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COST-EFFECTIVE MITIGATION STRATEGY DEVELOPMENT FOR BUILDING RELATED EARTHQUAKE RISK

Reporting on Economic Loss Models

Itismita Mohanty, Mark Edwards, Hyeuk Ryu and Martin Wehner
Geoscience Australia
Bushfire and Natural Hazards CRC

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EXECUTIVE SUMMARY

This report forms part of the output from Project A9 entitled "Cost-Effective Mitigation Strategy Development for Building Related Earthquake Risk" within the Bushfire and Natural Hazards Cooperative Research Centre.

Earthquakes have the potential to cause widespread damage to Australian communities and the economic activity that occurs within them. Recent earthquake events have illustrated this, including the Newcastle Earthquake (1989) and the Kalgoorlie Earthquake (2010). This potential is largely due to the fact that much of the Australian building stock has not been designed nor constructed with adequate consideration of earthquake hazard.

Mitigation intervention is needed to reduce this risk but an evidence base is lacking to inform investment. In particular, there is a need for economic measures of the benefits of retrofit as an offset to the sometimes large costs of upgrading structures for earthquake. This need exists in many other countries.

As part of this research an extensive literature review has been published to inform the best approach for assessing the costs of business interruption and the losses associated with injury and death. Frameworks have also been developed for a range of Australian decision makers. Decision makers include building owners, owners of both business premises and the business within, local government, state government and national government. The scale of decision making metrics range from individual building level up to business precinct level exposures and the interdependence of building performance within them. The information and models required as inputs into the framework have been identified along with how these will be met, either with outputs from this CRC project, or from other sources.

This report builds on the previous work and provides the experimental estimates for different components of economic loss that might occur in the event of an earthquake scenario. These are specifically business income loss, rental income loss and health care expenditure. The report considers these in the context of the future Greater Melbourne region (excluding Mornington Peninsula) as a case study.

Current research on the economic loss modelling is on track. Future work will estimate the actual business interruption loss values for assessing precinct level economic activity disruption.

INTRODUCTION

The CRC Project A9 entitled "Cost-Effective Mitigation Strategy Development for Building Related Earthquake Risk" is seeking to address the need for an evidence base to inform decision making on the mitigation of the earthquake risk posed by vulnerable Australian buildings. It aims to develop information related to more vulnerable Australian building types in the following areas:-

- retrofit strategy options for high risk buildings to reduce their vulnerability;
- the current and retrofitted performance of these buildings;
- the cost of implementing the retrofit strategies; and,
- the ability to assess the benefit of avoided societal costs through the implementation of these strategies.

This report describes progress made against the last component which is directed at economic loss modelling.

The economic loss modelling approach aims to encompass the information needs of a range of decision makers. These view benefits through different "lenses" and at differing scales. For this research they include:-

- Building owners.
- Owners of both the building and business.
- Local Government for a business precinct.
- Jurisdictional and Federal Governments and their additional interest in economic loss associated with health care and lost productivity.

In this report a background will is provided to the nature of the economic losses in business precincts and the scope of this framework. The report further describes the approach to business, rental and health care costs in the context of the forthcoming Melbourne city case study. This report corresponds with the 31 Dec 2015 project milestone deliverable "Reporting on Business Resilience Models".

PROJECT BACKGROUND

Earthquake hazard has only been recognised in the design of Australian buildings since approximately 1995. This oversight has resulted in the presence of many buildings within communities that currently present a high risk to property, life and economic activity. These buildings also contribute most of the post-disaster emergency management logistics and community recovery needs following major earthquakes. This vulnerability was in evidence in the Newcastle Earthquake of 1989, the Kalgoorlie Earthquake of 2010 and with similar building types subject to the Christchurch Earthquake of 2011. With new building construction representing 1.8% of the building stock nationally (ABCB 2014), the legacy of high risk buildings persists in all cities and predominates in most business districts of lower growth regional centres.

The two most vulnerable building types that contribute disproportionately to community risk are unreinforced masonry and low ductility reinforced concrete frames. Damage to these not only leads to direct repair costs but also to injuries and disruption to economic activity. This research project is drawing upon and extends existing research and capability within both academia and government to develop information on these that will inform policy, business and private individuals on their decisions concerning mitigation. It will also draw upon New Zealand initiatives that make use of local planning as an instrument for effecting mitigation. The Wellington City Council Resilience Program is an exemplar of this that has progressively resulted in the retrofit of a large proportion of earthquake prone unreinforced masonry buildings in that city. Other New Zealand cities have retrofitted vulnerable buildings. Figure 1 is of a two storey reinforced concrete frame building with unreinforced masonry infill in Napier. The city experienced a devastating earthquake in 1931 and this building was part of the extensive rebuild of the central business district (CBD) that took place in the 1930's. Ductile steel moment frames have been added to strengthen the structure in the transverse direction.

Project A9 has six key elements of research that are being progressed sequentially:-

1. Australian building stock vulnerability classification (completed).
2. Review of existing retrofit options (completed).
3. Development of Australian specific retrofit options (in progress).
4. Economic loss model development (in progress).
5. Benefit versus cost analysis of retrofit options
6. National assessment of retrofit needs.

Research on the fourth component draws upon international research and aligns with an earthquake impact and risk modelling capability developed by Geoscience Australia for use in elements 5 and 6.

Figure 1: Ground floor view of retrofitted two storey retail structure of the 1930s period in Napier, New Zealand. The building is of poorly detailed reinforced concrete frame construction with unreinforced masonry infill walls. Ductile steel moment frames have been retrofitted to strengthen the structure in the transverse direction.

NATURE OF ECONOMIC LOSSES IN BUSINESS PRECINCTS

The severe ground shaking that accompanies earthquake can cause physical damage to buildings. This has an attendant repair cost or, in a very severe event or with very vulnerable buildings, may require demolition and complete reconstruction of the damaged building.

The severity of physical damage has implications for the use of the building. Minor cracks and dislodgment of non-structural elements may permit full use of the structure post-earthquake, whereas more severe damage may limit or preclude access. Where the use of the building includes business activity, the resultant disruption to turnover adds to the economic loss. This impact may extend to businesses in less damaged adjacent structures where damage cordons impact their building access.

The contents of buildings can also be damaged in an earthquake. In high seismic regions of developed countries restraint is often provided to contents that can topple but this is not a common practice in Australia. Floor accelerations can overturn furniture and damage fit-out. On upper floors this can be more significant as the response of the building to ground motion accentuates the floor motion. Where a building sustains partial or complete collapse, direct damage to contents will also result.

Building damage also translates into deaths and injury to occupants. It is recognised that "earthquakes don't kill people, collapsed buildings do," (https://www.unops.org/english/News/Pages/Earthquakes-dont-kill-people-collapsed-buildings-do.aspx#sthash.oLoV6vEu.dpuf). Earthquake triggered landslide deaths aside, the performance of poorly designed and/or built structures directly affects occupants. This has an insidious aspect in that it is the human contribution to our built environments that has the greatest negative influence on human safety. Medical care requirements and lost productivity caused by recovery from injury, disability or death represent a further economic cost.

Utility and supply chain issues can also affect business turnover. Loss of electricity, water, sanitation, telecommunications and gas supply can render some business premises unusable. Lack of material supply to the business or the inability to dispatch goods can also disrupt business activity and cause economic losses.

Other costs often unquantified for mitigation investment include the greater cost of emergency response, the cost to effect clean-up and Government financial assistance to a range of recipients to promote community recovery.

SCOPE OF THIS REPORT

The previous report (Mohanty et al, 2017) on this research presents a literature review on earthquake related economic loss modelling and identified the precinct level direct economic costs that are considered practically computable such as the direct business interruption costs, rental income loss, direct health care cost and casualty costs to society from injury and loss of life.

Mohanty et al (2017) develops an economic loss modelling framework that is implementable in estimating a range of earthquake related economic costs that are identified and included in the scope of this project. The Report specifically presented a pragmatic framework and approach for which the information requirements are tractable for the above identified costs. The underpinning datasets that will be used to populate the respective modeling approaches were also described in detail.

As a progression of earlier work, this report presents the outcome of a trial run for the modelling approach developed in Mohanty et al (2017) and provides the experimental estimates for some components of the above identified economic costs such as the business interruption costs, rental income loss and the direct health care cost. The report considers the Greater Melbourne (excluding Mornington Peninsula) region as a case study.

BUSINESS INCOME LOSS

Based on the available input data sets and earthquake scenario modelling capability in Australia, Mohanty et al (2017) has identified that it is potentially possible to functionally link individual incomes in a geographical region in different employment types such as: Proprietary income or Wage/salary income to different earthquake severity level, building type, building damage state, and business interruption period and estimate the income loss at a regional level that might incur in an earthquake scenario. In this report the income losses are estimated as the product of the number of persons having that employment type in each industry, proportion of businesses affected in each industry by damage state and the business interruption period in each industry for each damage state.

The following equation presents Proprietor's income losses in regions (small areas) as:

$$PY_j = INC_i * N_j * \sum_{ds=1}^{5} PBINDS_{ds,j} * \sum_{ds=1}^{5} BIP_{ds,j}$$

PY_j	Proprietary income loss in industry sector j
INC_i	Average Individual proprietor income in industry sector j
N_j	Number of proprietors in industry j
$PBINDS_{ds,j}$	Probability of a business in industry j being in structural damage state ds
$BIP_{ds,j}$	Business interruption period for a business in industry j and damage state ds

This report estimates the wage/salary income loss in regions in the case of an earthquake scenario event.

The following section describes the methodology and presents the experimental estimates for earthquake related Business Interruption Costs in in the Greater Melbourne (excluding Mornington Peninsula) region as a case study, in the event of an earthquake scenario in Australia.

Geographical Area

The geographical unit of analysis are Census (ABS, 2011) Statistical Area Level 4 (SA4s) and used ABS Census *Place of Work* (POWP) statistics for estimating employment related income loss in Greater Melbourne (excluding Mornington Peninsula). Statistical Areas Level 2 (SA2s) forms the smallest unit for which the ABS publishes *Place of Work* (POWP) statistics. Place of Work data provide information on where a person goes to work. The address of the person's workplace in the week prior to Census Night is coded to a Destination Zone using an index provided by the State Transport Authorities. While it was proposed in the previous report (Mohanty et al, 2017) that the future work as part of this project will consider SA2s as the geographical unit of analysis for estimating the actual business interruption loss values for assessing precinct level economic activity disruption, in producing this experimental estimates this report considers eight SA4 in the Greater Melbourne (excluding Mornington Peninsula) region for analysis. They include

1. Melbourne – Inner
2. Melbourne – Inner East
3. Melbourne – Inner South
4. Melbourne – North East
5. Melbourne – North West
6. Melbourne – Outer East
7. Melbourne – South East
8. Melbourne – West

Income by Employment and Industry

In Australia for employed persons in their primary jobs Census (ABS, 2011) contains information on number of employed persons in different wage/salary brackets by their *industry of employment* and *employment types*.

Industry of Employment

Census uses the Australian and New Zealand Standard Industrial Classification (ANZSIC) 2006 (1292.0) (Australian Bureau of Statistics, 2006) that have been jointly devised by the Australian Bureau of Statistics and Statistics NZ. This classification is a hierarchical classification with four levels, namely, Divisions (the broadest level), Subdivisions, Groups and Classes (the finest level). In total, there are 19 divisions specified under ANZSIC (for details please refer Mohanty et al, 2017).

Geoscience Australia's Modelling capability producing the number of affected businesses for different earthquake severity levels, building damage states with their conditional probability of exceedance in each industry sector. To facilitate data matching between these and the Census income categories, the 19 industry divisions of the latter were combined into the three broad industry sector categories of primary, secondary and tertiary industries.

Employment Types

The Census *Employment Type* categories include:

1. Employee not owning business
2. Owner managers of incorporated enterprises
3. Owner managers of unincorporated enterprises
4. Contributing family workers
5. Not stated
6. Not applicable
7. Overseas visitor

Following FEMA (2003), Mohanty et al (2017) scopes to estimate loss in income in the following categories

1. Loss of income for the owners and managers of incorporated enterprises.
2. Loss of income for the owners and managers of unincorporated enterprises.
3. Loss of income for employees not owning business.

In this process the first two categories represent the loss in proprietary income and third category represents the loss in wage/salary income.

<u>Conditional Probabilities of the Earthquake Affected Businesses</u>

The *ABS National Regional Profile* contains information on the number of businesses in each industry sector in the regions. *Geoscience Australia's Modelling capability* will produce the number of affected businesses for different earthquake severity levels and building damage (Robinson et al, 2005). However, at this stage, the GA modelling capability has yet to come up with these conditional probabilities. In this report for experimental purpose a range of conditional probability estimates have been devised to produce income loss estimates in the Greater Melbourne (excluding Mornington Peninsula) region for a feasibility check of this methodology.

Using the total and earthquake affected numbers the report estimates the proportion of businesses affected in the regions in each industry, damage state and quake occurrence levels. The *proportions of businesses affected in each* of the above categories are applied to the *number of employed persons in those categories* to estimate the number of affected employees and owner managers of businesses.

Business Interruption Time

The next step for estimating earthquake related business income loss in these regions is to estimate the business interruption time. This corresponds with the number of days/weeks businesses in each industry sector would cease operation. The GA modelling capability is yet to simulate these estimates (please see Mohanty et al, 2017), the range of time periods for which a proportion of businesses in each industry will cease operation. These time periods will then be applied to estimate the total wage/proprietor's income loss in 2011, which would be subsequently adjusted to 2017/18 dollars. These would be used for estimating the actual business interruption loss values for assessing precinct level economic activity disruption in our subsequent final report. However, in this report we have estimated the business interruption cost for an average week.

Estimating Income Loss

The total personal weekly income ranges and mean values in Census with their mean values are presented in Mohanty et al (2017). The mean weekly income values in each income bracket and in each employment and industry division are multiplied with the number of affected employees/owners/manages (estimated above) and the total weekly loss in income in each employment category and quake severity level are estimated.

The following Tables 1-3 present the estimates of potential business interruption income loss in categories of proprietary income loss - owner Managers of Incorporated/Unincorporated Enterprises, and wage/salary income loss in the Greater Melbourne region (excluding Mornington Peninsula) for earthquake scenario events in Australia having different seismic intensity levels.

Table 1: Estimated Weekly Loss in Income: Owner Managers of Incorporated Enterprises (2011-12, AUD$)

Seismic Intensity Level	Proportion affected in Secondary Sector (Imaginary Values)	Estimated Income Loss in Secondary Sector	Proportion affected in Tertiary Sector	Estimated Income Loss in Tertiary Sector
sil1	0.35	12,598,940	0.25	29,987,860
sil2	0.28	10,079,150	0.18	21,591,260
sil3	0.27	9,719,180	0.17	20,391,750
sil4	0.26	9,359,210	0.16	19,192,230
sil5	0.25	8,999,240	0.15	17,992,720
sil6	0.23	8,279,300	0.13	15,593,690
sil7	0.20	7,199,390	0.10	11,951,440

Table 2: Estimated Weekly Loss in Income: Owner Managers of Unincorporated Enterprises (2011-12, AUD$)

Seismic Intensity Level	Proportion affected in Secondary Sector (Imaginary Values)	Estimated Income Loss in Secondary Sector	Proportion affected in Tertiary Sector	Estimated Income Loss in Tertiary Sector
sil1	0.35	6,116,280	0.25	18,408,410
sil2	0.28	4,893,030	0.18	13,254,060
sil3	0.27	4,718,270	0.17	12,517,720
sil4	0.26	4,543,520	0.16	11,781,380
sil5	0.25	4,368,770	0.15	11,045,050
sil6	0.23	4,019,270	0.13	9,572,370
sil7	0.20	3,495,020	0.10	7,363,650

Table 3: Estimated Weekly Loss in Wage/Salary Income (2011-12, AUD$)

Seismic Intensity Level	Proportion affected in Secondary Sector (Imaginary Values)	Estimated Income Loss in Secondary Sector	Proportion affected in Tertiary Sector	Estimated Income Loss in Tertiary Sector
sil1	0.35	91,127,790	0.25	304,512,670
sil2	0.28	72,902,240	0.18	219,249,140
sil3	0.27	70,298,590	0.17	207,068,620
sil4	0.26	67,694,930	0.16	194,888,110
sil5	0.25	65,091,280	0.15	182,707,610
sil6	0.23	59,883,980	0.13	158,346,580
sil7	0.20	52,073,030	0.10	121,805,070

RENTAL INCOME LOSS

Mohanty et al (2017) presents a modelling approach to estimate rental income loss in small areas/regions for an earthquake scenario. The rental income loss, distinct from temporary accommodation costs, includes the rental income lost to the owners of residential, commercial and/or industrial properties in the region. For estimating the rental income loss in the Greater Melbourne (excluding Mornington Peninsula) region, following are the two basic information requirements.

- The proportion of rental or owner occupied properties in the total residential/commercial/industrial dwellings in the region
- The sum of average weekly/monthly rent paid in each category

Based on input data availability, this report specifically focuses on rental income loss from residential occupied private dwellings. The ABS 2011 Census - Counting Dwellings, Place of Enumeration data is used. The data is customised for the eight SA4s in the Greater Melbourne region classified by the Dwelling Type, Tenure Type and Weekly Rent in Dollars. As Census does not contain tenure and rental information on commercial and industrial dwellings in Australia, the scope in this report is limited for estimating rental income loss in those categories.

Following Mohanty et al (2017) rental income loss in these regions is estimated as a product of number and types of dwelling in the region, proportion of rental properties in each category, average weekly rent by dwelling type and the rental interruption time for each damage state.

The following equation presents rental income losses in regions (small areas) as:

$$RY_i = PR_i * \sum^{j}_{j=1} (N_j * R_j) * \sum^{5}_{ds=1} PDWOCDS_{ds,j} * \sum^{5}_{ds=1} BIP_{ds,j}$$

RY_j	Rental income loss for occupancy class i
PR_i	Proportion Renting in occupancy class i
N_j	Number of properties in dwelling type j and occupancy class i
R_j	Average weekly rent paid in dwelling type j in occupancy class i
$PDWOCDS_{ds,i}$	Probability of dwellings in occupancy class i being in structural damage state ds
$BIP_{ds,i}$	Rental interruption period for a property in occupancy i and damage state ds

The total rental income loss estimation in the Greater Melbourne region is simplified to only one occupancy class - residential.

Dwelling Structure

The Census 2011 dwelling type categories include

1. Separate house
2. Semi-detached, row or terrace house, townhouse etc with one storey
3. Semi-detached, row or terrace house, townhouse etc with two or more storeys
4. Flat, unit or apartment in a one or two storey block
5. Flat, unit or apartment in a three storey block
6. Flat, unit or apartment in a four or more storey block
7. Flat, unit or apartment attached to a house
8. Caravan, cabin, houseboat
9. Improvised home, tent, sleepers out
10. House or flat attached to a shop, office, etc.
11. Not stated
12. Not applicable

In this report in order to facilitate data matching with GA's modelling capability the above more detailed classifications are grouped into the following four broad categories.

1. Separate House
   - 1.1 Separate house
2. Semi-detached, row or terrace house, townhouse etc. with
   - 2.1 One storey
   - 2.2 Two or more storeys
3. Flat or apartment
   - 3.1 In a one or two storey block
   - 3.2 In a three storey block
   - 3.3 In a four or more storey block
   - 3.4 Attached to a house
4. Other dwelling
   - 4.1 Caravan
   - 4.2 Cabin, houseboat
   - 4.3 Improvised home, tent, sleepers out
   - 4.4 House or flat attached to a shop, office, etc.

The dwellings in *Not Stated* categories are proportionately distributed among the other categories. There is no positive number of dwellings allocated to *Not Applicable* category in Census, consequently that category has been excluded from the analysis.

Tenure Type

The Census contains information about housing tenure - if the dwelling is

1. owned outright,
2. owned with a mortgage,
3. being purchased under a rent-buy scheme,
4. rented,
5. occupied rent free,
6. occupied under a life tenure scheme,

7. Other.

For the purpose of residential rental income loss estimation the information requirement is whether a person pays rent for where they live compared to whether he or she owns the place, pays mortgage or any other tenure type. Consequently, the above detailed classifications are grouped into the following three broad categories.

1. Pays Rent
   - 1.1 rented,
2. Pays Mortgage
   - 2.1 owned with a mortgage
   - 2.2 being purchased under a rent-buy scheme,
3. Pays Neither
   - 3.1 owned outright,
   - 3.2 occupied rent free,
   - 3.3 occupied under a life tenure scheme

Weekly Rent in Brackets

The Census also asked how much the household paid in rent or mortgage per week as a continuous variable and in weekly rental/mortgage payment brackets. The rent payment brackets and its mid values are presented below in Table 4.

Table 4: Weekly Rent Payments

	Rent Brackets	Mid values		Rent Brackets	Mid values
1	Nil payments	0	11	$275-$299	$287
2	$1-$74	$37	12	$300-$324	$312
3	$75-$99	$87	13	$325-$349	$337
4	$100-$124	$112	14	$350-$374	$362
5	$125-$149	$137	15	$375-$399	$387
6	$150-$174	$162	16	$400-$424	$412
7	$175-$199	$187	17	$425-$449	$437
8	$200-$224	$212	18	$450-$549	$499.5
9	$225-$249	$237	19	$550-$649	$599.5
10	$250-$274	$262	20	$650 and over	$699.5

The *Not Stated* rental payment categories are proportionately distributed across all other categories and *Not Applicable* values are not considered for the analysis. In all other rent brackets mid- values are considered for estimating the rental income loss.

Conditional Probabilities of Earthquake Affected Buildings

The information on conditional probabilities of different types of dwellings to be in different damage states will be produced with the Geoscience Australia's modelling capability (Robinson et al, 2005). Consequently, based on imaginary conditional probability values (presented in Table 5) this report presents experimental rental income loss estimates.

Table 5: Imaginary Values for Proportion of Buildings Affected by Dwelling Structure & Damage State

Seismic Intensity Level	Building Damage State	Proportion of Buildings Affected (Imaginary Values)			
		Separate House	Semi-detached, row or terrace house, town house	Flat, unit or apartment	Other dwelling type
sil1	ds1	0.25	0.26	0.27	0.28
	ds2	0.18	0.25	0.26	0.26
	ds3	0.17	0.23	0.25	0.25
	ds4	0.16	0.2	0.23	0.22
sil2	ds1	0.15	0.25	0.26	0.27
	ds2	0.13	0.18	0.25	0.26
	ds3	0.12	0.17	0.23	0.25
	ds4	0.1	0.16	0.2	0.23
sil3	ds1	0.13	0.15	0.25	0.26
	ds2	0.11	0.13	0.18	0.25
	ds3	0.1	0.12	0.17	0.23
	ds4	0.09	0.1	0.16	0.2
sil4	ds1	0.07	0.13	0.15	0.25
	ds2	0.06	0.11	0.13	0.18
	ds3	0.06	0.1	0.12	0.17
	ds4	0.05	0.09	0.1	0.16
sil5	ds1	0.35	0.07	0.13	0.15
	ds2	0.32	0.06	0.11	0.13
	ds3	0.3	0.06	0.1	0.12
	ds4	0.3	0.05	0.09	0.1
sil6	ds1	0.28	0.35	0.07	0.13
	ds2	0.26	0.32	0.06	0.11
	ds3	0.25	0.3	0.06	0.1
	ds4	0.22	0.3	0.05	0.09
sil7	ds1	0.27	0.28	0.35	0.07
	ds2	0.26	0.26	0.32	0.06
	ds3	0.25	0.25	0.3	0.06
	ds4	0.23	0.22	0.3	0.05

Estimating Residential Rental Income Loss

The weekly rent payment ranges in Census with their mean values are presented in Table 4. The mean weekly rent values in each rent bracket and in each dwelling type are multiplied with the conditional probabilities of the proportion of affected dwellings in each building damage state and seismic intensity level (presented in Table 5) and the total weekly rental income loss in dwelling type category and quake severity level are estimated.

The following Table 6 presents the estimates of potential rental income loss by dwelling type and seismic intensity level in the Greater Melbourne region (excluding Mornington Peninsula) for modelling an earthquake scenario in Australia.

Table 6: Estimated Weekly Rental Income Loss (2011-12, AUD$)

Seismic Intensity Level	Rental Income Loss			
	Separate House	Semi-detached, row or terrace house, town house	Flat, unit or apartment	Other dwelling type
sil1	40,533,890	20,999,780	42,675,580	929,810
sil2	26,667,030	16,978,550	39,717,870	929,810
sil3	22,933,650	11,170,100	32,112,320	865,370
sil4	12,800,180	9,606,280	21,126,530	699,660
sil5	67,734,270	5,361,650	18,168,810	460,300
sil6	53,867,410	2,837,250	10,140,730	395,860
sil7	53,867,410	2,256,360	53,661,380	220,940

HEALTH CARE EXPENDITURE COST

Mohanty et al (2017) presents a modelling approach to estimate direct health care costs in the immediate aftermath of an earthquake event in Australia. However, unlike direct business income loss and rental income loss, experimental estimates such as those presented in the previous sections are not available. However, the report presents a complete work plan for estimating direct health care expenditure cost that is considered implementable.

Estimation of the direct health care cost of injuries involves multiple steps to define an injury, categorise injury severity levels and matching injury severity levels to established diagnosis groups and streams of care services provided by the health care sector. It is also required to group records into episodes of care and group episodes of care into a single injury event. However, in this case the scope of the estimation of potential direct health care costs of an earthquake event in Australia will only be limited to the available international evidence base related to previous earthquake events in similar contexts to Australia.

Based on input data availability this report scopes to use the

1. National Hospital Cost Data Collection in Australia (NHCDC) available for the specific year,
2. Geoscience Australia's modelling capability to obtain potential number of injuries at different injury severity levels
3. the evidence based on 2011 Christchurch earthquake

Direct Health Care Cost

The direct health care cost of an injury includes the hospital in-patient, out-patient cost and emergency department cost. For non-earthquake related injuries, Hendrie et al (2012) identified the hospital cost for an injury (available in the National Hospital Cost Data Collection in Australia (NHCDC) for the specific year) as the sum of the costs for all hospital separations caused by the injury. Hospital separation costs are based on the Australian Refined Diagnosis Related Groups (AR-DRGs) code on each record. Codes are mapped to unit costs for each AR-DRG code using the AR-DRG version specified on records for the year (Hendrie et al, 2012).

Similarly, the emergency department cost for an injury is the sum of the costs for each emergency presentation caused by the injury. Each emergency department presentation for a specific year in NHCDC is given a fixed cost based on the average cost per presentation. The records from the emergency department data collection in Australia do not include a code to indicate the Urgency Related Group (URG), consequently the practice is to apply a single unit cost to all records in a year, rather than adjusting for case complexity (Hendrie et al, 2012).

Estimating Health Care Cost of Earthquakes

Mohanty et al (2017) identified the following required information to estimate the direct health care costs in the aftermath of an earthquake scenario:

1. the average unit cost for transportation to the Emergency Department (ED) (e.g. average unit cost incurred by ambulance service) per ED visit or hospital admission;
2. the percentage of fatal injuries involving hospital admission;
3. the average length of stay in hospital (in days) for different injury severity levels as defined above ;
4. the average cost per bed-day of hospital treatment, including "hotel costs", physician fees, operations, blood transfusions, tests and examinations (e.g. X-rays), and drugs;
5. the percentage of ED visits by injury severity level as defined above that required transportation (e.g. by ambulance);
6. the average cost of medical treatment in the ED per ED visit;
7. the percentage of hospital admissions for serious injuries that are admitted through ED; and,
8. the percentage of fatal injuries involving an ED-visit.

This report proposes to estimate earthquake related direct health care cost as a function of the above identified unit costs of medical expenditure, number and types of injuries and the proportion of persons in each injury type actually seeking health care in terms of ED visits and hospital inpatients. The following equation presents direct health care cost in regions (small areas) in the aftermath of an earthquake scenario for each injury severity level:

$$HC_j = N_j \times [(C1 \times N1_j) + (N2_j \times N3_j \times C2_j) + (C3_j \times N1_j)]$$

HC_j	Direct health care cost for injury severity level j
j	injury severity levels 1, 2, 3, and 4
N_j	Number of injuries for injury severity level j
C1	Transportation costs for ED/Hospital visits
$N1_j$	Proportion of ED visits for injury severity level j
$N2_j$	Proportion of Hospital Admissions for injury severity level j
$N3_j$	Average number of hospital bed days per hospital admission for injury severity level j
$C2_j$	Hospital cost per hospital bed day for injury severity level j
$C3_j$	Treatment cost per ED visit for injury severity level j

The total direct health care cost can be estimated as $HC = \sum_{j=1}^{4} HC_j$

Injuries by Severity Level

The information on the number of injuries by different injury severity levels (for details please refer Mohanty et al, 2017) will be simulated using the Geoscience Australia's modelling capability and these figures are yet to be produced.

Transportation Costs for Emergency Department/Hospital Visits

This report will use the unit cost for the Emergency Department transportation in Australia for the Ambulance Services. Ambulance fees and charges are approved by the Minister for Police and Emergency Services and are reviewed annually (ACT Ambulance Services Website, Dec 2017). The unit cost will vary across Australian States. For example, the current fees and charges as at 1 July 2017 in ACT are presented below.

Emergency Ambulance Services (These services are accessed by calling '000')

Services	**Cost**
Emergency ambulance service (treatment and transport)	$936 (+$12/km for every km travelled outside the ACT)
Emergency ambulance service (treatment not including transport)	$649

ED Visits/Hospital Admissions by Injury Severity Level

The information on number/proportion of Emergency Department visits, the number/proportion of hospital admissions and average number of hospital bed days by injury severity level in the event of an earthquake is something that this report proposes to obtain from the evidence based on 2011 Christchurch earthquake.

Treatment and Hospital Accommodation Cost

This report proposes to source the information on treatment cost per Emergency Department visit and hospital cost for hospital bed days from National Hospital Cost Data Collection (NHCDC), Australian Public Hospitals Cost Report 2013-2014 Round 18 (2016). In doing so the scope allows to avail the standard unit cost values for Australia different from the unit cost/treatment days values for different earthquake injury severity levels as required.

In the NHCDC (2016) Round 18 the expenditure is split between 5 streams of care services such as:

1. Admitted acute
2. Emergency Department
3. Non-Admitted
4. Subacute
5. Other Products

The information is available across these categories by jurisdiction on the following items,

1. Admitted Acute
   - 1.1 Average length of stay (days),
   - 1.2 Average Cost per day($)
   - 1.3 Average Cost per separation ($)
2. Emergency Department Presentation
   - 2.1 Average cost per ED presentation in the admitted/non-admitted/total categories
3. Non-admitted
   - 3.1 Average cost per service event ($)
4. Subacute Services
   - 4.1 Average length of stay (days)
   - 4.2 Average cost per separation($)

The NHCDC (2016) includes all episodes of hospital care for all public hospital facilities across Australia, and the costs incurred by the health service in relation to these episodes in financial year 2013-14 (Round 18). The classifications used include:

1. Admitted acute - Australian Refined Diagnosis Related Groups (AR-DRG) Version 7;
2. Emergency - Urgency Related Groups (URGs) Version 1.3;
3. Non-admitted - Non-admitted Tier 2 Classification Version 2; and
4. Subacute - Australian National - Sub and Non-acute (AN-SNAP) Patient Version 3.

The Admitted acute care for injury is provided to patients who go through a formal admission process where the clinical intent or treatment goal is to do one or more of the following:

1. provide definitive treatment of injury,
2. perform surgery,
3. relieve symptoms of injury (excluding palliative care),
4. reduce severity of injury,
5. protect against exacerbation and/or complication of an injury which could threaten life or normal functions, or
6. perform diagnostic or therapeutic procedures.

These patients are classified under the AR-DRG version 7 classification.

The emergency care presentations include patients who present to the emergency department who are treated and then leave (non-admitted emergency), and presentations that are subsequently admitted to hospital (admitted emergency). Patients declared dead on arrival are considered in scope if the death is certified by an emergency department clinician.

The non-admitted patient service event is an interaction between one or more healthcare provider(s) with one or more patient. It must contain therapeutic/clinical content and result in a dated entry in the patient's medical record. This includes service events occurring in non-admitted clinics in hospitals and in the community.

The subacute and non-acute admitted episodes of care include all separations performed at public hospitals with a care type of rehabilitation care (2), palliative care (3), geriatric evaluation and management (4), psychogeriatric care (5) or maintenance care (6).

This report scopes to match the simulated figures in different injury severity level categories that will be obtained from the GA impact and risk modelling capability to the Australian Refined Diagnosis Related Groups (AR-DRGs) code and above defined streams of care services categories available from the NHCDC (2016) in order to obtain the unit cost/treatment days values for different earthquake injury severity levels and estimate the direct health care cost of earthquake related injuries in Australian regions.

FUTURE WORK

Future work will include the estimation of already identified components of economic losses for precinct level economic activity disruption. This is expected to include utilisation of research undertaken in NZ on the recovery following the 2011 Christchurch Earthquake (Elwood *et al*, 2015)

SUMMARY

This report presents the interim findings of a trial run for the modelling approach developed in Mohanty et al (2017) and provides the experimental estimates for some components of the economic costs such as the business income and rental income loss and an implementable work plan for direct health care cost estimation. This research will progressively advance in parallel to the other physical testing and vulnerability assessment work enabling the project outputs to be brought together to obtain the metrics required for decision making.

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