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Smart Seismic Cities: Development of an Integrated Information and Communication Technology Architecture

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ABSTRACT

Effective decision-making following a large earthquake requires awareness of impacts to people, built infrastructure and critical services. Near Real-time Impact Tools, such as the Prompt Assessment of Global Earthquake for Response System (PAGER), increase situational awareness and improve decision-making. However, they do not necessarily include critical human data, for example: level of vulnerability and threat, location, and mobility. Among other constraints, this limitation may have resulted from a focus on engineering, rather than transdisciplinary, resilience concepts. The Smart Seismic Cities project will explore how Near Real-time Impact Tools that register both human and infrastructure impacts can be utilised in the pilot urban setting of Wellington's Central Business District. Pre-event, Near Real-time Impact Tools for gauging human and infrastructure impacts can be used to improve urban planning and development. In the near-immediate aftermath of strong earthquakes, information on built environment damage and population exposure estimates can be used to more accurately manage acute needs for evacuation, complex rescue and other responses. Additionally, such data can be used for longer-term socio-economic recovery modelling. This concept paper outlines on-going research toward the development of a comprehensive Information and Communication Technology System Architecture for integrating human data within a set of Near

Real-time Impact Tools. This architecture would leverage State of the Art Technologies, including: self-configurable Sensor Networks, other Internet of Things technologies, Next Generation Mobile and Broadcasting platforms, Machine Learning, and Artificial Intelligence. As part of social science contributions, we highlight ethical needs to understand the social acceptability of using personal identifiable information.

1 INTRODUCTION

Following a large and potentially damaging earthquake, effective decision making requires an awareness of impacts to people, built infrastructure and critical services. Situational awareness, is achieved with the accurate, comprehensive and timely combination of information from highly diverse sources (Bunker & Sleigh 2018). Near Real-time Impact Tools (NRITs), such as the United States Geological Surveys' Prompt Assessment of Global Earthquake for Response (PAGER) System (Wald et al., 2011), the Taiwan Earthquake Loss Estimations System (TELES) (Yeh et al., 2006) and the Japan Real-time Information System for earthquake (J-RISQ) tool (Nakamura et al., 2017), are used to substantially improve situational awareness and decision-making in the minutes following a large earthquake. These systems provide critical information about the earthquake, in terms of initial estimates of magnitude and location, to calculate potential impacts to infrastructure and critical services, such as roads, hospitals and airports. However, they do not necessarily include accurate human data, for example: level of vulnerability and threat, location, and mobility.

Among other constraints, established NRITs may have been limited by a focus on engineering, rather than transdisciplinary, resilience concepts. Emergency Managers' ability to make effective and timely decisions nonetheless depends on such information. For example, understanding crowd behaviours and how people are clustering is necessary for cordoning decisions and managing the flow of people. Likewise, emergency services can be more rapidly deployed when injured people are already located Evacuation behaviours also inform critical emergency management decisions, such as the provision of emergency housing. Given these potentials, alongside rapidly changing developments and shifting urban vulnerabilities, NRIT's need to be enhanced to capture human data as well as the spatial and temporal dynamics of urban areas.

Bearing the technological limitations of existing NRIT's in mind, the current paper outlines a novel approach to using human data as part of these systems. This approach draws on pre-existing smart cities initiatives and related research but adds a specific focus on responding to natural hazard events, being earthquakes in particular. The current paper will outline these pre-existing initiatives, before outlining recognised potentials and challenges as part of the overarching concept of a smart city. The paper will then outline how the Smart Seismic Cities initiative aims to leverage potentials and meet challenges, to make a genuine contribution to this aspect of urban development and emergency management.

2 BACKGROUND

The Smart Seismic Cities concept stems from the open and shared approach that many cities are using to leverage data to better understand local vulnerabilities and inform development decisions. The Smart Cities model utilises ICT systems, emerging technologies and local context for intelligent urban development as well as the operation of physical and service infrastructure. Common Smart City services encompass health, transportation and energy, including initiatives such as smart waste and smart buildings. (Gattulli et al. 2015; Lea 2017; Dey et al. 2018). From an urban planning and technology perspective, cities are viewed as complex ecosystems (Lea 2017). Human data used as part of these initiatives means that many urban residents now live in a world where they don't just seek information, they are information (Bunker & Sleigh 2018).

Many local governments are focused on building resilience to natural hazards for at-risk communities. However, it seems that Smart City initiatives can be much better focused on natural hazards, particularly earthquakes, and emergency management responses to those hazards. Emerging technologies and data processing tools, such as self-configurable sensor networks and Artificial Intelligence (AI), which are utilised in Smart Cities (Concilio & Rizzo 2016), present an opportunity to improve the emergency management response to, and people's experience of, a large and damaging earthquake. This can be achieved through efficient decision-making, including decisions and processes for communicating with the public.

The transdisciplinary concept of Smart Seismic Cities concerns exploring how Near Real-time Impact Tools and sensor networks that register both human and infrastructure impacts can be utilised in the pilot urban setting of Wellington's Central Business District. Pre-event, an integrated network for gauging human and infrastructure impacts can be used to improve urban planning and development. For example, population mobility data can be used in casualty estimation models, to improve estimates of injury distribution. These estimates can be used to prioritise mitigation initiatives and required funding. In the near-immediate aftermath of highly destructive earthquakes, population exposure can be used to more accurately manage acute needs for evacuation, complex rescues and other responses. Integrating both human and infrastructure impacts into NRIT's for the Wellington CBD will therefore substantially improve the situational awareness of many important decision-making teams and individuals, over both long- and short-term emergency management timeframes. Research is therefore needed to explore the most appropriate application of technology and use of an ICT system to meet the needs of Wellington people and Emergency Managers.

Authors of this paper have previously developed an integrated ICT system architecture in the context of Emergency Response to fires (Prasanna et al. 2017). Additionally, their previous work has looked at emergency responder's acceptance of information systems (Prasanna & Huggins, 2016). The main contribution of the current paper is to synthesise concepts from the smart cities model and set the research agenda for the development of an ICT system architecture. We introduce our on-going research and perspectives about the capabilities of emerging technologies in the context of emergency response to earthquakes.

2.1 Existing open data ecosystems in New Zealand

The shift toward open data ecosystems is already progressing in New Zealand. The Open Government Data Program is a cross-government programme that was established to set a shared direction of open government data release and reuse. The Data Strategy and Roadmap: setting the direction for New Zealand's data, outlines the plan for New Zealand's data system (data.govt.nz).

Additionally, in terms of open data and resilience, our pilot city, Wellington, has been part of the Rockefeller Foundation 100 Resilient Cities Organisation since 2015. Their main governmental partner, Wellington City Council, have implemented open and shared data frameworks into emergency management and resilient practices (Audain et al. 2018). The effectiveness of the data platform's geospatial capability to contextualize damage was demonstrated during the cities response to the Magnitude 7.8 Kaikōura earthquake, November 14 2016. This response was unified with a core spatial dataset that was accessible across the organisation, and which gave agencies the ability to produce and share common operating pictures, depicted as web maps and web scenes, for particular groups. These visualizations used innovative techniques such as three-dimensional images. Audain et al. (2018) reports that adopting a cloud-centric solution has significantly improved city management solutions and the ability to effectively engage with communities in Wellington, thus helping to build resilience. These pre-existing initiatives mean that the Smart Seismic Cities ICT system can build on existing capabilities and guidelines, and this point is discussed further in section 3.2 below.

3 SMART CITIES CONCEPTS

3.1 Emerging Technologies

A recent IEEE report (Lea 2017) detailed key ICT trends that are enabling cities to use emerging and state of the art technologies for the delivery of smart city services. According to Lea (2017), these technologies are shaping how cities are evolving. For example, infrastructure is increasingly becoming connected through Internet of Things technology. Cities that adopt cloud systems to capture data and develop comprehensive analytic capabilities will accrue advantages in development. However, when considering the appropriate application of technologies to solve local issues, human factors and institutional aspects need to be included as essential components of the ecosystem. The trends Lea (2017) highlights are:

- Networking and Communications
    - Low-Power Wan technologies
    - Next generation networking (3/4/5G) networks
- Cyber Physical systems and the Internet of Things
- Cloud and Edge Computing
- Open data
- Big Data and Data Analytics
    - Artificial Intelligence
    - Machine Learning

3.1.1 Challenges

Several challenges with the adoption of emerging technologies and ICT systems have been identified. Apparently the following challenges are more complex when multiple emerging technologies progress at the same time, generally due to a disruption in business models. Tensions between public protection and innovation is an on-going challenge for regulatory structures (Eggers et al. 2018). Key challenges, as identified by the QROWD (http://qrowd-project.eu/) project, are:

- Urban data is locked in isolated industrial and public sectors
- Big data integration is difficult technically because of a) heterogeneity of data sources, variety of formats, sizes, quality as well as update rates
- Significant human intervention needed
- Information credibility, particularly when considering crowd sourced data
- Exceptionally diverse and indispensable end-user groups

There are additional challenges around telecommunications following a damaging earthquake. Connectivity is often lost due to damage to lines and other fragile aspect of telecommunications infrastructure. Fortunately, there are additional research projects in New Zealand that are focussed on lifeline resilience, including the resilience of telecommunications infrastructure (Gul et al. 2018). These engineering resilience projects will also feed into the overarching development of the Smart Seismic Cities initiative.

3.2 Design Considerations for developing an ICT system

ICT systems underpin the successful implementation of Smart Cities and are used to aggregate and integrate data sources (i.e. to receive, process, analyse and redistribute data). The design considerations are categorised broadly as technical and non-technical, as follows.

3.2.1 Technical:

- Privacy & Safety: Understand public concerns about increasingly ubiquitous and pervasive tracking technologies – understand public perception about the adoption of technologies - optimal placement of sensors that reduces risk for public. It will be particularly important to align the Smart Seismic Cities ICT system with New Zealand's Data strategy and Roadmap: setting the direction for New Zealand's data.
- Cost: This includes using as few sensors, such as Closed Circuit Television, as possible, also requiring optimal sensor placement.
- Storage: Streaming data in a way that avoids data storage. This should ideally be compatible with AI and Machine Learning technologies.
- Agility: Agility, reliance and robustness of the system.
- Interoperability: This refers to the way that systems used by different agencies can work with one another.

3.2.2 Non-technical:

- Policies and frameworks: Outlining processes and constraints for data collection and sharing personal identifiable information and other sensitive data. Policies are likely to vary across different organisations and over-arching national policies (Privacy Commissioner) need to be engaged.

4 SMART SEISMIC CITIES

4.1 Smart Seismic Cities Vision

The Smart Seismic cities concept is part of wider efforts by QuakeCoRE, a Centre of Research Excellence (CoRE) funded by the New Zealand Government. Other research streams that align with the Smart Seismic Cities work include: a detailed building inventory database and a Wellington cordon project.

The vision of Smart Seismic Cities is to bring together:

1) Near Real–time Tools relating to earthquake parameters, such as shaking intensities across a region as well as estimates of shaking;

2) Spatial location data of buildings, lifelines as well as their characteristics, such as geotechnical information, detailed structural models and social mobility;

3) The response of these elements that can be predicted, measured or observed through sensors and other instrumentation, including social data and behavioural responses.

The ultimate output of the Smart Seismic Cities vision is improved situational awareness, in terms of perception, comprehension and forecasting, as well as decision–making, in terms of rational and non-rational. The schematic below shows the overarching summary of the Smart Seismic Cities Vision.

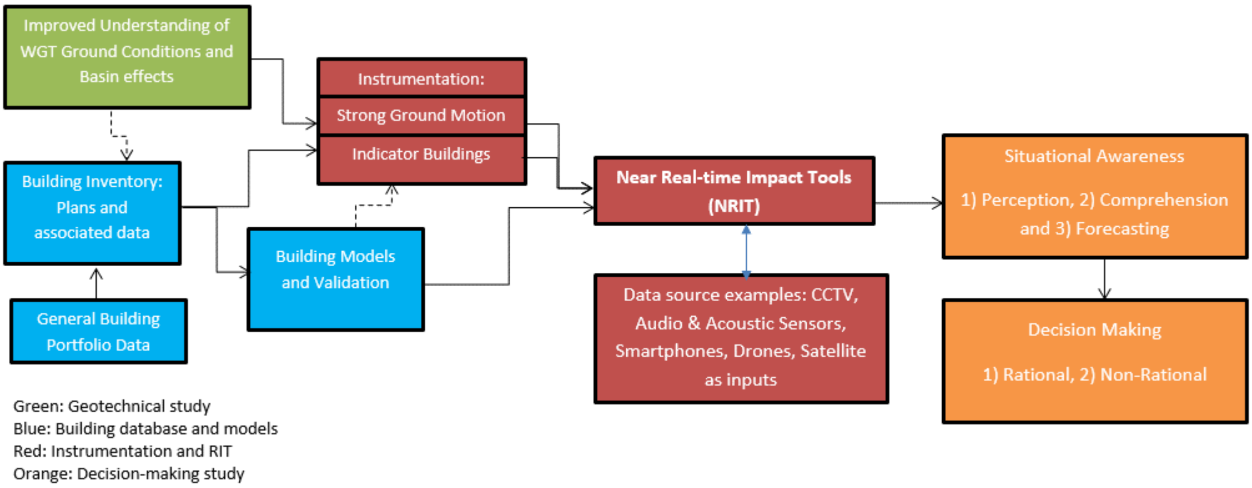

Figure 1: Smart Seismic Cities overarching summary

4.2 Research Agenda

Several research areas, specifically related to the social aspects of the Smart Seismic Cities project, are important to the overall conception and design of the Smart Seismic Cities ICT system.

- For emergency manager end-users, what are the satisfaction(s) and/or dissatisfaction(s) with the existing process used for situational awareness during an emergency event?
- What kind of things have become possible from a technological point of view – What technology can and cannot (or should not) be enabled in a post-earthquake context?
- What are the prerequisites from the emergency management sector to adopt these technologies, for example platforms for managing data, including open data?
- What existing and potential data sources can inform our understanding of population mobility data and infrastructure damage e.g. video/CCTV, accelerometers, GPS, social media, wearable technologies?
- Ethically, to what degree can you collect people's data in a state of emergency? Do people want their data to be collected in a post-earthquake environment? How do we manage data that is socially sensitive? What do people (as end-users) see as being the mutual benefit of sharing personal data (assuming a google, Facebook type arrangement)?
- What are the existing organisations that are developing technology for emergency response to natural hazards? Further engage with industry (as collaborative partners) to understand ethics and technology systems, explore considerations for collecting, managing, analysing and redistributing data.
- How might the Smart Seismic Cities system be useful in a pre-earthquake recovery planning and post-earthquake recovery operations (i.e. socio-economic modelling for wellbeing interventions)?

The biggest gap and assumption identified above is the social acceptability of providing highly individually identifiable data to multiple government and non-government agencies. Ethical considerations and value sensitive design are fundamental to ICT system development and technology (Kumar & Søraker 2015). Social acceptability may vary widely according to cultural (norms and behaviour) and legislative context (differences between USA federal privacy legislation vs. New Zealand's Privacy Act). Easton and Büscher (2015) discuss the strengths of integrating a holistic and evolutionary approach of privacy impact assessments (PIA) to information technology projects focussed on emergency response.

This means, in the first instance, that the Smart Seismic Cities development and research will focus on understanding how a user-centric approach, such as the emergency-response-specific goal-directed information analysis (GDIA) (Yang et al. 2015), could be adapted for members of the wider public as end users of the Smart Seismic Cities System. Adapting this, or a comparable framework, aims to engage urban populations as active end-users of smart city systems, rather than assuming that they will passively grant access to personally identifiable data such as the cellular phone IP address and location. At the same time, it is important to consult with industry to fully understand what emerging technologies can offer the emergency management sector, as well as existing policies concerning data security.

A user-centric approach, combined with simultaneous industry consultation aims to help determine what emerging technologies are most appropriate for the Smart Seismic Cities System, in terms of how data is processed and accessed for decision-making during an earthquake. Additionally, it will help eliminate our assumptions of what people expect from sharing data in a post-earthquake environment. Combining a user-centric approach with industry consultation will involve an iterative process of engagement to acquire information from end-users, understand behaviours and policies as well as feedback to ensure their needs have been captured and expectations met.

After adapting and implementing processes for end-user driven system development, the current social research toward the Smart Seismic Cities project will conclude with the development of relevant design considerations. Ideally, the design considerations will help develop and propose processes for engaging highly diverse stakeholders and end-users, as well as for incorporating relevant research while developing a Smart Seismic Cities ICT system.

5 CONCLUDING REMARKS

Cities with a high seismic risk must consider how emerging technology capabilities can be adopted for the effective use of spatial information in real time in an interconnected and inclusive way (Bunker & Sleigh 2018). Information and Communication Technology (ICT) systems and emerging technologies can contextualise data and increase situational awareness capabilities to support decisions that save lives. This concept paper summarises the Smart City model and trends in emerging technologies, in terms of potentials and challenges. We introduce our research into the development of a comprehensive ICT system that integrates physical infrastructure and service impacts as well as human data, such as population mobility, following a large earthquake. A user-centric methodology is needed to understand organisational and social acceptability of open data ecosystems in a post-earthquake environment. This will involve an iterative process of consulting with organisations working in the emerging technology space (as collaborative partners) as well as Emergency Managers and the general public (as end-users) to identify current data collection and security protocols, end-user behaviours and requirements. Given the use of personally identifiable data, concerning individuals' movements and other activities, the Smart Seismic Cities initiative will adapt these methodologies for the general public, in addition to established processes for engaging emergency managers in the design and development of ICT systems. The outlined research will conclude with explicit design considerations toward the development of an ICT system.

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