the research or the way it has been conducted please contact the researchers directly (see contact details above) or the ANU Human Research Ethics Office (02) 6125 3427 or email: human.ethics.officer@anu.edu.au

Survey

1. How long have you been involved in emergency management (in any capacity)?

Less than 5 years ☐
Between 5-10 years ☐
Greater than 10 years ☐
I am not involved in emergency management ☐

2. What type of organisation are you primarily associated with?

Federal government ☐
State government ☐
Local government ☐
Research sector ☐
Private sector ☐
Non-Governmental Organisation ☐

3. What is your age?

Under 35 years old ☐
35-49 years old ☐
50-64 years old ☐
65 years or older ☐

4. Where is your current organisation located?

Australian Capital Territory ☐
New South Wales ☐
Northern Territory ☐
Queensland ☐
South Australia ☐
Tasmania ☐
Victoria ☐
Western Australia ☐
Other (please specify)

Please specify……..

5. My role in the data supply chain mainly involves:

Data collection related tasks ☐
Value adding existing datasets ☐
User of data ☐
Other (please specify)

Please specify……..

6. In your current role, do you use sensor data (data from satellites, planes and ground based sensors including social media)?

Yes ☐ No ☐ Unsure ☐

7. Do you think sensor data should be used in emergency management decision making?

Yes ☐ No ☐ Unsure ☐

8. How aware are you of the following range of sensor data products?

	Never heard of it	Heard of it	Know it	Used it	Based a decision on it
Weather forecast	☐	☐	☐	☐	☐
Weather warnings	☐	☐	☐	☐	☐
Stream gauge	☐	☐	☐	☐	☐
Flood warning	☐	☐	☐	☐	☐
Seismograms	☐	☐	☐	☐	☐
Earthquake alerts	☐	☐	☐	☐	☐
Satellite or aerial imagery (Photo like/optical)	☐	☐	☐	☐	☐
Satellite or aerial imagery (RADAR)	☐	☐	☐	☐	☐
Satellite or aerial imagery (Multispectral)	☐	☐	☐	☐	☐
Imagery derived perimeter/extent/footprint information for either fire, flood, oil slick or landslide	☐	☐	☐	☐	☐
Burn intensity map	☐	☐	☐	☐	☐
Fuel load map	☐	☐	☐	☐	☐
Emergency phone calls (Triple zero)	☐	☐	☐	☐	☐
Individual social media message eg a twitter tweet	☐	☐	☐	☐	☐
Social media trend alert eg a trending keyword like earthquake	☐	☐	☐	☐	☐
Satellite positioning data eg GPS	☐	☐	☐	☐	☐

9. What types of sensor data do you use in your current role?

Raw data such as uncorrected satellite telemetry ☐
Processed data such as corrected satellite imagery ☐
Specialist data products such as wind speed/direction data feeds ☐
Standard data products such as the weather forecast ☐
Unsure ☐

10. Which of the following issues do you think are relevant to the use of emergency management sensor data today?

Availability of data ☐
Cost of the data ☐
Cost of capability development ☐
Openness and licencing ☐
Skills in the use of the data ☐
Documentation of data products ☐
Quality of data ☐
Timeliness of data products ☐
Trust of the data ☐
Other ☐

Please specify……..

11. How much do you think the following factors influence the use of sensor data in emergency management decisions?

	Not at all important	1	2	3	4	5	6	7	Highly important	Unsure
Lack of expertise and knowledge about sensor data		o	o	o	o	o	o	o		o
Concerns about **legal liability** in using sensor data in decision making		o	o	o	o	o	o	o		o
Government directives that limit the flexibility of emergency management decision-makers to use sensor data		o	o	o	o	o	o	o		o
Sensor data and its development is not a **budgetary priority** in emergency management agencies		o	o	o	o	o	o	o		o
Using sensor data creates difficult **political issues**		o	o	o	o	o	o	o		o
Meeting **community expectations for emergency suppression** makes it hard to consider other goals and priorities		o	o	o	o	o	o	o		o
In emergency management decisions there is **not enough time** to take account of all the available data including sensor data		o	o	o	o	o	o	o		o
Current and emerging sensor data products **lack specific relevance** to emergency management decisions		o	o	o	o	o	o	o		o
		o	o	o	o	o	o	o		o

12. Do you have any comments regarding factors that may encourage or discourage the use of sensor data in emergency management decisions?

Comment box:

13. How likely would you be to base a high consequence decision (eg life threatening decision) on the following dataset?

	Not at all likely	1	2	3	4	5	6	7	Highly likely	Unsure
Data collected by staff within your own organisation		o	o	o	o	o	o	o		o
Bureau of Meteorology weather forecast data ingested and displayed in your organisation's system		o	o	o	o	o	o	o		o
Bureau of Meteorology weather forecast data displayed on their public website with commercial advertising		o	o	o	o	o	o	o		o
Weather forecast data from a private company on their website		o	o	o	o	o	o	o		o
Coarse resolution (250 metre) satellite imagery from the NASA website		o	o	o	o	o	o	o		o
Bushfire hotspots on the Geoscience Australia Sentinel system		o	o	o	o	o	o	o		o
Bushfire hotspots ingested and displayed in your organisation's system		o	o	o	o	o	o	o		o
A single stream gauge measurement		o	o	o	o	o	o	o		o
An official warning from the Bureau of Meteorology		o	o	o	o	o	o	o		o
A university created satellite based fire perimeter map with the associated image		o	o	o	o	o	o	o		o
A university created satellite based fire perimeter map without associated image due to licencing restrictions		o	o	o	o	o	o	o		o
A government agency created satellite based fire perimeter map with the associated image		o	o	o	o	o	o	o		o
A government agency satellite based fire perimeter map without associated image due to licencing restrictions		o	o	o	o	o	o	o		o
A single tweet from twitter saying there is a fire at a location		o	o	o	o	o	o	o		o

An alert from a commercial service which tracks trends in social media	o	o	o	o	o	o	o	o
Emergency phone calls (Triple zero)	o	o	o	o	o	o	o	o

14. Would your answers to question 13 be different if the consequences were lower, eg the decision had resource implications, but was not life threatening?

Yes ☐ No ☐ Unsure ☐

If you answered yes to Question 14, please describe how your answers would be different, would the changes be universal or just for specific datasets?

Comment box:

15. Is an emergency phone call (Triple zero) a form of sensor data?

Yes ☐ No ☐ Unsure ☐

16. Is social media information a form of sensor data?

Yes ☐ No ☐ Unsure ☐

17. Which **quality factors** affect the likelihood of a sensor data product being used to inform an emergency management decision?

	Not important at all	1	2	3	4	5	6	7	Highly important	Unsure
Accuracy of a sensor data product		o	o	o	o	o	o	o		o
The speed which a data product is delivered to the user ie **Timeliness**		o	o	o	o	o	o	o		o
Reliability of a data products eg its ability to be consistently reproduced		o	o	o	o	o	o	o		o
The **clarity or simplicity** of sensor data products content and/or presentation		o	o	o	o	o	o	o		o
The **completeness** of a sensor data product in coverage and/or presentation		o	o	o	o	o	o	o		o
The time it takes to become familiar with how to use a product ie **useability**		o	o	o	o	o	o	o		o
The **consistency** within one data product or across a time series of data products		o	o	o	o	o	o	o		o
The description of how the data product was made ie **provenance**		o	o	o	o	o	o	o		o
The product complies with relevant **standards** and meets predefined **specifications**		o	o	o	o	o	o	o		o
The quantity of **documentation** which accompanies the product		o	o	o	o	o	o	o		o
The **interoperability** of the data product to connect with your systems		o	o	o	o	o	o	o		o

18. Which **reputational factors** affect the likelihood of a sensor data product being used to inform an emergency management decision?

	Not at all likely	1	2	3	4	5	6	7	Highly likely	Unsure
The **mandate** of the provider to be producing emergency management data products		o	o	o	o	o	o	o		o
The **reputation** of the provider		o	o	o	o	o	o	o		o
Your **familiarity** with the **data provider**		o	o	o	o	o	o	o		o
The **popularity** of the **data product**		o	o	o	o	o	o	o		o
The **business model** of the data product such as daily weather forecasts vs. a once off burn intensity map		o	o	o	o	o	o	o		o
The sensor was owned and/or operated by your country ie **sovereignty**		o	o	o	o	o	o	o		o
The ability to **access** the data product securely		o	o	o	o	o	o	o		o
The **security** of the **network** which transported the data product		o	o	o	o	o	o	o		o
Whether or not the sensor is **civilian or defence** operated ie dual-use		o	o	o	o	o	o	o		o

19. Which data policy factors affect the likelihood of a sensor data product being used to inform an emergency management decision?

	Not at all likely	1	2	3	4	5	6	7	Highly likely	Unsure
Cost of the sensor data product		o	o	o	o	o	o	o		o
Access restrictions on the raw data which created the sensor data product		o	o	o	o	o	o	o		o
Ability to **publically disclose the source** of the data		o	o	o	o	o	o	o		o
Ability to **publically release the raw data**		o	o	o	o	o	o	o		o
Restrictions on your ability to distribute the data ie **copyright**		o	o	o	o	o	o	o		o
The **responsibilities and liabilities** associated with your use and the use of those to whom you distribute the data product		o	o	o	o	o	o	o		o

20. In your opinion, what are the most important features that a sensor data product must have if it is going to be used in a decision making process?

Comment box:

21. Do you have any additional comments on this survey?

Comment box:

Appendix G: Sensor data in disaster decision making web survey results

Dates: 3/17/2014 - 6/9/2014

How long have you been involved in emergency management (in any capacity)?		
Answer Options	**Response Percent**	**Response Count**
Less than 5 years	13.5%	31
Between 5-10 years	16.6%	38
Greater than 10 years	68.1%	156
I am not involved in emergency management	1.7%	4
	answered question	**229**
	skipped question	**1**

What type of organisation are you primarily associated with?		
Answer Options	**Response Percent**	**Response Count**
Federal government	12.7%	29
State government	71.6%	164
Local government	3.9%	9
Research sector	1.7%	4
Private sector	3.1%	7
Non-Governmental Organisation	7.0%	16
	answered question	**229**
	skipped question	**1**

What is your age?		
Answer Options	**Response Percent**	**Response Count**
Under 35 years old	15.4%	35
35-49 years old	36.4%	83
50-64 years old	45.6%	104
65 years or older	2.6%	6
	answered question	**228**
	skipped question	**2**

Where is your current organisation located?		
Answer Options	**Response Percent**	**Response Count**
Australian Capital Territory	10.5%	24
New South Wales	25.8%	59
Northern Territory	2.6%	6
Queensland	10.0%	23
South Australia	12.7%	29
Tasmania	6.1%	14
Victoria	17.9%	41
Western Australia	6.6%	15
Other (please specify)	7.9%	18
	answered question	**229**
	skipped question	**1**

Number	Response Date	Other (please specify)	Categories
1	**May 30, 2014 3:26 AM**	Malrborough Kaikoura New Zealand	
2	**May 29, 2014 4:32 AM**	Njgeria, Abuja	
3	**May 28, 2014 11:13 PM**	New Zealand	
4	**May 15, 2014 8:37 AM**	New Zealand	
5	**May 13, 2014 10:34 PM**	New Zealand	
6	**May 13, 2014 1:48 AM**	New Zealand	
7	**May 5, 2014 12:15 AM**	New Zealand	
8	**May 4, 2014 12:42 AM**	New Zealand	
9	**Apr 30, 2014 4:54 AM**	Kenya,Africa	
10	**Apr 30, 2014 4:24 AM**	New Zealand	
11	**Apr 30, 2014 1:57 AM**	New Zealand	
12	**Apr 30, 2014 1:46 AM**	Fiji	
13	**Apr 30, 2014 1:33 AM**	New Zealand	
14	**Apr 29, 2014 11:37 AM**	In all States except WA	
15	**Apr 28, 2014 6:39 AM**	Kingston, Jamaica	
16	**Apr 28, 2014 4:08 AM**	China	
17	**Apr 28, 2014 3:34 AM**	Australia-wide	
18	**Apr 21, 2014 12:32 AM**	National	

My role in the data supply chain mainly involves:

Answer Options	Response Percent	Response Count
Data collection related tasks	12.0%	27
Value adding existing datasets	9.3%	21
User of data	61.8%	139
Other (please specify)	16.9%	38
	answered question	**225**
	skipped question	**5**

Number	Response Date	Other (please specify)	Categories
1	May 30, 2014 3:26 AM	I am a General Manager of a Fire Authority	
2	May 23, 2014 5:54 AM	Equally in data collection and value adding datasets	
3	May 20, 2014 6:08 AM	1 and 2	
4	May 15, 2014 8:37 AM	Operational Data Management, Modelling and Analytics	
5	May 6, 2014 9:09 PM	Combination of above	
6	May 6, 2014 12:23 AM	Strategy	
7	May 5, 2014 12:15 AM	Management, audit, facilitation, monitoring, encouraging.	
8	May 4, 2014 12:42 AM	Director of Training NZFS & Assistant National commander	
9	May 3, 2014 3:12 AM	Research and development	
10	May 2, 2014 7:25 AM	IT	
11	May 2, 2014 6:32 AM	indirectly	
12	May 1, 2014 11:44 PM	Supporting data capture and analysis	
13	May 1, 2014 7:51 PM	Supply training in EM	
14	May 1, 2014 11:31 AM	All of the above	
15	May 1, 2014 2:28 AM	contractor	
16	Apr 30, 2014 6:14 AM	Initiator of data collection	
17	Apr 30, 2014 5:59 AM	Co-ordination of meteorological data collection and forecast products	
18	Apr 30, 2014 4:24 AM	Manager of performance information	
19	Apr 30, 2014 4:13 AM	All of the above	
20	Apr 30, 2014 2:56 AM	Developing data capture	
21	Apr 30, 2014 2:38 AM	Standards	
22	Apr 30, 2014 2:34 AM	Business owner of projects requiring spatial data	
23	Apr 30, 2014 2:34 AM	In my role I'm trying to ensure crews operating the tankers have ready and in-cabin access to relevant data	
24	Apr 30, 2014 2:11 AM	Procurement	
25	Apr 30, 2014 2:06 AM	My role encompasses all three of these	
26	Apr 30, 2014 1:33 AM	Database administrator inc. report creation	
27	Apr 30, 2014 1:32 AM	Provision of community warnings, advice and information during preparedness, response and recovery.	
28	Apr 30, 2014 1:22 AM	All of the above	
29	Apr 29, 2014 7:48 AM	Both collection and value add	
30	Apr 29, 2014 1:05 AM	Commercial data acquisition and distribution.	
31	Apr 28, 2014 11:16 PM	All of the above	
32	Apr 28, 2014 10:06 PM	all of the above	
33	Apr 28, 2014 11:37 AM	front line data	
34	Apr 28, 2014 8:47 AM	following procures which have changed as a result of data	
35	Apr 28, 2014 7:53 AM	State Situation Officer: value adding and using	
36	Apr 28, 2014 3:34 AM	All of the above	

37	**Apr 28, 2014 3:34 AM**	Assessing how we collect data (including what data we collect) and educating our end-users to use that data to help make operational & strategic decisions
38	**Apr 21, 2014 12:32 AM**	Resaerch Manager with portfolio covering al of the options

In your current role, do you use sensor data (data from satellites, planes and ground based sensors including social media)?

Answer Options	Response Percent	Response Count
Yes	82.6%	166
No	14.9%	30
Unsure	2.5%	5
	answered question	**201**
	skipped question	**29**

Do you think sensor data should be used in emergency management decision making?

Answer Options	Response Percent	Response Count
Yes	97.0%	197
No	1.0%	2
Unsure	2.0%	4
	answered question	**203**
	skipped question	**27**

How aware are you of the following range of sensor data products?

Answer Options	Never heard of it	Heard of it	Know it	Used it	Based a decision off it	Response Count
Weather forecast	0	7	16	46	134	203
Weather warnings	0	7	19	40	136	202
Stream gauge	41	34	51	34	34	194
Flood warning	2	19	72	48	58	199
Seismograms	23	56	90	20	9	198
Earthquake alerts	10	48	94	30	15	197
Satellite or aerial imagery (Photo like/optical)	0	10	27	75	91	203
Satellite or aerial imagery (RADAR)	1	22	49	62	66	200
Satellite or aerial imagery (Multispectral)	22	34	50	40	52	198
Imagery derived perimeter/extent/footprint information for either fire, flood, oil slick or landslide	11	21	42	58	68	200
Burn intensity map	17	36	53	43	51	200
Fuel load map	14	35	50	44	57	200
Emergency phone calls (Triple zero)	8	12	58	70	53	201
Individual social media message eg a twitter tweet	1	30	83	66	22	202
Social media trend alert eg a trending keyword like earthquake	12	51	83	45	8	199
Satellite positioning data eg GPS	0	4	27	72	100	203

	answered question	**203**
	skipped question	**27**

What types of sensor data do you use in your current role?

Answer Options	Response Percent	Response Count
Raw data such as uncorrected satellite telemetry	14%	29
Processed data such as corrected satellite imagery	62%	125
Specialist data products such as wind speed/direction data feeds	62%	126
Standard data products such as the weather forecast	85%	172
Unsure	7%	14
	answered question	**202**
	skipped question	**28**

Which of the following issues do you think are relevant to the use of emergency management sensor data today?

Answer Options	Response Percent	Response Count
Availability of data	87%	177
Cost of the data	59%	119
Cost of capability development	48%	98
Openness and licencing	52%	106
Skills in the use of the data	81%	165
Documentation of data products	32%	65
Quality of data	69%	139
Timeliness of data products	84%	171
Trust of the data	54%	109
Other (please specify)	6%	13
	answered question	**203**
	skipped question	**27**

Number	Response Date	Other (please specify)	Categories
1	**May 13, 2014 11:37 PM**	Data overload, selection of most significant information	
2	**May 13, 2014 10:57 PM**	Data transmission / network problems - lack of coverage, lack of speed and bandwidth, topography difficulties, emergency services are not profitable enough for commercial infrastructure, mobile data terminals too expensive and hard to retro-fit into vehicles	
3	**May 13, 2014 10:39 PM**	Plenty of data - usually requires trusted expert analysis	
4	**May 5, 2014 12:21 AM**	Real time data is best. I.e. less than an hour old.	
5	**May 3, 2014 3:19 AM**	Interoperability of data, especially between agencies and between jurisdictions	
6	**Apr 30, 2014 5:01 AM**	Analysis of vast amounts of data under time constraints	
7	**Apr 30, 2014 4:24 AM**	Skills in analysis and interpretation	
8	**Apr 30, 2014 2:08 AM**	This should be graded as this technology is evolving and the decision making requires the appropriate skill set to interpret the data in context of the events conditional factors. This is an analytical process not practiced enough with emergency managers not that I consider operational managers as ‘emergency managers’ but in the field most operational	

		managers use a dynamic decision making process which arguably creates a risk propensity.
9	**Apr 28, 2014 5:23 AM**	The loss of services from Gov't Depts to maintain datasets due to budget cuts
10	**Apr 28, 2014 4:34 AM**	Interoperability across the EM Sectors
11	**Apr 28, 2014 3:39 AM**	getting the old school operators to respect new data sources suchs as socmed
12	**Apr 28, 2014 2:55 AM**	Ability to get the data to the front line
13	**Apr 21, 2014 12:49 AM**	Capability (people and systems) do use high-tech data products, at local, regional and national levels

How much do you think the following factors influence the use of sensor data in emergency management decisions?

Answer Options	Not at all important 1	2	3	4	5	6	Highly important 7	Unsure	Rating Average	Response Count
Lack of expertise and knowledge about sensor data	0	4	2	18	40	58	67	11	5.84	200
Concerns about legal liability in using sensor data in decision making	12	46	23	31	29	18	22	19	3.89	200
Government directives that limit the flexibility of emergency management decision-makers to use sensor data	8	28	24	25	26	28	35	27	4.48	201
Sensor data and its development is not a budgetary priority in emergency management agencies	3	8	13	27	40	49	44	16	5.26	200
Using sensor data creates difficult political issues	36	48	33	19	13	14	13	21	3.11	197
Meeting community expectations for emergency suppression makes it hard to consider other goals and priorities	8	25	25	31	29	32	30	18	4.47	198
In emergency management decisions there is not enough time to take account of all	8	13	13	27	36	49	45	8	5.08	199

the available data including sensor data										
Current and emerging sensor data products lack specific relevance to emergency management decisions	7	32	28	35	28	26	13	29	4.04	198
									answered question	**201**
									skipped question	**29**

Do you have any comments regarding factors that may encourage or discourage the use of sensor data in emergency management decisions?

Answer Options	**Response Count**
	57
answered question	**57**
skipped question	**173**

Number	**Response Date**	**Response Text**
1	**May 29, 2014 4:38 AM**	no
2	**May 20, 2014 6:12 AM**	Quality and accuracy of data. Disclosure of personal information.
3	**May 18, 2014 10:26 PM**	Human resources to process and interpret data
4	**May 13, 2014 10:57 PM**	Data availability, terminals to process it, slow speed to set-up specialists, impossible to get high-speed data out to remote fire commanders, lack of money to develop apps for portable / tablet terminals
5	**May 13, 2014 10:39 PM**	Trusted, known sources and analysis are best.
6	**May 6, 2014 5:35 AM**	The timeliness and availabillity of "sensor assets" is a huge issue in disasters. I have experienced this locally during a disaster where it was difficult to find a "go to" point of contact in government (even through the disaster coordination centre) who understood the range of capability that could be brought to bear, and then have the ability to coordinate and act on it.
7	**May 6, 2014 1:50 AM**	Lack of use and/or understanding. Lack of intuitiveness of social media.
8	**May 5, 2014 4:17 AM**	Speed of access, correctly geo referenced and quality assessment
9	**May 5, 2014 3:17 AM**	Satellite data seems to have limited coverage across south east Australia (eg: Sentinel Hotspots)
10	**May 5, 2014 12:21 AM**	I have to have teh data in a timely way to use it. Googl maps is handy. Met service satellite images are better but often very broad scale. Scale is important to the nature of the project worked on.
11	**May 2, 2014 6:56 AM**	Lack of expertise and 'head space' to consider changes in service provision.
12	**May 2, 2014 1:00 AM**	Some data is either difficult to use or too time consuming to obtain. Also, I believe that most of the above questions are important but was not sure how the questions are to be interpreted...
13	**May 1, 2014 11:45 PM**	I agree with the statement (Q.11 of this survey) "In emergency management decisions there is not enough time to take account of all the available data including sensor data" and this is a cultural problem that must be addressed by my Agency. In my Emergency Management

		role for example, Topographic maps are essential to providing an effective and timely service; however, individual emergency responders frequently do not equip themselves with topographic maps, which are readily available, due to (perceived) response time targets and perhaps a 'hero' mentality of trying to be the first responder on scene.
14	**May 1, 2014 11:24 PM**	In my organisation this sort of data and supporting hardware is simply not available to assist frontline personnel
15	**May 1, 2014 7:54 PM**	Should be done on a national scale. Not up to individual organisations. Make cost effective
16	**May 1, 2014 11:39 AM**	People in charge who don't understand how technology can help des idiom making are less likely to listen advice derived from sensor data.
17	**Apr 30, 2014 4:24 AM**	National Security and Defence silos of sensor data limit utility in some instances
18	**Apr 30, 2014 4:20 AM**	The awareness factor is critical here. It includes the fact that users mis-understand the products - for example few realise that radar data can be used in a GIS directly using WMS feeds, and that very detailed fire intell can be derived from it. Also BoM does not release volumetric products or CAPPIs to end users, impeding the intell gathering. All up the tendency is that end-users ask for what they are comfortable with, and providers make them comfortable with what they ask for - and no progress occurs. I ran a $2M Federal awareness grant in 2000 (GeoInsight) to tackle this, and we need to do that again.
19	**Apr 30, 2014 4:04 AM**	There should be more of it at a cost effective price. more training is required across the board. better representation at fed, state and organisational level
20	**Apr 30, 2014 3:49 AM**	traditional / historical approaches, availability
21	**Apr 30, 2014 3:15 AM**	Needs to be processes to flag the mission critical information (the needle) in the data haystack
22	**Apr 30, 2014 3:01 AM**	Sometimes decisions are made at a high level based on a minimal scope of data steam rather than the wider picture ("Tunnel Vision"). This can be a negative to effective use of real time data.
23	**Apr 30, 2014 2:53 AM**	Agencies need to be aware of and able to access relevant data sets for maintaining the information picture and informing planning and public information operations
24	**Apr 30, 2014 2:40 AM**	there is never enough time or resource to review all the data - esp social media. Social media is primarily a predictive tool. But I'd rely an authoritative source before I rely on facebook or twitter
25	**Apr 30, 2014 2:39 AM**	Ability to handle big data. Ability to interpret data
26	**Apr 30, 2014 2:34 AM**	has to be user friendly
27	**Apr 30, 2014 2:09 AM**	the availability of more timely data in a format that can be used more readily than currently available will likely increase its use significantly
28	**Apr 30, 2014 2:08 AM**	Sensor to budgetary priority in emergency agencies should not be an issue. There is enough data from events that would allow a prudent collective return on investment business case to be developed that would encompass all agencies allowing them to fund their appropriate needs. There is in my opinion considerable development to be had in what is enough time in EM decision making. Agencies / Government have created a false interpretation to the community on the capability to respond. Technically the first responder is the community, the resilience (capacity and capability) of the community is key in allowing appropriate time frames for EM decision making. For the community to get this 'key' they have to understand and take responsibility for the hazards they are exposed to. EM at this level is 'Governance' and the decision making must be

		prudent and any reference to 'dynamic decision making' needs to be removed. Unfortunately the majority of EM's making the decisions have had extensive front line operational exposure to dynamic decision making and I have already eluded this creates a risk propensity and is contextually in breach of the HSW harmonised legislation. There are too many examples where EM has risked life for what? I have read many times in EM documents that agencies are prepared to risk life to save saveable life this at best is a neutral mathematical equation and yet this is the mindset of some EM's.
29	**Apr 30, 2014 1:43 AM**	Sensor data might replace local knowledge. It could lead to centralised decision making. Delegation to the field operators may suffer. Getting the data to the field is a challenge.
30	**Apr 29, 2014 12:29 PM**	Lack of benefits of data application, and failure to provide training to end useres
31	**Apr 29, 2014 8:01 AM**	Data source information should be included in media reports and political statements related to progress of emergencies.
32	**Apr 29, 2014 6:36 AM**	Trust in the system and the higher managers to allow you to use it in decision making, and then defending your use if it does not prove a good outcome
33	**Apr 29, 2014 5:24 AM**	Some of the answers to question 11 don't match the question, a bit confusing
34	**Apr 29, 2014 1:09 AM**	Lack of timeliness in EOS supply chain limits utility of data in response phase of disaster management.
35	**Apr 28, 2014 11:18 PM**	Sensor data innovation is great but someone has to analyse and use it in a valuable way i.e. intelligence otherwise its just data.
36	**Apr 28, 2014 10:32 PM**	The questions phrased above can be interpenetrated differently depending on your level of experience in using sensor data for decision making processes during emergencies. For example we use flood warning rain gauges and flow monitoring telemetry equipment as well as GIS, GPS and a range of tools to to assist in giving our communities relevant information prior, during and after an emergency.
37	**Apr 28, 2014 9:58 PM**	Moving from prescriptive analytics to predictive is going to be increasingly important - however access to data feeds in real time, cost of technology platforms (particularly cross jurisdiction) will continue to limit our ability to utilise sensor data in this fashion.
38	**Apr 28, 2014 10:28 AM**	Packaging of sensor data for easy consumption by incident managers is a challenge. Many incident managers are not technically literate so do now know how to use the data, or do not trust it. Accessing sensor data for L1 and L2 incidents is extremely difficult.
39	**Apr 28, 2014 7:59 AM**	The lack of expertise is exacerbated by the limited budgets for capability development
40	**Apr 28, 2014 7:20 AM**	Ability to integrate datasets including with our own rather than just rely on standalone published data.
41	**Apr 28, 2014 7:10 AM**	Most Important decisions are badly impacted by public servants with no knowledge of the real world.
42	**Apr 28, 2014 6:03 AM**	Time factors in dissemination of the data down through the chain of command may discourage the use of data, say, in a major bushfire. Firefighters on the fire ground may have to make choices based on situational awareness rather than sensor data.
43	**Apr 28, 2014 5:38 AM**	Having highly trained and capable operators is essential for all use of sensor data.
44	**Apr 28, 2014 5:23 AM**	In Qu 11. I am unsure what is meant by "Meeting community expectations for emergency suppression makes it hard to consider other goals and priorities: In Qu11. I don't believe these items should be rated on importance more is it perceived as an issue low to high.

45	Apr 28, 2014 5:01 AM	timeliness is more important that quality but data will only be trusted if quality is understood. value added products are more useful than image products but need to be standardised and interoperable to be useful
46	Apr 28, 2014 5:01 AM	One of the critical factors is data access and sharing between government agencies responding to an incident.
47	Apr 28, 2014 4:34 AM	Development of a central point of Intelligence and Mapping at the Regional Level to streamline Tactical/Local level operations & information flow AND supported by the Strategic/State level
48	Apr 28, 2014 4:32 AM	data not always readily available in "field operations" due to the lack of communications and data connections
49	Apr 28, 2014 3:52 AM	trust in data, timeliness of data and ability to send to others are issues about the use of data
50	Apr 28, 2014 3:51 AM	I my experience I cannot over emphasize that TIMELESS is the most critical factor for sensor data. No matter how good the sensor data is - if the emergency has passed before the sensor information has arrived then it is tantamount to being irrelevant.
51	Apr 28, 2014 3:46 AM	One of the key challenges faced by EM and IM managers is access to timely information and a complete suite of datasets. Foe example, difficult to access all layers of data for both flood and fire planning and modeling - area, terrain, topography and geography is good, modeling is hit and miss however base layers of properties, owners, mitigation measures et all is difficult to assemble and collate into a single tool, where layer can be turned on and off dependent on the risk and type of emergency
52	Apr 28, 2014 3:39 AM	in Q. 11 above, I could answer this very differently for the type of sensor data so its hard to generalise. e.g. we are huge users of multispectral data for fire, use it all the time, all resect it, same can't be said for socmed data...
53	Apr 28, 2014 3:36 AM	Cost and availability to volunteer organisations / non-private NGOs
54	Apr 28, 2014 2:58 AM	Lack of suitable data communication capability in many areas
55	Apr 28, 2014 2:55 AM	Having the tools required to access data at whatever level of the IMT it is required, especially in the field.
56	Apr 28, 2014 2:23 AM	people in AIIMS structures that are unaware or can not interpret information is a planning function inhibit the benefits of technology. Mobile ICV's are also not kept up to date with technology based on tight budgets.
57	Apr 21, 2014 12:49 AM	No

How likely would you be to base a high consequence decision (eg life threatening decision) on the following dataset?

Answer Options	Not at all likely 1	2	3	4	5	6	Highly likely 7	Unsure	Rating Average	Response Count
Data collected by staff within your own organisation	2	4	3	6	25	47	96	4	6.1	187
Bureau of Meteorology weather forecast data ingested and displayed in your organisation's system	3	3	2	6	33	49	88	4	6.1	188
Bureau of Meteorology weather forecast data displayed on their public website with commercial advertising	4	4	19	20	49	51	35	4	5.2	186
Weather forecast data from a private company on their website	18	26	26	34	45	23	4	8	3.8	184
Coarse resolution (250 metre) satellite imagery from the NASA website	12	21	21	29	39	29	12	24	4.2	187
Bushfire hotspots on the Geoscience Australia Sentinel system	18	14	16	18	26	44	29	20	4.6	185
Bushfire hotspots ingested and displayed in your organisation's system	19	8	8	16	28	46	45	15	5.0	185
A single stream gauge measurement	23	22	28	26	16	14	10	43	3.5	182
An official warning from the Bureau of Meteorology	1	3	2	8	22	52	98	1	6.2	187
A university created satellite based fire perimeter map with the associated image	19	10	22	24	38	32	17	22	4.3	184
A university created satellite based fire perimeter map without associated image due to licencing restrictions	34	20	25	27	28	15	3	31	3.3	183
A government agency created	13	4	6	12	36	56	43	14	5.3	184

satellite based fire perimeter map with the associated image										
A government agency satellite based fire perimeter map without associated image due to licencing restrictions	22	11	24	26	32	34	10	21	4.1	180
A single tweet from twitter saying there is a fire at a location	68	51	26	19	10	5	2	4	2.3	185
An alert from a commercial service which tracks trends in social media	30	34	41	27	29	11	3	10	3.2	185
Emergency phone calls (Triple zero)	2	4	6	12	24	50	82	7	5.9	187
								answered question		**189**
								skipped question		**41**

Would your answers to question 13 be different if the consequences were lower, eg the decision had resource implications, but was not life threatening?

Answer Options	Response Percent	Response Count
Yes	33.7%	63
No	52.9%	99
Unsure	13.4%	25
If you answered yes to Question 14, please describe how your answers would be different, would the changes be universal or just for specific datasets?		35
	answered question	**187**
	skipped question	**43**

Number	Response Date	If you answered yes to Question 14, please describe how your answers would be different, would the changes be universal or just for specific datasets?	Categories
1	May 23, 2014 2:37 AM	I expect the actual decision making process would rely on the different data sources to very different ways based on the instinctive response you feel at the time. I rate a single tweet low now, but in the heat of battle, it might be the one thing that triggers a set of decisions in a high consequence environment as the individual data sources mean nothing without context and regardless of the research or the theories about recognition primed decision making, the decision will always consult several aspects. If the stakes are lower, the decisions might need more validated data to be made.	
2	May 22, 2014 4:59 AM	Mor important to get it right if the situation is life threatening Answers would be different for specific datasets	
3	May 13, 2014 10:41 PM	Trusted data quality and time important	
4	May 6, 2014 5:45 AM	Answers would be different for specific datasets. Some of the datsets are great for "situational awareness" but you'd never rely on them for any more than that (i.e weather forecast data from private company on their website Vs data from BoM). Often you don't have the financial resources for such private sources but could help provide awareness.	
5	May 5, 2014 3:49 AM	I would investigate all the data, collate and compare. I would probably do the same for a life threatening situation above, however would relly on the more accredited respected organisations for data.	
6	May 2, 2014 7:34 AM	my position does not require me to make life threatening decisions	
7	May 2, 2014 6:58 AM	Being certain about the identity and source of any individual/agency supplying data/information.	
8	May 1, 2014 11:51 PM	Given the time-constraint difference between life-threatening and non-life-threatening emergencies, data pertaining to a non-life-threatening emergency warrants further investigation and data analysis, to build up a full picture of the emergency and its associated hazards, before then acting on it.	
9	May 1, 2014 7:56 PM	Stand to lose a lot then you risk a lot	
10	May 1, 2014 2:47 AM	Would depend on other available systems and information and possibly the validation of the information from a secondary source	
11	Apr 30, 2014 6:18 AM	They would be specific to the dataset - the circumstances being considered	
12	Apr 30, 2014 5:21 AM	I would more likely to be open to universal datasets - or I would at least consider them.	
13	Apr 30, 2014 5:04 AM	Risk evaluation ie lower impact may allow for a lower error tolerance in decision making and therefore encourage the use of alternate information sources	
14	Apr 30, 2014 4:32 AM	Firstly, Q13 is incomplete, as I would have my team analysing a range of satellite feeds directly, and not relying on a third-party value-adder. Also I use, in order of preference for hotspot data, WA LandGate, Uni of	

		Maryland then GA's Sentinel. I was on the initial steering committee for Sentinel. Now for this question... Sensor data is just that "data". According to AIIMS 4 doctrine, it needs to be turned into information, and then into Intell. It is intell that does the decision support within an IMT. The act of developing intell has to account for the reliability of the source data. A non-critical decision may use intell based on lower quality source data. If you have the time to do validation, or if you have to react to an incorrect decision, then making a decision is better than not doing so. Finally a comment on Q17 (over the page). The use of a data source to support decision making, as I have said, is through a two step processing chain, with other data added along the way. MY answers are from this perspective. The topics that I have not ticked are irrelevant - you need to know the tool before the emergency. You will not learn about 3.9 micron imagery while the fire bears down on the urban edge.
15	**Apr 30, 2014 4:30 AM**	Life thretening raises the bar, too many decision variables to answer this question in depth
16	**Apr 30, 2014 2:56 AM**	More likely to make the decision.
17	**Apr 30, 2014 2:16 AM**	if situation not life-threatening and hence time available, would seek in circumstances where likelihood is low to confirm data by other means.
18	**Apr 30, 2014 2:14 AM**	Organisational focus is on protecting life, soif consequnece was not related to this, may have a different outlook
19	**Apr 30, 2014 2:04 AM**	reliability is not so relevant when lives are not at risk.
20	**Apr 30, 2014 1:54 AM**	I think you mean yes to Q14
21	**Apr 30, 2014 1:34 AM**	Generally.
22	**Apr 29, 2014 6:38 AM**	Time to assess, use different resources and consult or cross reference other data sources. Universal.
23	**Apr 29, 2014 5:27 AM**	I would be more inclined to make decision on other information if it wasn't life threatening
24	**Apr 28, 2014 10:01 PM**	Typically non-life threatening situations are rated as a lower priority; this would also be the case if the event was likely to incur substantial property loss without consequential threat to life. I would expect this to be a universal response.
25	**Apr 28, 2014 8:55 PM**	less time critical, specific datasets
26	**Apr 28, 2014 8:05 AM**	The timeliness of the data would be very influental so it would push everything to the left
27	**Apr 28, 2014 7:24 AM**	The LDCC would seek to verify any information that required a major decision. All information on social media is treated as suspect.
28	**Apr 28, 2014 5:51 AM**	Data specific, based on agency specific guidelines etc
29	**Apr 28, 2014 5:02 AM**	Lower consequences would make me feel more comfortable using some of the data sources.
30	**Apr 28, 2014 3:39 AM**	More preceedence can be given to single data instances (twitter/commercial services).
31	**Apr 28, 2014 3:25 AM**	Generally universal
32	**Apr 28, 2014 3:16 AM**	Life threatening decisions need to be validated by an accurate agencey approved system/s to add weight to your final course of action
33	**Apr 28, 2014 3:01 AM**	All decisions in volunteer firefighting consider the implications to life or property. Very often the threats to these things change your approach.
34	**Apr 28, 2014 3:01 AM**	Less risk may allow for a more aggressive strategy, in saying that high risk may only leave an aggressive strategy so very hard to quantify

35	**Apr 28, 2014 3:00 AM**	My decision making is based on the reliability of the data available from the most apropriate sources.

Is an emergency phone call (Triple zero) a form of sensor data?

Answer Options	Response Percent	Response Count
Yes	66.5%	125
No	14.4%	27
Unsure	19.1%	36
	answered question	**188**
	skipped question	**42**

Is social media information a form of sensor data?

Answer Options	Response Percent	Response Count
Yes	62.8%	118
No	19.7%	37
Unsure	17.6%	33
	answered question	**188**
	skipped question	**42**

Which quality factors affect the likelihood of a sensor data product being used to inform an emergency management decision?

Answer Options	Not at all likely 1	2	3	4	5	6	Highly likely 7	Unsure	Rating Average	Response Count
Accuracy of a sensor data product	0	0	0	3	13	40	122	0	6.58	178
The speed which a data product is delivered to the user ie Timeliness	0	0	0	1	18	45	113	0	6.53	177
Reliability of a data products eg its ability to be consistently reproduced	0	0	0	3	21	44	108	0	6.46	176
The clarity or simplicity of sensor data products content and/or presentation	0	1	2	8	31	66	68	0	6.06	176
The completeness of a sensor data product in coverage and/or presentation	0	1	4	16	43	67	44	2	5.73	177
The time it takes to become familiar with how to use a product ie useability	1	5	8	23	41	48	51	0	5.52	177
The consistency of the data product each time it is delivered	0	1	2	10	28	66	69	2	6.06	178
The description of how the data product was made ie provenance	3	8	17	32	28	38	33	15	5.01	174
The product complies with relevant standards and meets predefined specifications	3	6	15	12	32	55	50	3	5.48	176

The quantity and/or sufficiency of documentation	2	9	14	27	50	44	28	2	5.06	176
The interoperability of the data product to connect with your systems	1	7	7	12	22	49	78	2	5.88	178
								answered question		**178**
								skipped question		**52**

Which reputational factors affect the likelihood of a sensor data product being used to inform an emergency management decision?

Answer Options	Not at all likely 1	2	3	4	5	6	Highly likely 7	Unsure	Rating Average	Response Count
The mandate of the provider to be producing emergency management data products	1	7	9	16	36	39	63	6	5.62	177
The reputation of the provider	1	1	4	9	22	67	71	2	6.06	177
Your familiarity with the data provider	2	5	4	24	30	60	48	2	5.58	175
The popularity of the data product	10	18	25	44	39	28	10	2	4.20	176
The business model of the data product such as daily weather forecasts vs. a once off burn intensity map	5	13	15	23	41	42	20	17	4.81	176
The sensor was owned and/or operated by your country ie sovereignty	18	26	11	23	30	34	25	8	4.34	175
The ability to access the data product securely	4	14	18	21	23	48	44	5	5.12	177
The security of the network which transported the data product	6	12	14	29	29	41	39	6	5.01	176
Whether or not the sensor is civilian or defence operated ie dual-use	20	31	16	34	19	25	17	15	3.89	177
								answered question		**177**
								skipped question		**53**

Which data policy factors affect the likelihood of a sensor data product being used to inform an emergency management decision?

Answer Options	Not at all likely 1	2	3	4	5	6	Highly likely 7	Unsure	Rating Average	Response Count
Cost of the sensor data product	8	11	9	19	30	42	56	2	5.30	177

Access restrictions on the raw data which created the sensor data product	7	6	15	20	44	45	30	9	5.05	176
Ability to publicly disclose the source of the data	13	15	15	33	30	36	25	9	4.56	176
Ability to publicly release the raw data	14	24	21	32	30	27	22	5	4.23	175
Restrictions on your ability to distribute the data ie copyright	6	19	18	22	31	32	38	9	4.81	175
The responsibilities and liabilities associated with your use and the use of those to whom you distribute the data product	1	12	12	27	35	39	38	13	5.15	177
									answered question	**177**
									skipped question	**53**

In your opinion, what are the most important features that a sensor data product must have if it is going to be used in a decision making process?

Answer Options	**Response Count**
	124
answered question	**124**
skipped question	**106**

Number	**Response Date**	**Response Text**
1	**May 29, 2014 4:47 AM**	Cost of data acquisition
2	**May 28, 2014 11:29 PM**	Up to Date Easily accessable In a usable format
3	**May 23, 2014 6:08 AM**	consistency, repeatability, accessibility, historical record, timeliness, interoperability based upon standards, credibility and confidence of source
4	**May 22, 2014 5:02 AM**	Reliability and accuracy
5	**May 20, 2014 6:33 AM**	Quality and use of data has a direct and positive outcome for decision making
6	**May 19, 2014 4:47 AM**	interoperability, high availability, reliability
7	**May 16, 2014 1:20 AM**	Long term availibity
8	**May 15, 2014 8:50 AM**	Quality, currency, accuracy
9	**May 15, 2014 6:46 AM**	reliable,a ccurate and able to stand up in court
10	**May 14, 2014 1:03 AM**	Quick, close to real time due to changing nature of fire, cheap $ and in easily transportable data format
11	**May 13, 2014 11:48 PM**	Awareness of assumptions and limitations of the product.

		Simplicity to use Relevance to operational use
12	**May 13, 2014 10:44 PM**	Known and trusted. Also identification of the underlying assumptions the data is based on.
13	**May 13, 2014 1:56 AM**	Accuracy Proven track record
14	**May 7, 2014 12:16 AM**	reliability - frequent, consistent date giving reliable results
15	**May 6, 2014 9:26 PM**	Accuracy of user end product
16	**May 6, 2014 6:00 AM**	Government based, timeliness, proven and reliable technology
17	**May 6, 2014 2:04 AM**	Accuracy and therefore reliability.
18	**May 6, 2014 12:58 AM**	Reliability, validity, information easy to digest, user friendly at the coal-face
19	**May 5, 2014 9:27 AM**	Community accessible
20	**May 5, 2014 4:22 AM**	quality, maturity of organisation producing it, pre agreed access and copy right details.
21	**May 5, 2014 3:53 AM**	Accurate, secure and proven
22	**May 5, 2014 3:23 AM**	Accuracy Reliability Relevance
23	**May 5, 2014 2:28 AM**	Acuracy and timeliness
24	**May 5, 2014 12:30 AM**	The sensor data will only confirm a situation which an "on the ball manager" already knows of or suspects due to prior monitoring of other fire weather or environmental attributes.
25	**May 4, 2014 12:48 AM**	accuracy and timliness
26	**May 3, 2014 9:06 AM**	Clear and concise information that can be quickly interpreted into operational decisions either strategic or on the ground. The information sources ideally should interoperate and present one or at most a few pictures from many sources as a decision tool to be used at any level.
27	**May 3, 2014 6:48 AM**	Ease of use, data manipulation, migration and intergration with existing agency systems and data.
28	**May 3, 2014 3:24 AM**	Timeliness, accuracy and relevance
29	**May 2, 2014 10:30 PM**	Has provenance Is endorsed by government (any level) for use Easily accessed Simple Provides summary Has a 'what if' ability associated with the product or service Is usable across a rage of platforms including portable devices without massive data downloads Has a level of public accessibility for education, informed action and socialisation into understanding decisions made
30	**May 2, 2014 7:41 AM**	acceptance of usefulness, ability to display in an understandable format
31	**May 2, 2014 7:01 AM**	The ability to stand up to a legal challenge regarding making decisions based on the data.
32	**May 2, 2014 1:56 AM**	Reliability
33	**May 2, 2014 1:44 AM**	accuracy, credibility, timeliness, ease of use.

34	**May 2, 2014 12:20 AM**	# Granularity of data - too much information can impede interpretation; vs. too little information makes it hard to make an informed decision. # Data products should be provided in conjunction with ongoing training for the end-user # Access to a variety of different data products - ie. not relying on only on a single type of data or a single provider of data products
35	**May 1, 2014 11:52 PM**	Credibility and availability
36	**May 1, 2014 11:33 PM**	From a frontline perspective: Timeliness, currency, accuracy and portability. And from a departmental perspective: cost
37	**May 1, 2014 7:59 PM**	Accuracy, timeliness, accessible remotely ie on tablets etc, $$$$
38	**May 1, 2014 11:47 AM**	Timeliness and accuracy
39	**May 1, 2014 4:24 AM**	Features include data that meets user needs both in terms of content and presentation, is accurate, timely, consistent and reliable.
40	**May 1, 2014 2:51 AM**	Accurate, timely and reliable
41	**Apr 30, 2014 12:18 PM**	Accurate, readily available and easy to use
42	**Apr 30, 2014 10:39 AM**	timeliness
43	**Apr 30, 2014 6:26 AM**	Accuracy and timeliness.
44	**Apr 30, 2014 6:20 AM**	Cost, ease of use, accessibility, standards
45	**Apr 30, 2014 6:17 AM**	accurate, current and readable
46	**Apr 30, 2014 5:26 AM**	timely, reliability,interpretation,relevance
47	**Apr 30, 2014 5:08 AM**	Accurate, applicable within an operational context, reliable and evidence based./ Validated in peace time.
48	**Apr 30, 2014 4:59 AM**	Data must have specific relevance to the end user need, not be adapted to suit a vatiety of needs. Should not be used as answer to everything.
49	**Apr 30, 2014 4:49 AM**	For any band, there is a balance needed between resolution, repeat time and processing time. The purpose of accessing the sensor data also needs to be clear. Labour intensive beginning and end of shift maps are one thing, but how the event unfolds during the shift can be more important. Knowing what to look for - lenticularis clouds in an MTSAT image, an anomalous plume base in a radar image - can provide real wisdom the user knows (a) what should be situation at that time and (b) what a deviation from that expectation might look like. Thus real value of sensor data is in confirming (or not) that the "script" being followed. If it is, the intell is simply "as we predicted", if it isn't then the data in the image gives the first clues as to what the anomaly is.
50	**Apr 30, 2014 4:37 AM**	quick easy understanable and relevant
51	**Apr 30, 2014 4:34 AM**	Familiarity and interoperability
52	**Apr 30, 2014 4:28 AM**	Its relevance to the decision
53	**Apr 30, 2014 3:55 AM**	Timely, relevant, accurate, local
54	**Apr 30, 2014 3:47 AM**	Reliability of data, cost vs effectiveness
55	**Apr 30, 2014 3:22 AM**	Timeliness and reliability
56	**Apr 30, 2014 3:06 AM**	Timely, accurate and legal
57	**Apr 30, 2014 3:00 AM**	Timely credible integrated and useful
58	**Apr 30, 2014 2:50 AM**	Consistent availability. Significance factor: I don't need the data from 20 river sensors if only one of them reaching a certain threshold is indicative of potential flooding. Associated interpretation: eg - if a river gauge show a height

		increase of 1m - what does this mean in terms of potential impact.
59	**Apr 30, 2014 2:46 AM**	reliability – emergency management decisions have to be based on authoritative information. There isn't sufficient emergency resource and the stakes can be very high to gamble
60	**Apr 30, 2014 2:44 AM**	accurate & reliable trusted source
61	**Apr 30, 2014 2:37 AM**	Accuracy, accessibility, timeliness, ease of interpretation, frequency of supply.
62	**Apr 30, 2014 2:29 AM**	Timeliness
63	**Apr 30, 2014 2:22 AM**	If the data is valid and current then it becomes a mandatory component of all the other information gathered to identify the risks that will be placed in context for the decision making process.
64	**Apr 30, 2014 2:21 AM**	relevance, accuracy, timeliness and reliability
65	**Apr 30, 2014 2:17 AM**	Must be reliable and easliy used/interpreted to assist with decision making
66	**Apr 30, 2014 2:17 AM**	Accuracy and reliability
67	**Apr 30, 2014 2:08 AM**	Availability
68	**Apr 30, 2014 2:08 AM**	1) Fit for purpose. 2) Timely 3) Accurate, or provided with confidence statements 3)fit for purpose. As an example from personal experience, a map produced by professional cartographer and available 6 hrs after the data is received is no use to a fire crew, (though it will be of great value to the subsequent Royal Commission) whereas a sketch map traced onto a photocopied sheet available 5 minutes after the helicopter lands is much more use in dealing with the incident.
69	**Apr 30, 2014 2:00 AM**	Accuracy Timeliness Precison
70	**Apr 30, 2014 1:49 AM**	Well understood
71	**Apr 30, 2014 1:44 AM**	Accuracy, Timeliness, Operability, Relative to my task.
72	**Apr 30, 2014 1:43 AM**	Reliability, timeliness and accuracy
73	**Apr 30, 2014 1:42 AM**	Maeningful, useful, valid, reliable and timely
74	**Apr 30, 2014 1:37 AM**	Robustness I'd the data process underpinning.
75	**Apr 30, 2014 1:37 AM**	timely accurate relivant usable individually verifiable
76	**Apr 30, 2014 1:31 AM**	Accuracy, timeliness, interface,
77	**Apr 29, 2014 5:38 PM**	Accuracy, micro level eh suburb or village level, user friendly for volunteers.
78	**Apr 29, 2014 12:40 PM**	Current, acurate, and ability to interigate (drill down)
79	**Apr 29, 2014 11:37 AM**	Accuracy, reproducability, speed and ease of access
80	**Apr 29, 2014 10:17 AM**	reliability
81	**Apr 29, 2014 8:33 AM**	timeliness, reliability, familiarity
82	**Apr 29, 2014 8:10 AM**	Speed, reliability, accuracy
83	**Apr 29, 2014 8:08 AM**	authenticity and reliability
84	**Apr 29, 2014 7:56 AM**	Reliability, timeliness, cost benefit, ease of use and interoperability
85	**Apr 29, 2014 6:40 AM**	Trust in the source, the data is able to be replicated consistently and be a legal source of data.
86	**Apr 29, 2014 6:31 AM**	Given that most emergency situations are time critical, timeliness and reliability are the most critical aspects of sensor

		data products. Near-real time intelligence is crucial in order for effective response actions to be applied.
87	**Apr 29, 2014 5:31 AM**	accuracy and timeliness
88	**Apr 29, 2014 2:12 AM**	timeliness, accessibility and ease of use
89	**Apr 29, 2014 1:18 AM**	Accuracy, timeliness, limited number of access restrictions, 'open' licensing, familiar format.
90	**Apr 28, 2014 11:29 PM**	Quality, credibility, consistency and timeliness
91	**Apr 28, 2014 11:25 PM**	Timliness, accuracy, reliability, functionality, tailored/simplicity
92	**Apr 28, 2014 10:46 PM**	Data must be reliable, instill trust in the user that the information can be shared with a confident amount of accuracy and that it is part of the decision making process.
93	**Apr 28, 2014 10:07 PM**	Reliability, timliness and fit for purpose. This is all about trust in what the data is telling us, this includes trust in down stream processes that transform the raw input into "actionable intelligence".
94	**Apr 28, 2014 9:27 PM**	timely, accurate accessable from remote locations
95	**Apr 28, 2014 9:02 PM**	Reliability, accuracy, timeliness
96	**Apr 28, 2014 10:32 AM**	Ease of consumption, and integration with existing systems, eg, emap
97	**Apr 28, 2014 9:27 AM**	Availability, reliability, accuracy.
98	**Apr 28, 2014 8:09 AM**	Timeliness, consistency, suitability
99	**Apr 28, 2014 8:04 AM**	consistent, timely quality
100	**Apr 28, 2014 7:27 AM**	Accuracy. Timeliness.
101	**Apr 28, 2014 7:13 AM**	Accuracy, cost, open access, reputation
102	**Apr 28, 2014 6:26 AM**	Timeliness, accuracy, effectiveness.
103	**Apr 28, 2014 5:57 AM**	Timeliness and no restrictions on use.
104	**Apr 28, 2014 5:54 AM**	Timeliness, accuracy, ability to be manipulated into operational maps etc
105	**Apr 28, 2014 5:46 AM**	reliable and accurate
106	**Apr 28, 2014 5:08 AM**	acuurate
107	**Apr 28, 2014 5:05 AM**	Accuracy.
108	**Apr 28, 2014 5:05 AM**	Authentic, reliable, secure, free, simple to use, access to private information in EM PPRR.
109	**Apr 28, 2014 4:55 AM**	consistency and reliability
110	**Apr 28, 2014 4:48 AM**	time relvant
111	**Apr 28, 2014 4:37 AM**	accuracy and efficiency
112	**Apr 28, 2014 3:51 AM**	Timeliness, accuracy, ability to reuse, redistribute, ability to share with stakeholders
113	**Apr 28, 2014 3:49 AM**	No secrets, we need to know everything about it including what sensor is, its temporal and spatial information associated. This has been the case often with the use of Military classified systems; we must have our own people in the details, again no secrets. It's also now the case that the public demand how we source our data and media will investigate and interrogate us re the source (see MH370), not disclosing is a big public concern that we must resects and understand.
114	**Apr 28, 2014 3:42 AM**	Cost and availability
115	**Apr 28, 2014 3:35 AM**	Reliable, accurate and timely.
116	**Apr 28, 2014 3:31 AM**	ease of use, access and accuracy
117	**Apr 28, 2014 3:29 AM**	Accuracy and currency
118	**Apr 28, 2014 3:20 AM**	Consistancey in application, assumptions on predictive modeling, intergration with cuttently available data
119	**Apr 28, 2014 3:19 AM**	Trust the source
120	**Apr 28, 2014 3:06 AM**	Ease of access, regularly updated, preferably supported by organisation
121	**Apr 28, 2014 3:05 AM**	Availability, reliability and timeliness

122	**Apr 28, 2014 3:04 AM**	Reliability and accuracey
123	**Apr 28, 2014 2:31 AM**	Accuracy, Timeliness, reliability, cross state, Dept., agency, NGO support and function common use
124	**Apr 8, 2014 3:29 AM**	Timeliness

Do you have any additional comments on this survey?

Answer Options	**Response Count**
	32
answered question	**32**
skipped question	**198**

Number	**Response Date**	**Response Text**
1	**May 29, 2014 4:47 AM**	No
2	**May 14, 2014 1:03 AM**	I think some specialist questions may have been useful... drawing the differences between emergency sectors; a flood is different, to a torrential downpour, is different to a fire, is different to an explosion, is different to a road crash, is different to a sunken aircraft.
3	**May 6, 2014 6:00 AM**	There needs to be a "Sensor Coordinator" built into the Australian disaster management arrangements. i.e The District Disaster Management Groups should have clear access to "capability" of assets. E.G - There is no use having all the best satellites in the world when our disaster management system relies on the locals doing the ground work and not having or knowing about such information or assets being available. It's kind of like developing an evacuation route map and forgetting to educate the locals on what it is, where its found and how to use it.
4	**May 6, 2014 12:58 AM**	National standardization is important. Training needs to be easy to access, consistent between agencies and across state borders.
5	**May 5, 2014 3:53 AM**	Im not in the field however have answered based on if i was to utilise the information for my curretn role.
6	**May 5, 2014 12:30 AM**	Sensor data is useful but must not substitute for Management by walking / driving / flying around to see field situations for oneself prior to or post emergency. This way we get few surprises, only confirmations! PNB.
7	**May 2, 2014 10:30 PM**	Good luck
8	**May 1, 2014 11:33 PM**	Yes. I wish our supposedly World Class fire service actually had any of these things so that frontline fire officers have all the relevant info when making decisions on the fire ground.
9	**Apr 30, 2014 4:49 AM**	This survey seems to be predicated on the notion the EM users take feeds of data from providers in some formal relationship. This is less relevant than it was even five years ago. For most products there are up to three possible feeds. Satellite data is widely available, from far more platforms than are known to most users (AQUA, TERRA, OMI, ASTER, LANDSAT, CloudSat, NOAA, GOES, HIMAWARI (8!) etc, etc), while most users don't know about the really valuable bands. (Knowing lead researchers gives you access to expedited data sometimes!) The scientific difference between the 2003 ACT fires and Black Saturday is that the latter had almost no sensors pointed at it. Yes commercial arrangements are essential for things like airborne multipsectral sensors, but flexibility is also essential elsewhere. Having spent years in this sandpit, feel free to contact me: ****
10	**Apr 30, 2014 4:37 AM**	nope

11	**Apr 30, 2014 2:50 AM**	Lot of fire related questions!
12	**Apr 30, 2014 2:46 AM**	do we get to see the results? even displayed on this survey sight would be interesting
13	**Apr 30, 2014 2:37 AM**	No
14	**Apr 30, 2014 2:08 AM**	1) My primary involvement is/was fire management and suppression, hence the limited interest in seismograms and stream gauges. 2) Mnay of the questions seemed to me to require answers that would vary with context. So for example I would use a product of a lower resolution or precision from a producer known to be consistent. A producer with erratic quality control, so right on the button sometimes and wildy wrong at other times is of no use to anyone.
15	**Apr 29, 2014 12:40 PM**	Most thought provoking survey. Congratulations
16	**Apr 29, 2014 8:10 AM**	Happy to answer additional questions **********
17	**Apr 29, 2014 8:08 AM**	no
18	**Apr 28, 2014 11:29 PM**	No
19	**Apr 28, 2014 11:25 PM**	No
20	**Apr 28, 2014 10:07 PM**	In my day job I am an Intelligence Analyst for a federal agency - I see sensor data in the EM space as no different to SIGINT etc in the Law Enforcement space - you need reliable, trusted data sources, usable interfaces to make sense of what the sensors are telling us, and trained and capable staff (e.g. Intelligence Analysts) to determine the "so what" and provide this in a usable fashion to the decision makers. Simple really:). (A good survey by the way!)
21	**Apr 28, 2014 9:27 AM**	Thanks!
22	**Apr 28, 2014 8:09 AM**	Bit difficult to keep some of the variables independent as some are co-dependent
23	**Apr 28, 2014 7:13 AM**	Done!
24	**Apr 28, 2014 6:26 AM**	What would happen if the Bureau of Meteorology was privatised? Will it become more or less efficient and effective in provision and/or timeliness of fire weather forecasts.
25	**Apr 28, 2014 5:57 AM**	This survey should have somehow incorporated the disaster charter and the effects it has on cost, restrictions and timeliness.
26	**Apr 28, 2014 5:05 AM**	My coincerns with univerisity drerived data relates to timeliness of delivery of information.
27	**Apr 28, 2014 5:05 AM**	Pre identified or benchmark of sensor data products for EM use to keep all the stakeholders on the same page facilitated at the Regional level to enhance continuity and redundancy for the state.
28	**Apr 28, 2014 4:55 AM**	No
29	**Apr 28, 2014 3:51 AM**	Australia needs a generic data suite, that is all hazards, that can be used across jurisdictions by agencies to provide a source of consistent data
30	**Apr 28, 2014 3:35 AM**	No.
31	**Apr 28, 2014 3:06 AM**	In the last few years online information and the ability to send and receive that information has been critical in decision making and I think we are only just understanding it, the future is enormous especially with drones etc for real time information
32	**Apr 21, 2014 12:59 AM**	Takes longer than 10 minutes.

Appendix H: Web survey results: Question 17-19 factors affecting uptake

Table 61: Results from question 17-19, values greater or less than 0.5 from the mean have been highlighted in bold.

	Summary			Experience			Location							
	Count	Mean	SD	< 5 yrs	5-10 yrs	> 10 yrs	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
Accuracy	178	**6.6**	0.7	6.7	6.4	6.6	6.3	6.6	6.2	6.9	6.5	6.9	6.7	6.3
Timeliness	177	**6.5**	0.7	6.7	6.7	6.5	6.8	6.6	6.2	6.8	6.3	6.6	6.4	6.6
Reliability	176	**6.5**	0.8	6.6	6.2	6.5	6.2	6.5	6.3	6.9	6.4	6.5	6.3	6.5
Simplicity	176	**6.1**	1.0	6.0	6.1	6.1	6.1	6.0	6.0	6.1	6.0	6.2	6.1	6.3
Completeness	175	5.7	1.0	5.3	5.9	5.8	5.6	5.9	5.8	5.6	5.7	5.8	5.7	5.8
Useability	177	5.5	1.3	**4.7**	5.7	5.6	**6.1**	5.5	5.2	5.4	5.5	**4.8**	5.6	**6.2**
Consistency	176	**6.1**	1.0	6.1	6.1	6.1	6.2	6.2	6.3	6.3	5.8	5.9	5.9	6.2
Provenance	**159**	5.0	1.6	**4.5**	5.2	5.1	5.6	5.0	**5.6**	**4.2**	4.7	5.3	5.0	5.4
Standards & specifications	173	5.5	1.5	5.8	5.4	5.5	5.1	5.7	5.7	5.3	5.8	5.7	5.2	5.2
Documentation	174	5.1	1.4	5.1	5.1	5.1	5.1	5.3	**5.7**	**4.6**	5.1	5.1	4.7	5.1
Interoperability	176	5.9	1.4	6.1	6.0	5.9	5.5	6.3	6.2	**5.4**	6.2	5.9	5.6	5.7
Mandate	171	5.6	1.4	5.8	5.6	5.6	**4.9**	6.0	5.3	**6.2**	5.6	5.5	5.4	5.8
Reputation	175	**6.1**	1.1	5.9	6.0	6.1	5.8	6.3	5.8	6.0	5.9	6.2	6.0	5.8
Provider familiarity	173	5.6	1.3	5.4	5.8	5.6	5.4	5.6	5.5	5.6	5.7	**6.1**	5.7	**4.9**
Product popularity	174	4.2	1.6	4.2	4.5	4.1	**3.7**	4.4	4.0	4.5	4.1	4.2	4.1	4.2
Business model	**159**	4.8	1.6	**4.2**	5.1	4.9	4.4	5.1	5.2	5.1	4.7	**4.3**	4.7	5.0
Sovereignty	167	4.3	**2.0**	4.4	4.4	4.3	**3.2**	**4.8**	**5.3**	4.1	4.0	3.9	4.5	4.6
Access security	172	5.1	1.7	4.8	5.1	5.1	**3.9**	**5.6**	**5.7**	5.1	5.0	**4.5**	5.0	5.4
Network security	170	5.0	1.7	4.8	4.6	5.1	**4.1**	5.4	**5.8**	5.0	5.1	4.9	4.6	5.0
Dual-use	**162**	3.9	**1.9**	3.8	3.7	3.9	**3.4**	4.1	**5.4**	3.7	3.8	3.9	3.9	4.1
Cost	175	5.3	1.7	5.7	5.3	5.2	**4.8**	5.3	5.7	**5.8**	5.4	5.7	5.0	**5.9**
Access to raw data	167	5.1	1.6	4.7	4.8	5.1	4.9	5.1	5.2	4.8	5.4	**4.5**	5.4	5.3
Publicly disclose the source	167	4.6	1.8	4.8	4.4	4.5	4.8	4.9	**5.4**	4.7	**4.0**	**3.9**	4.6	4.4
Publicly release the raw data	170	4.2	1.8	4.1	4.1	4.3	4.4	4.6	**4.8**	4.2	3.9	**3.5**	4.3	4.5
Copyright	166	4.8	1.8	4.4	4.6	4.9	**5.4**	**5.3**	4.6	4.6	5.0	**3.4**	5.0	4.7
Responsibilities and liabilities	164	5.1	1.5	5.3	4.7	5.2	**5.8**	**5.6**	5.0	5.0	5.1	**4.1**	5.0	5.2
Average	171	5.3	1.4	5.2	5.3	5.3	5.1	5.5	5.5	5.3	5.3	5.1	5.2	5.4

	Summary			Organisation type						Age			Role in supply chain		
	Count	Mean	SD	Fed Govt	State Govt	Local Govt	Research	Private	NGO	Under 35	35-49	50-64	Provider	Value adder	User
Accuracy	178	**6.6**	0.7	6.4	6.6	6.9	6.7	6.7	6.6	6.6	6.6	6.5	6.3	6.4	6.7
Timeliness	177	**6.5**	0.7	6.6	6.5	**7.0**	**7.0**	6.7	6.6	6.5	6.6	6.5	6.6	6.6	6.5
Reliability	176	**6.5**	0.8	6.3	6.5	6.8	6.7	6.7	6.2	6.3	6.6	6.4	6.2	6.3	6.5
Simplicity	176	**6.1**	1.0	5.9	6.1	6.3	**6.7**	6.3	6.0	6.0	6.1	6.1	5.9	5.8	6.1
Completeness	175	5.7	1.0	5.3	5.7	5.9	**6.3**	**6.4**	5.9	5.5	5.7	5.8	5.4	5.3	5.8
Useability	177	5.5	1.3	5.6	5.5	5.1	5.3	**6.4**	5.9	5.3	5.6	5.5	5.6	5.1	5.5
Consistency	176	**6.1**	1.0	5.9	6.1	6.4	6.0	**6.6**	5.9	6.0	6.1	6.0	5.8	5.8	6.1
Provenance	**159**	5.0	1.6	5.2	4.9	**4.4**	**6.7**	5.0	**5.5**	5.1	4.9	5.1	4.7	5.1	4.9
Standards & specifications	173	5.5	1.5	**4.8**	5.6	5.4	**6.7**	5.6	5.3	5.8	5.4	5.5	**4.6**	**4.8**	5.6
Documentation	174	5.1	1.4	4.9	5.2	**4.5**	**6.5**	5.0	**4.5**	5.0	4.9	5.1	4.7	**4.6**	5.1
Interoperability	176	5.9	1.4	5.7	5.9	6.3	6.0	5.7	**5.4**	5.9	5.9	5.8	**5.4**	5.5	6.0
Mandate	171	5.6	1.4	5.5	5.7	**6.3**	**6.3**	5.7	**4.8**	5.9	5.5	5.5	5.4	5.9	5.6
Reputation	175	**6.1**	1.1	6.1	6.1	**5.6**	**6.7**	5.9	5.8	6.2	6.1	6.0	5.7	5.9	6.1
Provider familiarity	173	5.6	1.3	5.2	5.6	5.4	**6.7**	5.7	**6.3**	6.0	5.6	5.5	5.6	5.9	5.6
Product popularity	174	4.2	1.6	4.0	4.3	**3.5**	**5.3**	4.3	3.9	**5.0**	4.3	4.0	**5.1**	4.0	4.1
Business model	**159**	4.8	1.6	4.7	4.9	4.5	**5.5**	**5.6**	**4.0**	5.2	4.5	4.9	4.6	4.5	4.8
Sovereignty	167	4.3	**2.0**	4.1	4.5	**3.4**	4.0	**5.1**	**3.8**	**5.3**	4.0	4.4	4.0	4.0	4.4
Access security	172	5.1	1.7	5.2	5.2	**3.9**	5.3	**5.6**	**4.6**	**5.6**	4.9	5.2	5.4	**4.4**	5.2
Network security	170	5.0	1.7	4.8	5.1	4.6	5.3	5.3	**4.3**	5.2	4.8	5.1	4.9	**4.2**	5.1
Dual-use	**162**	3.9	**1.9**	3.9	4.0	**2.5**	**5.0**	**4.7**	**2.9**	**4.4**	3.6	3.9	3.8	**3.0**	4.0
Cost	175	5.3	1.7	**4.7**	5.4	5.0	5.3	**6.1**	5.1	**6.0**	5.2	5.3	5.2	5.1	5.2
Access to raw data	167	5.1	1.6	5.0	5.1	**3.6**	**4.3**	**5.6**	**5.6**	5.4	5.0	5.1	5.2	5.4	4.9
Publicly disclose the source	167	4.6	1.8	4.7	4.5	4.4	**6.3**	5.0	4.6	4.9	4.4	4.5	5.0	4.9	4.4
Publicly release the raw data	170	4.2	1.8	4.4	4.3	**3.6**	4.0	**4.7**	**3.4**	4.5	4.2	4.2	**4.9**	4.0	4.2
Copyright	166	4.8	1.8	5.1	4.9	5.0	**3.3**	4.6	4.4	5.1	4.8	4.7	4.9	4.8	4.8
Responsibilities and liabilities	164	5.1	1.5	5.5	5.1	**5.6**	5.5	5.1	**4.6**	**5.6**	5.0	5.1	**5.9**	5.3	5.0
Average	171	5.3	1.4	5.2	5.4	5.1	5.7	5.6	5.1	5.6	5.2	5.3	5.3	5.1	5.3