AUTHOR RESPONSE: We sincerely thank the reviewer for their carefully considered and constructive comments on the manuscript. We have responded to each comment below, and made amendments in text where required; any amendments are indicated in our responses below.

Interactive comment on "Variable population exposure and distributed travel speeds in least-cost tsunami evacuation modelling" by S. A. Fraser et al.

Anonymous Referee #1

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General comments:

This paper addresses the estimation of population exposure and travel speeds in least-cost distance (LCD) tsunami evacuation modeling. The method is applied to a case study of local-source tsunami evacuation in Napier City, Hawke's Bay, New Zealand.

Since the mentioned evacuation factors have been applied as static values in previous LCD approaches, the Authors justify the need for this research in order to include their potential variability in evacuation planning. The aim of the paper is to demonstrate a method for introducing variability in population exposure scenarios, evacuation departure times and travel speeds into an anisotropic LCD model of pedestrian evacuation potential. The paper includes (1) an introduction; (2) a description of the study area; (3) a description of the methodology for the analysis of the anisotropic least-cost path distance, the time-variable population exposure and the evacuation time; (3) a discussion of the main results, as well as (5) some final conclusions.

The article is well written and based on an in-depth understanding of the evacuation's main concepts. It provides an interesting assessment of spatio-temporal human exposure which is a key issue on tsunami risk assessments and tsunami evacuation modeling, not being usually analyzed so exhaustively. This is in the main contribution of the paper, the findings on travel speed or evacuation departure time being less relevant, in my opinion. Nevertheless, the evacuee density maps provided are useful. Even if the spatio-temporal exposure distribution is interesting, the applicability to other study sites is difficult to see, so further efforts need to be done.

Specific comments:

The work deals with an enormous amount of data and very detailed analyses but I am not sure about the benefits of the results or the applicability of the method compared to previous simpler approaches. Such amount of needed information makes difficult to replicate it in other areas world-wide as well as to update the results once new data is available. Maybe the proved benefits of this method compared to others should be explicitly mentioned.

AUTHOR RESPONSE:

1. We have adjusted the language of our abstract and introduction, to better reflect the aims of this paper to test the feasibility of applying this approach elsewhere, rather than to demonstrate this approach as a better method than previous methods. We have added a caveat to the abstract: '*This method improves least-cost modelling of evacuation dynamics for evacuation planning, casualty modelling, and development of emergency response training scenarios. However, it requires detailed exposure data, which may preclude its use in many situations.*'

In the conclusions, we have added text as follows: '*Whilst this approach displays several benefits, the large amount of detailed data required to develop a detailed temporally-variable exposure model poses a significant challenge to its wider application.*'

It is clear in the text that the Authors focus on improving the evacuation planning, and that providing the number of people unable to evacuate facilitates planning of additional evacuation and emergency response solutions; however the paper is not clear enough regarding what the product provided to someone responsible of the evacuation planning of Napier would be. The amount of information generated could be useful but is not practical for a manager. Further contribution is suggested on this issue.

AUTHOR RESPONSE:

2. The outputs to be used by an emergency manager would be evacuation time curves and maps showing density of population who cannot evacuation before wave arrival. A paragraph has been added at the start of section 4 (Results), to explain this.

Besides providing the specific numbers (i.e. results) for the Napier study area, it is important to think on the international readers who are more interested in the potential applicability of the method to their study sites than in the results obtained here. Clear conclusions should be extracted and provided together with the results.

AUTHOR RESPONSE:

3. We have elected to present our results and conclusions separately in this paper. We believe that this enables the conclusions to be presented more coherently, rather than interspersing conclusions amongst the detailed results. Having reviewed the structure of our results and conclusions following the reviewers' comments, we have decided to maintain the original structure.

Regarding the structure of the paper:

Following the argument in the paper is sometimes confusing due to the structure of the text. There is one section for methodology and one for results; however, some of the results are partially provided in both sections. The same happens with some figures: Fig. 3, 4 and 6 are mentioned continuously in both sections, so the first time the figures are presented you have not read all the related text yet. Figure 4, for example: the first time that Fig.4 is mentioned (page 4175, Method section) only part of the figure (4a) is explained and no conclusions at all are provided. The scenarios modelled and the results for Fig 4b and 4c appear in page 4179, and the results for Fig. 4-d-e-f are in the next 3 pages, everything already in the Results section. This should be improved somehow, maybe combining both sections in one, or just explaining at the beginning what the reader is going to find.

AUTHOR RESPONSE:

Agreed – this was something we struggled with because of the

4. The first reference to Figure 3 (and elderly travel speed distributions) has been moved to section 3.3.2, where evacuation travel time is introduced and discussed in most detail.
5. The reference to 4a does include conclusion, that 500 simulations are conducted because of similar confidence interval but 50% computation expense compared to 1000 simulations.

Having considered moving the reference to 4a to the results section, it was decided to keep it in section 3, as this is where the justification for using 500 simulations sits best. Having fixed this issue for figure 3, we feel that this is a minor issue and the costs to the manuscript of moving this reference do not outweigh the benefits.

6. Figure 6 is mentioned repeatedly in the results section only. The six sub-figures are presented as one figure for reader comparison, and the repeated references clarify which subfigure they are referring to. We believe this to be acceptable and no change has been made.

The 12 selected scenarios are described too late in the text (page 4179). Figure 4 is presented in the text in page 4175 and shows results for some scenarios, but it is not possible to understand the figure as the reader cannot understand the scenario-coding for the graphs (d2, e12, etc.). The same happens with Fig. 4-d-e-f, as they show results that have not been mentioned yet in the text.

AUTHOR RESPONSE:

7. We have moved the reference to the 12 scenarios forward, to the end of section 3.2. This now follows the description of the time-variable exposure model, therefore states the use of the time-variable model for the reader at a better location in the text.
8. By the nature of these figures, all codes cannot be explained at the first mention of the figure in the text. Conversely, there would be too many similar figures in the manuscript if these were separated into six different figures to ensure the relevant figure was mentioned at the relevant point in the text. To aid the reader, we have now defined the scenario codes in the figure caption. As the reader progresses through the results section, they can see the repeated reference to this figure and can return to it accordingly.

Regarding the exposure distribution:

The analysis regarding the location of the different population groups along the day is more accurate than others in literature. The population-time profiles are quite interesting information. However, the overwhelming amount of population data and the various criteria assigned makes difficult to think on its applicability to other study sites since the used data might not be easily available in other places and due to the assumptions considered. A table resuming the distribution of population groups by time and location, including the percentages applied (e.g. 60% at home/facility, 40% at unspecified location), would help having the entire picture of the proposed exposure distribution analysis.

Do the mentioned percentages applied respond to expert criteria? Or site-specific characteristics? This is not justified enough and should be mentioned in the paper, explicitly clarifying that these percentages might not be valid for other case studies (other countries, etc.).

AUTHOR RESPONSE:

9. It has proven very difficult to compile a table suitable for publication that summarises the location of each population group at each time during the daily cycle, and we feel this is best presented by time profiles in Figure 2. Therefore, we have not included this suggested table. The mentioned percentages correspond to a combination of proportions derived from national/regional and local statistics data (primarily from publicly-available census data, but also from school and childcare centre attendance information). Where statistical data is not available, we have confirmed that this implemented as an assumption (e.g. p4171 l24) Sections 3.2.1-3.2.5 explain this for each population group, to what we believe is generally

to an adequate level of detail. However, we agree that the profiles for which we have made assumptions do not explicitly state that this is based on the judgement of the authors, and we have amended this accordingly.

10. We have also clarified, in Section 3.2, the site-specific nature of the data, and limitations of the method in these time profiles not being internationally applicable: *'Employment data, education rolls and care facility capacities are used to define the proportion of URP in each population group. These data are site-specific; data relevant to the local area should be sought for in analyses for other areas.'*

Figure 2: the population-time profiles for independent/dependent elderly and visitors are not provided, why?

AUTHOR RESPONSE:

11. These profiles were omitted to limit the number of figures, as the profiles were relatively simple and explained in the text. We recognise, however, that these may be useful to the reader, so these have been included in a subsequent figure to ensure all charts are legible. References to the new figure have been made in text at the appropriate locations.

Regarding the evacuation speeds:

The Authors state that the analyzed evacuation factors (population exposure, departure time and travel speed) have not been adequately addressed in previous LCD approaches.
However, after working with and analyzing such amount of information, the use of a static speed value of 1.1ms-1 is accepted in the Results section as providing a reasonable assumption to estimate the population unable to evacuate. This speed value is for sure consistent to many of the previous LCD approaches that have been considered inadequate in the paper. This indicates that more complexity does not translate here into better results. The same might happen with the other evacuation factors. I suggest avoiding the expression "not adequate" when this has not been really proved.

AUTHOR RESPONSE:

12. We agree – stating that previous approaches were 'not adequate' is too strong an assertion and given our later findings, is incorrect. We have removed the words 'not been adequately addressed' from the introduction, alternatively, stating that this variability has not been included before: *'Three other evacuation factors -- population exposure, departure time and travel speed -- have been consistently applied as static values in previous LCD approaches, which may not represent the potential variability in these factors.'*
13. We have also included in the conclusion, text to confirm the results demonstrate that using a fixed travel speed 1.1m/s gives an adequate approximation of the distributed travel speed, and that this should be considered appropriate for further research, while slower speeds are not so appropriate.

To estimate the evacuation speeds the walking speeds identified in previous literature are grouped into one of the five proposed travel speeds groups and associated to one of the five population groups (POPULATION GROUPS: 1. Working-age adults, 2. School/childcare, 3. Dependent elderly, 4. Independent elderly, 5. A proportion of individuals and groups who might run; TRAVEL SPEED GROUPS: 1. Adult unimpaired, 2. Child, 3. Elderly, 4. Adult impaired, 5. Running).
Having this in mind:
The calculation of the proportion of individuals and groups who might run rather than walk in an evacuation seems to be too detailed and maybe unnecessary analysis. In fact, the authors decided to omit it from some scenarios (page 4178).

According to the Authors, the travel speed distributions for elderly and impaired adults could be combined with minimal impacts on the results (page 4173). However, both curves and the subsequent analysis are maintained separately. Instead of simplifying the analysis based on a justified result, the Authors keep the complexity to demonstrate the functionality of the proposed method. More complexity does not translate into better results.

As resumed before, the proposed travel speed groups are: 1. Adult unimpaired, 2. Child, 3. Elderly, 4. Adult impaired, and 5. Running. If the Running group has been omitted from some scenarios, and he distributions for Elderly and Impaired adults could be combined with minimal impacts on the results, then the proposed 5 travel speed groups could be reduced to 3, i.e. adults, child and elderly, which is not so different from those previous references rated as inadequate. This should be mentioned or, instead, justify why the 5 classes are maintained.

AUTHOR RESPONSE:

14. In this study they could be combined with minimal impact, due to the small number of elderly, however, in study areas with a larger elderly population / an elderly population with long travel distances, we could expect that the greater range of the elderly curve (see Table 2) is likely have more of an impact. We have included text to clarify this in section 4.3.
15. Five classes are maintained in order to test this method. One of the unexpected findings was that travel speeds for elderly and adult impaired were similar, but as noted in the above response, the distributions are maintained because of the potential for differences. Agreed, the distributions could be combined but in this test we believe it is prudent to maintain separation, and allow other researchers to reduce the number of categories in later analyses of this method – again, we are demonstrating here that more complexity is not always required. If we had consolidated into just three categories, our manuscript would not highlight this.

Only age has been considered to estimate the evacuation speed of these population groups; however, several references consider disabilities in population as a factor hindering evacuation speed. The Authors have translated this disabilities category in Table 1 into adult impaired, but the data used to calculate it is only related to independent elderly, disabilities in the entire population not being considered at all. Please justify why this factor has not been included.

AUTHOR RESPONSE:

16. The New Zealand national disability survey provides data on disabilities in the population (http://www.stats.govt.nz/browse_for_stats/health/disabilities.aspx). This shows that in the Hawke's Bay region, 23% of all people living in private households have a form of registered disability, and 13% are mobility-impaired. Nationally, 90% of people living in care facilities are mobility-impaired, which we have captured by considering carehome populations as

having 'adult impaired' travel speed. Split by age group (nationally), 1% of children (age 0-14 y) are have mobility impairment; 6% of age 15-44 y; 15% of age 45-65 y; and 46% of age 65 and over. The mobility impairment statistics may not account for those people with 'sight' 'hearing', 'agility', 'intellectual', 'psychiatric', or 'learning' impairments, which may also impact evacuation decision-making and/or mobility during travel.

It is very difficult based on the available data, to determine the magnitude of increase in evacuation time due to each mobility/non-mobility disability. Nevertheless, we recognise that it is an oversight to not explicitly include disability statistics with some impact on evacuation time. Mobility-impairment increases with age according the NZ statistics above, therefore we have captured the largest proportion of mobility-impaired population by assigning slower travel speeds based on age, and have been conservative, given that only 46% of people over 65 years have mobility impairment. We recognise that disability impact on evacuation time should be explicitly accounted for, and requires further in-depth research to constrain the magnitude of different disabilities' impact on evacuation. In recognition of this, we have stated this clearly in the text of section 3.2: *'Whilst it is recognised that physical and intellectual disabilities can affect evacuation decision-making and mobility in evacuation, resulting in an increase in required evacuation time, it is not possible to determine the magnitude of impact of each type of disability registered. By using age to determine mobility impairment, we have captured the majority of mobility impairment in the population, however, this represents an important area of further study.'*, and mentioned this again in the conclusions.

Table 2 shows the travel speed statistics for each travel speed group, compiled from travel speeds in literature, which are shown in Table 1. It seems that n (in Table 2) indicates the sample size for each travel speed group; represented by the number of times it appears in Table 1. The values of n in Table 2 for Adult impaired, adult unimpaired, child, elderly and running are 7, 19, 3, 11, 3, respectively. However, checking Table 1, I would say that n should be 5, 15, 3, 9, 1. Please clarify this.

AUTHOR RESPONSE:

17. The *n* value refers to the number of speeds in each category. Table 1 shows, for some rows, multiple travel speeds that have been assigned to the same travel speed group, e.g. Source number 2 provided three different travel speeds. These have all been considered in this analysis, but have represent different points on the curve for the 'adult unimpaired' group. Therefore, this row contributes 3 speeds to the *n* value in Table 2.
    Having said that, while returning to this table in light of the reviewer's comment, we noticed that the table hadn't been updated to reflect one change in group assignment in Table 1 – therefore, Table two has been updated to show n=6 for adult impaired and n=20 for adult unimpaired. There are minimal corresponding changes, <0.03, to the mean speed and SD values in these columns.

Technical corrections:

Page 4182, line 15: there is a mistake when referring to the figure (Fig. 4g); it should be replaced with (Fig. 6g).

AUTHOR RESPONSE:

18. This should actually be 4e. This has been corrected accordingly.

Figure 4: PVE should be described in the figure caption

AUTHOR RESPONSE:

19. The definition of P_{VE}, initially given on page4175 line 18, has been repeated in the caption of Figure 4.