Post-disaster socioeconomic earthquake loss modelling and evaluation: the challenges, implementation and future needs for Australia and beyond.

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Abstract

In the aftermath of the next big earthquake, governments and public agencies, companies and international organisations require rapid socioeconomic loss estimates for the provision of financial support for households, relief and recovery for basic services and for buildings, infrastructure and sector.

Over the past few years, methodologies like the Global RApid post-disaster Damage Estimation (GRADE) approach have been developed to provide such a tool before in-depth assessments are undertaken.

In this paper,
a) a review of existing open software packages and solutions for rapid earthquake loss modelling is made;
b) the tools and new methods to aid rapid loss estimation are presented;
c) identification of the needs and gaps in loss estimation in the aftermath including detailed baseline information for key sectors such as schools
d) the losses from Newcastle 1989 are compared to sectoral loss ratios from other events around the world in events reminding us of the need for research into non-building and holistic losses.

Keywords: socioeconomic loss, rapid loss, GRADE, risk modelling

1 Introduction

With the need for faster loss estimation methodologies to facilitate the use of public goodwill payments and government interest post-disaster in line with existing methods, better characterisation and recording of loss data post-disaster is required, along with databases built in advance of disasters. Hopefully some of the existing gaps can be filled by researchers and industry projects in the coming years.

Rapid loss estimation models have become commonplace post-disaster in recent years. Indeed, post-disaster (specifically in this case for earthquake), there are numerous products which support the analysis process as can be seen in Table 1.

Rapid loss estimation has been previously explained in a past paper within the AEES (Daniell et al., 2014) and thus the concept will only be briefly explained in this paper with respect to the methods covered pre-2014. Before 2014, six major earthquake loss estimation models existed in a post-disaster rapid setting (rapid referring to ca. 10 mins-12 hrs after an event) for quantifying socioeconomic losses such as fatalities and economic losses.

Table 1: Software Packages which can be used for rapid loss modelling (updated from Daniell, 2014) – references to be added on the online archive

Type of Software Package	Acc.	Open/ Closed	Lang.	Tested Locations	Rapid Loss	Exposure	Vuln.	Hazard	Social	Economic
ELER	**YES**	**O**	Matlab	Turkey, Europe	**Yes**	B,P,Es	Both	MM, Sp	Ss, Auto	None
EQRM	**YES**	**O**	Python	Australia adapted	**No**	B,P,Es	Both	Sp	Ss	DC
ELER has 3 versions – Level 0, Level 1 and Level 2										
CATDAT-EQLIPSE (this study)	**YES**	**C**	Matlab, GIS	Global	**Yes**	P, Es	Emp	MM	Ss	DC
EQLIPSE has 2 versions – Q and R										
OpenQuake	YES	O	Python	Global	Yes	B, P, Es	Both	Sp	Ss	DC
APE-ELEV	NO	C		Global	Yes	P, Es	Emp	MM	Ss	DC
Extremum	**NO**	**C**	Win, GIS	Turkey etc.	**Yes**	B,P,Es	Emp	MM	Ss Auto	RE
HAZ-Taiwan (TELES)	**NO**	**C**	C++ and MapInfo	Taiwan	**Yes**	B,I,P, Es	Anl.	Sp, SE	Ss Auto Sc	DC, IO
HAZUS-MH	**YES**	**O**	VB6, C++, Arc	USA	**Yes** *	B,I,P, Ec	Anl.	Sp, SE	Ss, Sc	DC, IO
InaSAFE EQ	**YES**	**O**	Java, QGIS	Jakarta	**Yes** *	B,I,P, Es	Both	MM, Sp, SE	Sc	DC
PAGER	**NO**	**C**	Matlab, unknown.	Worldwide	**Yes**	B, P, Es	Both	Sp, MM, SE	Ss Auto	Many DC, RE
PAGER has 3 different versions – Empirical, Semi-Empirical and Analytical (Jaiswal et al. (2011))										
QLARM	**NO**	**C**	Java	Worldwide	**Yes**	B, P, Es	Both	MM	Ss Auto	No
REDARS	**YES**	**C**	GUI Windows, Basic	California	**Yes**	I,Es	Emp	Sp, SE	No	DC, IO
REDAS	**NO**	**C**	GUI Windows, Basic	Philippines	**Yes**	B,I,P,Es	Emp	MM, SE	Ss	DC
SAFER	**NO**	**C**	Same as SELENA	European Settings	**Yes**	B,I,P, Es	Both	Sp	Ss	DC
SELENA	**YES**	**O**	Matlab, C++	Oslo	**Yes**	B, P, Es	Anl.	Sp	Ss	DC
SES2002 and ESCENARIS	**NO**	**C**	VB	Spain	**Yes**	B,I,P, Es	Emp	MM	Ss, Sc	DC, RE
SIGE/ESPAS	**NO**	**C**	VB	Italy	**Yes**	B,I,P, Es	Emp	MM	Ss, Sc	DC, RE
PLINIVS	**NO**	**C**	Unk. – DPMs	Naples	**Yes**	B,P	Emp	MM	Ss	No
QuakeIST	**NO**	**C**	C++	Lorca, Faial, Iceland	**Yes**	B,I,P	Both	Sp, MM	Ss, DI	DC, RE

O/C – open or closed software package; VB = Visual Basic, Arc=ESRI ArcGIS or similar, *= as shown below.
Exp =Exposure, B=Buildings, I=Infrastructure, P=Population, Es=economic values for infrastructure, Ec=complex economic values using regional or location assessment values
Haz =Hazard, MM=intensity, Sp=spectra, SE=secondary effects
Vuln =Vulnerability Type, Anl.=Analytical, Emp.=Empirical
Soc. =Social, Ss=simple social analysis, Sc=complex social analysis, US=user inputted curves or assessment, Auto=automatic analysis for rapid loss estimation, DI=Disruption Index
Econ. = Economic, DC= direct conversion to replacement cost, RE= rapid loss estimation possible, IO= indirect and additional analysis.

QLARM/WAPMERR (Wyss, 2004) provided a tool quantifying fatalities and injuries for each disaster globally based on intensity-building typology relationships for various building distributions with towns globally. The modelling was loosely based on the earlier EXTREMUM system (Larionov et al., 2000) which was used in the USSR and other locations around the world, based on a regression of 1500 earthquakes. PAGER

(Jaiswal et al., 2011) used a regression of Shakemaps, population (EXPO-CAT), vulnerability functions based on fitting a regression to the fatality database of PAGER-CAT (Allen et al., 2009); and MunichRe data on economic losses. CATDAT-EQLIPSE was released in 2009 (Daniell et al., 2014) and provided two methods of assessment (a Q model, which provided an empirical regression of the losses from the CATDAT database) and an R model, which used building typologies, soil effects and associated fatality functions from over 200 methods globally for fatalities (Daniell, 2014). In addition, there are other methods that were developed for economic losses and social losses using rapid functions.

ABES (Italy) (Greco et al., 2019), IERRS (Istanbul), SUPREME (Tokyo), READY (Yokohama) and AFAD-RED (Yalcin et al., 2017) (Turkey) are additional rapid loss models that have not been reviewed in this format. Zhang et al. (2018), Tang et al. (2019) and Li et al. (2019) provide three new rapid disaster loss assessment methods for earthquakes in China which have not been applied above. RISKPLAN, OpenQuick, EconoMe, CLIMADA and other such generalised methodologies among others have not been reviewed and indeed there exist a large number of software packages which have not yet been used in the rapid estimation field.

Fakhruddin et al. (2018) gives some insight into the new methods used in Kaikoura 2016, in the days after the event for rapid damage counting, however is not as such a rapid loss estimation software and GRADE via Gunasekera et al. (2018) will be explained in greater depth later but is built on an extended CATDAT-EQLIPSE framework .

A significant number of risk assessments have been undertaken in Australia, including many by Geoscience Australia over a number of years (see Fulford et al., 2002, AGSO Cities Projects, Dhu et al., 2004; Edwards et al., 2019, WA government (DFES) through various BNHCRC publications, QFES (2019).

The seismic hazard assessment and models are available at:
http://www.ga.gov.au/about/projects/safety/nsha

- Commercial models include: Risk Frontiers - PerilsAUS (Briefing note 373, July 2018); AON, RMS (2019 update), AIR, Reinsurers (such as MunichRe, SwissRe etc.); CoreLogic (based on 2012)
- Models developed as part of government and private initiatives: Global Earthquake Model
- Academic models include: Daniell et al. (2015)

Investment in past disaster data and loss data is priceless in a post-disaster setting. Knowing how infrastructure systems, buildings, and people have reacted in past events; and their associated losses informs the models. In this way, work such as Malpas et al. (1991), McCue (2013 a,b,c), McCue (2014), Daniell and Love (2010), Atlas of isoseismal maps of Australian earthquakes are essential to the process, and more work should be made to create improved catalogues and geodata associated with such events; including the need in advance to accurately collect data in an open repository where the data can be archived and used by multiple parties.

It is critical to the process to build the required sectoral baseline information for the design of rehabilitation and reconstruction plans. The GRADE approach provides this information, as it is based on an assessment of vulnerability and damage distribution of the affected infrastructure and assets and provides a more detailed and faster estimate than other forms such as Figure 1.

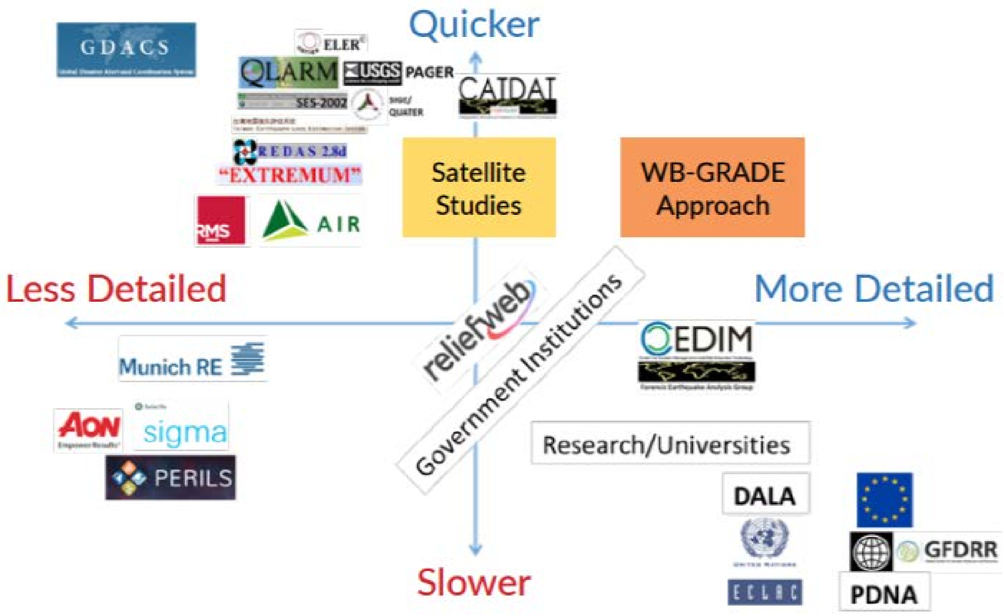

Figure 1: Global stakeholders providing various types of information or analytical services in the aftermath of natural disasters, categorized by level of detail and speed of delivery

2 What happens if an event occurs

The following is a "lessons learned" from the last 11 years of doing this in near real-time, and the changing landscape of post-disaster loss estimates globally, hopefully of which a few points could be helpful in developing an Australian or surroundings post-disaster loss framework incorporating loss estimation, social sensors, other surveys and lastly PDNA and direct-indirect loss to recovery and reconstruction efforts.

2.1 The first minutes after an event

In the first minutes after a disaster, the first information comes from social media before seismometers in most cases despite platforms like earthquakes.ga.gov.au with real-time station information. The TENAS system of Dittrich, 2016), TED system from USGS and any other manner of alert systems from Facebook (Crisis Response), Google (Public Alerts and SOS Alerts), and other private and public entities are present. Websites like Earthquake Report (www.earthquake-report.com) rely on keywords and the increase in users per second to determine the location of events.

This information is often in local language so there exists the need to use automatic translators. In the case of Australia, depending on where the event occurs, most social media will be in English, as well as some foreign language results. Natural language algorithms are needed along with abbreviations, slang and checks as to plausibility. In all cases, these automatic translators need manual checks especially with the definition of numbers (i.e. the meaning of "million").

In the past few years, the number of automatic aggregators have increased globally so in most cases the relevant information is often difficult to find in amongst the amount of automated data. However, Google Crisis Response as well as Facebook work with credible sources, bringing results to the top of immediate searches. For Australia, until now, only two state fire agencies are working with them. Geonet, CWB, USGS, BMKG and other agencies provide information currently to Google for use within this platform. Geoscience Australia, state agencies, ES&S and other entities could potentially provide data in the aftermath, to ensure that the local information is available. This would support local DYFI initiatives (community intensity maps) and shakemaps efforts.

In addition, for a large enough quake, felt aftershocks will likely occur, confusing a public not used to earthquakes (or even understanding what an aftershock is). In such cases, this confuses the initial response of emergency services (see Virginia 2011, Nepal 2015). Note: Newcastle did not have significant aftershocks so this has not really been experienced yet in Australia; however lessons from Christchurch can of course be learnt.

2.2 Magnitude and Intensity estimates

Many intensity maps and magnitude assessments are available after events. The usual global magnitude assessments come from USGS, GEOFON and EMSC soon after events. They are generally automated and then have manual checks within a half hour or so. International press generally quotes these magnitude assessments. In addition, macroseismic intensity maps and ShakeMaps are produced by not only these groups but also via WAPMERR (QLARM), CATNews, GDACS and other groups produce their own shakemaps based on existing IPEs, GMPEs and GMICEs. In general, the highest values will be reported in the press regardless of where they are from; or those which are from the top of a Google search – hence another impetus why the Crisis Response groups need to be approached.

Felt reports and assessed reports are collected generally via local entities and those higher in Google searches. For Australian earthquakes, Geoscience Australia would likely receive the most felt reports. Generally there will be a large skew in a bigger event in Australia due to a lack of knowledge as well as shock, thus felt reports may not provide the most realistic data.

At the very least, the damaging radius and felt radius should be able to be determined quite early on through the combination of intensity calculation and social media. Secondary effects are generally not taken into account by most models, however, liquefaction via the Zhu et al. (2017) model (earlier models included Zhu et al., 2015) and landslide rapid hazard via the Nowicki Jessee et al. (2018) model has been examined as part of the USGS program. Earlier landslide models included Godt et al. (2008) and Nowicki et al. (2014).

However, secondary effects modelling for tsunami has been undertaken in near real time from Schäfer et al. (2018); JTWC; and other groups. Tsunami runup heights are generally modelled via various agencies, all with large uncertainties given uncertainties in the source mechanism. On an Australian level, the tsunami hazard modelling guidelines of AIDR (2018) give an insight into this. In addition the PTHA18 via Davies and Griffin (2018) provides tsunami scenarios for local-scale inundation which in certain cases could be used given certain events which match well with the event set to be used in rapid analysis.

2.3 Conflicting information via news reports in the 15 min-hours stage of the event on fatalities, displaced and damage

In the first hour to six hours after an event, death toll information generally comes in sporadically from different reports. In the Philippines, barangays report deaths to the

PDRRMC which then are sent to the NDRRMC. For Japan, municipality reports of fatalities, injuries, sheltered are then transmitted to provincial counts which are then applied at a national level via FDMA or NPA. The National Incident Room may be activated, but the States and Territories are generally involved. Given the movement around Australia on any one day of population, there will be likely issues with double counting as was seen in Chile 2010; and many other disasters with death tolls in the 100-1000 mark.

A mixture of religions, cultures and rituals is present in Australia, thus, there may be difficulties in the initial stages to determine the death toll. This range of death tolls post-disaster can occur for many different reasons, including misinformation, double counting, lack of formal processes, knowledge of where population is at any one time, as well as evacuations post-disaster (Daniell et al., 2018). In a paper for ECEE in 2018, the author presents the range of the top 100 earthquakes since 1900 combining the most complete loss databases for fatal earthquakes – the CATDAT database and the Pomonis database, showing the range for a myriad of reasons.

In current times, misquotes of government officials, typos and false information are all present in this time period helping to fuel panic as well as the unknowns of the public (see Daniell, Pomonis et al., 2018). The speed with which media reports has sped up markedly in the last 10 years, to a point where a misquote can be across the internet within minutes (a non-earthquake example of the last month being Hurricane Dorian on the Bahamas, where over 90% of houses on the Abaco Islands were quoted as being destroyed). Compared to 1989 in Newcastle before the wider advent of the internet, this is one issue to reckon with. Politics is swayed by such information in the aftermath, with decisions made often ad hoc (Aceh 2004, Fukushima 2011, Ecuador 2016). Having good formalised situation report protocols such as INDECI (Peru), FDMA (Japan) or NDRRMC/DROMIC (Philippines) can support this issue.

Large loss facilities, as well as landmarks are often focussed on in the time period, as well as schools and hospitals. Using the national registers and having either sensor or established information post-disaster on these facilities often helps planning. Economic loss estimates are also often in this time period multiplications of exposure estimates or mistaken land value “expert” costs, which can be very different to the final replacement costs. Again such estimates have been discussed in past AEES papers.

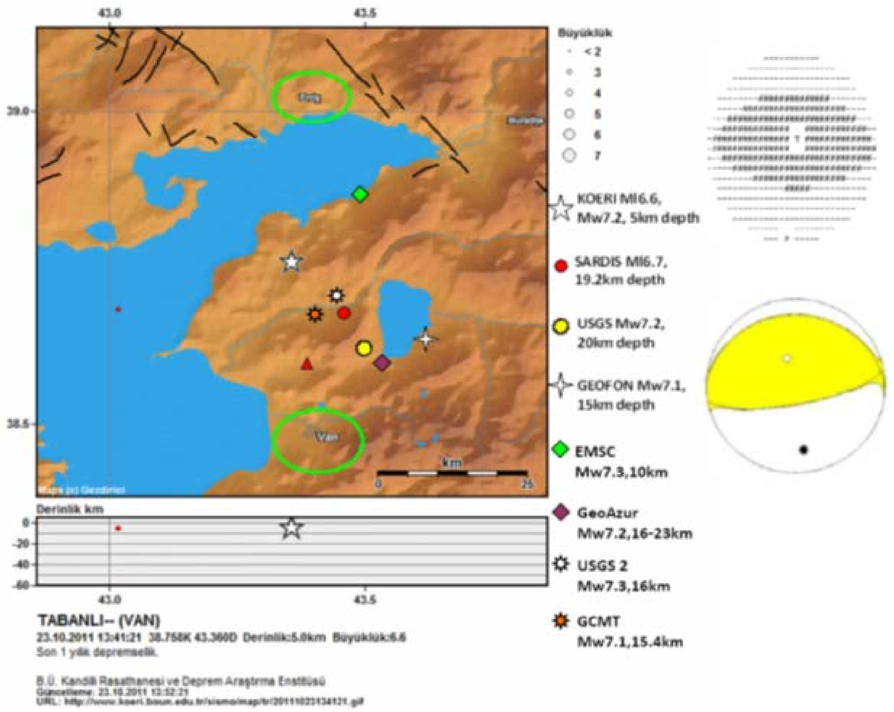

Figure 2: Differences in the epicentre of the Van earthquake 2011 signifying a massive difference in location comparatively for loss assessment.

Intensity maps usually start to settle, however here in Australia, it perhaps may look like Van 2011 (Figure 2) in terms of unknowns post-event due to lack of instrumentation.

2.4 Displacement including examples from countries where good reporting systems are in place

Post-disaster if there is significant damage (which we can expect from a large earthquake in an Australian city) there will be a lot of displaced people who will try to work out where they will have shelter while engineering checks are occurring for houses.

Without significant training in post-disaster structural checks of buildings, it can be expected that there will be significant delays due to protocols of people returning to their homes.

Depending on the time of year and location in Australia, people may sleep in their gardens while aftershocks are going on, or simply leave the city to stay with friends or family in other unaffected locations.

Reporting systems to account for this are needed as this creates significant uncertainty for collapsed houses and/or search and rescue; as well as with counting of the affected population for shelter provisions.

It should be assumed that the pre-earthquake homeless population will also use homeless shelters in such an event.

Using a system like that of the municipalities in Japan, or Philippines (Figure 3) gives the public a clear list of shelters and statistics; as well as the number of those displaced in hotels or living with family. For DROMIC it includes affected people, families, deaths, injuries, the reasons for the deaths and injuries, ongoing evacuation numbers (both cumulative and current), building damage, and sectoral losses among other data. For Japan similar situation reports are released – at the start every 30 min to 1 hr; and then 3 hrs up to daily in the months after the disaster. This also means less misinformation in the media.

II. Status of Displaced Families / Persons

a. Inside Evacuation Centers

There are 58 families or 352 persons who are taking temporary shelter in four (4) evacuation centers in Regions XI and XII (see Table 2).

Table 2. Displaced Families / Persons Inside Evacuation Center

REGION / PROVINCE / MUNICIPALITY	NUMBER OF EVACUATION CENTERS (ECs)		INSIDE ECs			
			Families		Persons	
	CUM	NOW	CUM	NOW	CUM	NOW
GRAND TOTAL	5	4	558	58	2,852	352
REGION XI	3	3	28	28	202	202
Davao del Sur	3	3	28	28	202	202
Bansalan	1	1	3	3	77	77
Matanao	2	2	25	25	125	125
REGION XII	2	1	530	30	2,650	150
North Cotabato	2	1	530	30	2,650	150
City of Kidapawan (capital)*	1	-	500	-	2,500	-
Makilala	1	1	30	30	150	150

Note: *The reported affected families or persons in City of Kidapawan have already returned to their area of residence. Thus, ongoing assessment and validation being conducted.

Source: DSWD-FOs XI and XII

b. Outside Evacuation Centers

There are 547 families or 2,673 persons who are currently staying with their relatives and/or friends (see Table 3).

Table 3. Number of Displaced Families / Persons Outside Evacuation Center

REGION / PROVINCE / MUNICIPALITY	OUTSIDE ECs			
	Families		Persons	
	CUM	NOW	CUM	NOW
GRAND TOTAL	547	547	2,673	2,673
REGION XI	547	547	2,673	2,673
Davao del Sur	547	547	2,673	2,673
Bansalan	123	123	553	553
Matanao	227	227	1,135	1,135

Note: Ongoing assessment and validation being conducted.

Source: DSWD-FO XI

III. Damaged Houses

Page 2 of 5 | DSWD DROMIC Report #3 on the Earthquake Incident in Tulunan, North Cotabato as of 18 October 2019, 6PM

DSWD Department of Social Welfare and Development

DROMIC DROMIC.DSWD.GOV.PH

There are 716 damaged houses; of which, 329 are totally damaged and 387 are partially damaged (see Table 4).

Table 4. Number of Damaged Houses

REGION / PROVINCE / MUNICIPALITY	NO. OF DAMAGED HOUSES		
	Total	Totally	Partially
GRAND TOTAL	716	329	387
REGION XI	337	177	160
Davao del Sur	337	177	160
Bansalan	126	11	115
Magsaysay	195	165	30
Matanao	16	1	15
REGION XII	379	152	227
North Cotabato	379	152	227
M'lang	5	-	5
Tulunan	374	152	222

Note: Ongoing assessment and validation being conducted.

Source: DSWD-FOs XI and XII

DSWD DISASTER RESPONSE INFORMATION

２　被害の状況（各県からの報告）

都道府県名	人的被害			住家被害					非住家被害		火災
	死者	負傷者		全壊	半壊	一部破損	床上浸水	床下浸水	公共建物	その他	
		重傷	軽傷								
	名	名	名	棟	棟	棟	棟	棟	棟	棟	件
山口県						3					
福岡県		1	16		4	251					
佐賀県		4	9			1				2	
長崎県						1					
熊本県	270	1,184	1,553	8,657	34,491	155,095	114	156	467	12,857	15
大分県	3	11	23	10	222	8,110				59	
宮崎県		3	5		2	39					
合　計	273	1,203	1,606	8,667	34,719	163,500	114	156	467	12,918	15

《参考》死者数の内訳
【熊本県からの報告】平成３１年４月１２日　１６時３０分現在
・警察が検視により確認している死者数　５０名
・市町村において災害弔慰金の支給等に関する法律に基づき災害が原因で死亡したものと認められたもの　２１５名
・６月１９日から６月２５日に発生した豪雨による被害のうち熊本地震との関連が認められた死者数　５名
【大分県からの報告】平成２９年３月２７日　１６時３０分現在
・災害弔慰金の支給等に関する法律に基づき災害が原因で死亡したものと認められたもの　３名

○その他の被害

➢原子力発電所・コンビナート等の被害情報
・川内（鹿児島県）、玄海（佐賀県）、伊方（愛媛県）の各原子力発電所は被害なし
・八代地区コンビナート（熊本県）　道路に若干の液状化あるも被害なし
・大分地区コンビナート（大分県）内の JX エネルギー㈱大分製油所の原油タンク（５基）の浮き屋根に油のにじみあり
　→措置完了（４月１６日１８時１５分）
・その他のコンビナートは被害なし

Figure 3: Left: Mindanao 2019 earthquake via DSWD-DROMIC; Right: Kumamoto 2016 earthquake via FDMA

2.5 Social Sensors, Remote Sensing and News Propagation

A major change in rapid loss estimation has occurred over the last 5 years in the quality and breadth of rapid social sensor products. Five years ago, skant information was available post-disaster with respect to social sensor and crowd-sourced projects. Work like GEO-CAN from 2010 in Haiti showed the first remote sensed damage assessments albeit with variable results.

Since then, resolution of imagery has improved markedly post-disaster, with faster systems in place in order to assess post-disaster imagery. Traditional 2D systems from satellite cannot compete with 3D views and data (see next section for the common systems)

COPERNICUS, ARIA, UNOSAT do amazing work with their methodologies. In addition, new AI methods of "damage detection" are increasing in post-disaster. Although giving an indication, the false positive rate for such methodologies creates huge errors when using these for any type of post-disaster economic or social assessment in near real-time.

Automated processes as well as trained systems also do not allow for better definition of damage as was seen in the recent Bahamas event. The same can be said for earthquakes. However, where collapse is clear, and displacement of roofs occurs with debris, then detection is often visible.

With drone imagery becoming a lot cheaper; as well as higher quality phones, high resolution pictures are provided generally within a day of an event (for an earthquake faster compared to hurricanes due to inclement weather generally). With the amount of

Instagram, Facebook, Twitter and personal account data, a plethora of imagery of high resolution is available post-disaster. Again, compared to 4 years ago, where phone battery issues were present when looking at geocoding information; photos generally have some form of location information, as well as track information. The data is generally available within 3-4 days over a platform like planet.com; nasa.gov; government websites; or ReliefWeb.

The HOTOSM community, often digitises a lot of missing polygons, roads, and other data where spatial information is missing within OpenStreetMap; as well as adding useful damage information. Monitter, individual codes like FloodTaggs, IVM, are available which aggregate relevant twitter data. In addition improved natural language algorithm systems are becoming commonplace to find relevant data.

However, there still exists the issue of false reuse, false locations, misinformation and automated errors which AI remains in its infancy. This causes a lot of false detections, often rendering large automatic detection datasets as untrustworthy. It is my hope that in 5 years I will be able to write a paper saying that the training sets and improved technology will allow for this. In reality, it will likely come down to a combination of sensor based systems for infrastructure, structural monitoring, change detection data, microsatellites and a number of new technology items like those coming out of Moonshot Factory, Facebook or some innovation labs of universities and private companies.

2.6 Secondary Effects in a post-disaster context

In terms of secondary effects globally, these have been shown to be upwards of 30% of fatalities, and 20% of economic losses by Daniell et al. (2017). However, these are the global numbers, and it is likely that a major event will not have as many secondary effects losses when looking at Australian cities. In certain locations like Adelaide, landslide and rockfalls will contribute to losses; and it can be expected that direct fault rupture, liquefaction and/or wave action may play a role.

Again, in these cases, it is the unknown for fire, police, SAR and other response services; as in many cases, the response services, will not know about secondary hazards; fake news of tsunami alerts may be present; the number of calls to switchboards will be immense, and the unknowns of aftershocks, liquefaction and landslide processes will add to the confusion.

Rapid mapping facilities of land displacement processes are currently available and these provide a detailed view of landslides and often liquefaction areas as compared to a few years ago. Planet.com; DLR; NASA ARIA; and drone products are available quickly.

The Flood Forecasting Initiative of Google has produced detailed flood analyses for various parts of the world in a post- or near real-time perspective to support their Public and SOS Alerts facilities, however it is the 1m DEM produced from combinations of aerial, satellite and machine learning; which provides the possibility for detailed ground displacement analysis in the aftermath of an event. This may be important if such an issue like 1968 Meckering occurs where the ground displacement caused flooding in the aftermath. It may also be useful should there be a compound or concurrent event for a multi-hazard context (see NARSIS-EU; MATRIX; Gill et al., 2014 or de Ruiter et al., 2019).

2.7 Airports, ports and other critical facilities

In cases of smaller islands, and locations which are often inaccessible with only a single airport; damage to these facilities can cause major issues. Generally this information is transmitted via social media and/or personnel to official sources meaning that pictures of critical facilities can be seen a lot faster than in the past. Remote analysis of multi-directional imagery by engineers, can thus support the assessment of critical facilities remotely, often in a walkdown survey quality. 3D imagery for specific buildings has been reconstructed in the last few years for events like Taiwan with the collapse of the Golden Dragon Building, allowing engineers globally to hypothesise about the failure mechanism.

The other advancement of the past few years is high-resolution video from smartphones. After events, or even during events, depending on the time of the event, there are 10s to 100s of videos from the event. Although the videos are often from different locations, georeferencing allows for a quick view of shaking, and as image analysis improves, this will provide the first pass loss estimation for a PDNA style assessment (with the uncertainties which come with it).

Rapid aftershock seismometer deployment would likely be done in less than 24 hours, for a very large disaster, accounting for potential airport damage, driving times and other issues, but in most cases there are redundancies expected with it being unlikely that all road, rail, air and ship options are out of order.

In neighbouring island countries, the port and airports play a larger role than in Australia; where a mixture of road, airport and port options occur. An Australian event may hit one major Australian city, but it would likely not affect all cities directly around Australia. Thus, aid, support, engineers, SAR support could be called on from these locations; with a maximum (with the exception of Perth) of 8-10 hours to get support.

Having a detailed and up to date GIS, excel and listing of each critical facility is important and to be able to account for them quickly is essential post-disaster, which brings us to the post-disaster datasets, modelling and frameworks required in the post-disaster phase.

3 Post-disaster datasets and modelling

3.1 Exposure and vulnerability datasets

Huge steps have been made in the last years with the NEXIS Exposure databases and work at Geoscience Australia and within academia to create exposure models such as the ANHEF and AEIP (Nadimpalli et al., 2018). Outside of Australia, open data initiatives are present in most countries, with much information from census and surveys feeding in to GIS calculations. However, there are still significant uncertainties on the economic replacement cost side; due to post-disaster demand surge, different building standards, quality of construction, unknowns as to materials; as well as the unknowns of the existing stock.

Given the lack of large scale catastrophes in Australia; demand surge is likely to be one of the key drivers of uncertainty. Depending on the shortage of skilled laborers and the need for large scale civil infrastructure repairs, it is likely there will be this demand surge. Another issue that will occur will be the influx of workers from other capital

cities and the need to house and document these workers. Depending on the context, a lot of undocumented work occurs post-disaster and it is important to have a method to account for such building changes. Generally in Australia, this is done through the local council, however in the worst affected councils, the procedures where there are usually only 10 to 15 modifications per week to houses; may skyrocket to the 1000s. For adherence to building codes this is one of the most important issues; along with post-disaster survey and upkeep of the post-disaster situation.
Various methodologies have been employed around the world in post-disaster settings, and lessons can be learnt from Christchurch with the implementation of the 33%, 66% and 100% of code in the aftermath; as well as the used of skilled engineers adhering to code. In a post-hurricane setting, examples from the Bahamas in September show the difficulty where rapid repairs are undertaken in non-commercial settings to ensure shelter is available with inclement weather. On the other hand, commercial facilities want to get back in business as quickly as possible and thus reconstruction is often made with substandard materials; or with untrained personnel without a formal approval process. Because a building may have previously been approved; the changes are often not traceable.
Using methodologies like Gunasekera et al. (2015) can aid the quantification of capital stock; in addition to using the formal calculations via investment compared to UCCs. Non-structural and contents data is of course uncertain, but compared to many countries there is less uncertainty. The further that Australia can get in quantifying and documenting building stock at LOD2, LOD3 and LOD4 (levels of detail) where a building modification can be traced; the better a council will be able to cope post-disaster. Further checks of the AEIP could be made along these methodologies.
Although talking about the building stock is important; and/or the critical facilities; the temporal dynamics of population play a key role in any fatality model. The time of day was clearly a factor in 1989 Newcastle, with 13 deaths occurring instead of potentially hundreds was the collapsed Worker's club full at the time (Carr et al., 1997). However, in the next disaster, it may occur at 12pm or 12am; 3pm or 3am and high quality estimation methods are required. Geoscience Australia has done some work on this in the past publications of Fulford et al. (2002) among others, and Daniell et al. (2017), Tsang et al. (2018) have also developed time-sensitive fatality functions; however given the seasonal, weather, and sport related dynamics of population among other things, a dynamic population model like that of Facebook at a very high resolution is needed, or using data such as Twitter aggregation and/or Flowminder style applications. In a post-disaster context it has been seen that this can affect the fatalities by a factor of five or more in both directions (Nepal 2015; Great Alaska 1964; Tangshan 1976 disasters).

In terms of physical vulnerability, the natural starting point is Maqsood et al. (2016), Ryu et al. (2013), Edwards et al. (2004), Edwards et al., (2019), Ingham and Griffith (2011).

3.2 Post-disaster damage assessments

One of the key issues that has been seen in natural hazards events of the past years is the lack of trained engineers in the post-disaster environment for damage assessment, tagging and subsequent reconstruction. In the post-disaster aftermath, if an event hits a major city in Australia, upwards of 200,000 residential buildings may need tagging. However, it is not just the buildings which are the issue. Infrastructure, public buildings, commercial and industrial facilities and importantly large loss and critical facilities often need to be prioritised with specialised assessment. Given problems of debris, search and rescue, as well as aftershocks; the damage classification often needs multiple attempts and updates meaning a significant delay due to reassessment.

Groups such as SARAID, EEFIT, EERI have trained engineers who are skilled in post-disaster damage classification need to be organised ahead of time, to ensure that the right number of engineers is available. In addition, a training program for local engineers in multi-hazard damage assessment has proved useful in many countries before events – Philippines, Colombia, Chile. This could be as simple as a 2 day damage detection course or an e-learning course which could accredit engineers for the post-disaster phase.
Knowledge as to secondary effects and checks in aftershock environments need to be undertaken as commented upon earlier.

3.3 Insurance and Government Payouts

In terms of risk assessments, key datasets can be established in the aftermath of the earthquake. A systematic collection methodology via drone, walkdown survey and other methods is needed with government support payouts tied to such collections. In this way, access to all infrastructure can be established.
In order to establish a damage estimate for an individual building, there is often a large difference depending on the insurer, policy details and assumptions made. Similarly a scaling up of the uninsured vs. insured portion of the "assumed exposure" is an easy way of calculating a rapid estimate, however often leads to large differences given the varied damage ratios over a certain insured portion and non-insured portion; and the aforementioned estimator uncertainties.
Governments need to know the private vs. public portion; however it is difficult to estimate such portions quickly post-disaster due to the complex interweb of PPP (public-private partnerships), and different interconnected parts of networks with respect to investment. The gross fixed capital formation associated with each portion and the capital stock associated with such portions of GFCF contribute to the final GCS. The information post-disaster is often swayed in the direction of "insured losses" or these aggregate estimates via risk modelling firms post-disaster often including business interruption and an unknown distribution of capital stock based on partial portfolios (usually buildings). As will be seen in the next section, the sectoral losses of major earthquake events differ greatly around the world and thus such estimates are to be taken with a grain of salt. The effect of disaster levies and taxation in the post-disaster phase needs more research, with macroeconomic methods still needing better models.

3.4 GRADE, PDNA and other post-disaster recovery estimates

This Methodology Note was prepared to inform governments and other key stakeholders who are involved in post-disaster damage assessment, relief, and recovery phases about the utility and outputs of the GRADE approach. To prioritize and plan for overall reconstruction and specific interventions, stakeholders require approaches that provide a more in-depth assessment, with an engineering focus, than GRADE provides. However, before in-depth assessments are undertaken, it is critical to build the required sectoral baseline information for the design of rehabilitation and reconstruction plans. The GRADE approach provides this information, as it is based on an assessment of vulnerability and damage distribution of the affected infrastructure and assets.
This report presents the overall methodology approach (Figure 4) in GRADE's four components—Hazard, Exposure, Vulnerability, and Loss Modeling—and discusses implications for World Bank staff, clients, and other stakeholders. The report closes with extended appendices that present the development team's experience using GRADE after four recent major disasters and a summary of other post-disaster damage assessment approaches.

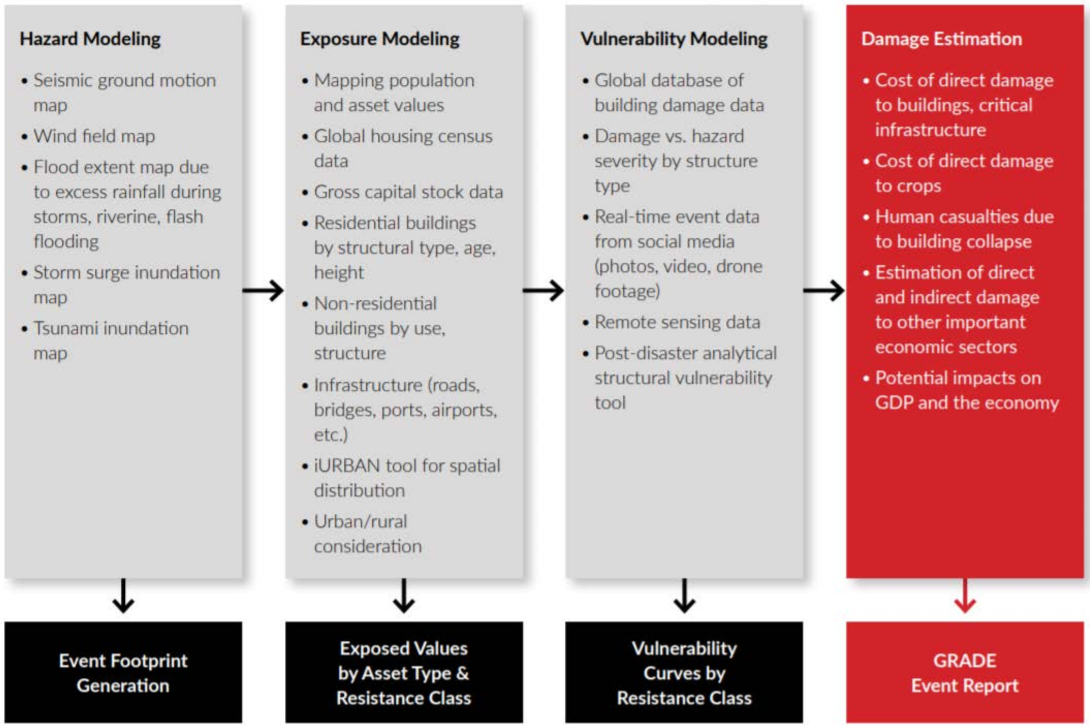

Figure 4: The components of a GRADE (Global Rapid Damage Estimation Approach)

PDNA (Post Disaster Needs Assessments) are based on a more in depth sectoral analysis of damages and is generally undertaken in the 2-6 month period post-disaster (methodology report links will be included in the archive).

4 Sectoral Analyses and a view based on the 1989 Newcastle Earthquake

As has been said in many previous presentations on the 1989 Newcastle, it is extremely difficult to ascertain the total economic costs associated with the event (Table 2).

Table 2: Estimates for the Newcastle 1989 earthquake in terms of economic losses.

Reference	Economic Loss Estimates	Additional Comments
NCC (Website)	$4bn AUD	
McAnaney et al. (20199	$4.244bn AUD in 2019 normalised	NORMALISED estimate of insured portion of losses.
Deloitte Access Economics	$8.5bn AUD in 2015 dollars with $10.2 bn AUD intangible costs	
Deloitte Access Economics	$3240m AUD in 2011 (Insured)	
Ladds et al., 2017	$2016m AUD (time of event)	Time of event losses
GEMECD, 2013	$1200m USD (inc. $670m insured via Munich Re) (1989)	NSW government via heritage (direct)
GEMECD, 2013	$3200m AUD (2001)	BTE (direct)
Daniell, 2010	$3246m AUD (1650m-4000m)	Total economic losses
Walker, 2010	$1000-1500m AUD (1989) - $2000-3000m AUD (2009)	
IDRO, 2002	$684m insured loss (2002)	
Sinadinovski, 2005	$862m AUD insured in 1990 dollars	
BTE, 2001	$4500m AUD	2001- report_103
SwissRe Sigma, 1989	“at least $792m USD” total, and “at least $475m USD” insured	

NGDC	$1100m USD ($1400m AUD)	
EM-DAT	$1000m USD ($1270m AUD)	
Tiedemann, 1990	As high as $1.5 billion AUD	Sydney Newspaper (1 day after)
Tiedemann, 1990 Assumption 1	$200-300 million AUD building damage	SwissRe
Tiedemann, 1990 Assump. 2	$360 million AUD building damage	
Time Magazine, 08.01.1990	$1.5 billion AUD rough insured losses thus over $2 bn AUD	

*I have not included all Tiedemann 1990, Blong 1992, Irish 1992 estimates
*many commercial and industrial enterprises were not insured for business interruption
*AUD 4.3 billion (Risk Frontiers, Australian and New Zealand Institute of Insurance and Finance Journal in 2007) to AUD 6.2 billion (AIR, Flyer on Earthquake Model for Australia in 2012) or USD 3.8 to 5.4 billion.

More work will be needed to do an in-depth study of the Newcastle earthquake, using consumer price indices for housing whatever the dollar amount of losses in 1989 was, it would be 2.27 times higher in today's dollars. Using consumer price indices for Sydney it would be 2.1 times higher. Domestic capital would be in the order of 1.9 times higher, and labour costs in the order of 1.94 times higher, unskilled wage being in the order of 2.07 times higher. All this leads to a Newcastle 1989 economic cost in 2019 terms being in the order of 2 times higher than whatever the original value was of between $1-4bn AUD. McAnaney et al. (2019) provide a normalised estimate of $4.244bn for the event – meaning a potential loss would be ca. 5 times higher with today's exposure using their methodology vs. the original $862mn.

Sectoral losses have been stated previously are extremely important when it comes to post-disaster investment, budgets and timeframes for the recovery and reconstruction. Various methodologies for post-disaster needs assessment have been put forward with the PDNA from the tripartite agreement generally the preferred methodology. The DALA by ECLAC (2014), and other methodologies are included in the GRADE; but for direct losses can be broadly placed into the 5 categories of residential buildings, other buildings, infrastructure, productive sectors and cross-sector losses (Figure 5 for previous events). BTE (2001) as has been explored in previous papers, also put forward a similar framework for counting economic losses in their report with various sectors for direct, indirect and intangible costs associated with an event including the use of NDRRA (National Disaster Relief and Recovery Arrangements) numbers for determining infrastructure impact. In the direct aftermath of the event this is difficult but for long term analyses such a methodology may work for the determination of the losses to services of infrastructure (essential public assets – roads, Road infrastructure (including footpaths, bike lanes and pedestrian bridges, Bridges, Tunnels, Culverts, Public Infrastructure, Public hospitals, Public schools, Public housing, Prisons/correctional facilities, Police, fire and emergency services' stations, Levees, State/territory or local government offices, Stormwater infrastructure). The onset of NDRRA payments is difficult to determine in rapid onset thus would have limited use in the post-disaster quantification (the theme of this paper), but is a useful mechanism for alleviating the state burden of a future earthquake given the likelihood that the direct effects will mostly be borne by one state. The 'Disaster Recovery Funding Arrangement' (DRFA) has replaced the process with much the same methods since November 2018 (Scott, 2018).

The " Building our Nation's Resilience to Natural Disasters" work by Deloitte in 2013 and 2017 does detail a methodology along the lines of BTE (2001) to determine the economic cost of disasters with some overlap with the PDNA methodology, however, in the end they use the same methodology as the reinsurers by just multiplying "Insurance Council of Australia" losses by the uninsured portion, thus mimicking reinsurance estimates or even worse where a multiplier of 4 is simply used without major justification.

SIFRA (http://geoscienceaustralia.github.io/sifra/index.html) (System for Infrastructure Facility Resilience Analysis) has been developed from the component level of certain critical infrastructure (Rahman and Edwards, 2015) in order to examine the sequential damage states associated with the earthquake and is compatible with the work done during the SYNER-G project in Europe on buildings and infrastructure network systems with regards to micro and macro components. This is very important with regards to restoration of the networks themselves as these are generally done piecewise.

The EIRAPSI project has put forward numbers for 7 scenarios in WA (Edwards et al., 2019) as a good first step to examining some parts of the earthquake risk and their consequences in the aftermath of a large event such as building damage (including local building types – Vaculik et al., 2018) and homelessness, casualties, transport (bridge and tunnels), electricity (transmission), and water pumping facilities and pumping stations including some cross-sector issues. It is as far as this author can see, the first published attempt to openly model a number of components/asset types of the PDNA methodology simultaneously in Australia creating meaningful scenarios for emergency management.

A good question is, when is a loss a loss, and the difficulty of measuring the losses post-disaster where many estimates are present based on often very different economic capital and vulnerability baselines. Many baselines can be ported from other disaster types such as flood, tropical cyclones etc., so learning from other disaster types is key.

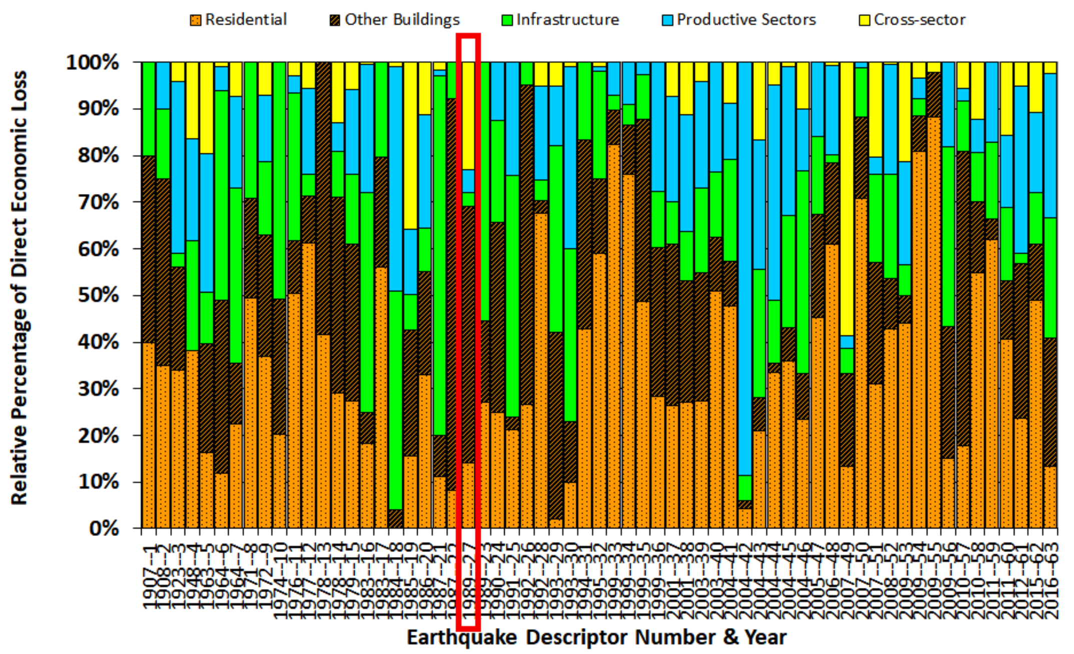

Figure 5: Sectoral direct losses of previous major earthquake events where available including an estimate of Newcastle 1989 (sources to be added in an online archive as stated below)

In the interests of not making this paper into a novel, the AEES papers from the last 30 years of conferences where I can see a "lessons learned" for Newcastle and post-disaster damage assessment in Australia will be characterised with ontology and taxonomy in a freely accessible and extendable online archive to be published early in 2020 (hopefully through AEES pending discussion) along with the component parts needed to be compatible with a GRADE or PDNA (with appropriate links to unportable products).

5 Conclusions and Needs Assessments

This review into post-disaster practices in Australia with a particular focus on earthquakes has attempted to identify some of the key issues and challenges in the post-disaster phase within a potential Australian earthquake.

There is a lot of good work being done in the last few years within the BNHCRC work which provides a significant advancement in this field as well as for the AEIP, however, there also exist some key potential gaps for research and implementation in the next few years.

A focus on key infrastructure components can be seen in present studies (Rahman et al., 2019, this conference), following on from work done in SIFRA and EIRAPSI projects. Key studies into each sector across Australia could provide prioritisation studies for potential improvement, along the lines of work done in the Global Program for Safer Schools or other such initiatives.

It is very promising that WA via EIRAPSI, Queensland and NSW via QFES and I am assuming others, have been working on in-depth scenarios with Geoscience Australia and other universities. A combined private-public study would potentially allow for a more holistic study into the after effects of major earthquakes, especially with regards to financial quantification. With the large number of private schools and hospitals it is important to take the dynamics of this into any public study and any gamification of such disasters.

Much of this paper can of course be applied to locations outside of Australia, which of course are either covered under GRADE or existing methodologies. The identification of the problem of sufficient trained engineers, SAR, and availability of NZ colleagues and responders is extremely important for recovery and is already being identified as part of EIRAPSI etc., however is one problem that needs to be further addressed in order to reduce downtime and long-term consequences.

Issues in the aftermath such as social input, political change, misinformation, international data sources and resolution have been presented above, along with existing issues identified in Australian papers.

Much work can hopefully be done taking stock of the current risk assessments around Australia, and increased work into harmonisation of socioeconomic losses for disasters historically. Adequate social media auditing and seismological integration linked to the other major agencies to ensure coherence of the story nationally and abroad is key in the future to make sure that the preferred models and data are actually the ones being used in practice which in this day and age is by no means a given.

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