When is a hazard not a hazard? A review of fatality factors for dambreak consequence assessments.

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Current empirical approaches assume different fatality factors for the 'fail' and 'no fail' scenarios even when the same hazard is experienced by a property. This approach can lead to some inconsistencies particularly for small dams and retarding basins. This paper looks at the base data behind the current fatality factors and explores possible alternatives to the current approach. The paper will rely on a number of examples from a recent investigation undertaken by GHD for Melbourne Water on a number of their retarding basins.

Keywords: *PAR, PLL, Fatality Rates, Consequence Category*

1 Introduction

In early 2016 GHD was commissioned by Melbourne Water to undertake a consequence and risk assessment for a number of retarding basins (RBs). During this process GHD explored a number of key factors which could influence the outcomes of the risk assessment, namely, itinerants (in particular on roads), blockage of the outlet structures and the fatality rates applied to non-break floods. This paper explores one of these aspects, fatality rates applied to non-break floods.

The current Guidelines on the Consequence Categories for Dams (ANCOLD, 2012) require the determination of the incremental Potential Loss of Life (PLL), which requires the estimation of PLL for both the ‘fail’ and ‘no fail’ scenarios. The empirical method developed by Graham (1999) is currently the most widely applied approach for the estimation of loss of life from dam failures (i.e. the ‘fail’ scenario). In 2014, the US Bureau of Reclamation released an update to the Graham (1999) method called the Reclamation Consequence Estimating Methodology (RCEM) (US Bureau of Reclamation (USBR), 2014). As with Graham (1999), the RCEM continues to rely on case histories, which consist of a combination of dam failure events and natural flood events, to guide the selection of fatality rates. Given the lack of smaller dams or retarding basins in the dataset there was concern whether Graham (1999) or the RCEM was applicable for estimating PLL downstream of the RBs being assessed for Melbourne Water, as the ‘depth velocity product’ (or DV) expected following failure of these structures are generally small compared with most of the case histories used to develop the methods. In an attempt to overcome this shortcoming, a method developed by the UK Government Environment Agency titled “Guide to Risk Assessment for Reservoir Safety” (UK RARS) was adopted for the consequence assessments for Melbourne Water as per the Guidance Note (HARC, 2016) provided by Melbourne Water.

The UK RARS method was developed in the Interim Guide to Quantitative Risk Assessment for UK Reservoirs (Brown and Gosden, 2004). The UK RARS method is based on a line of best fit to fatality rates used to develop the Graham (1999) method. The advantage of the UK RARS method over Graham (1999) for retarding basins is that the suggested fatality rate decreases as flood severity decreases. Therefore, the UK RARS method will estimate different fatality rates downstream of retarding basins of varying size compared to Graham (1999) which adopts a fatality rate of 0.01 (no warning) until the flood severity reaches the ‘medium’ classification.

In regards to the PLL for flood events (i.e. the ‘no fail’ scenario) the Guidelines on the Consequence Categories for Dams (ANCOLD, 2012) states that “procedures are currently being developed that can be used to determine the PLL for flood events without dam failure. No one methodology is suggested in these Guidelines but reference could be made to such models as LifeSim being developed by the Utah State University or the Life Safety Model developed by BC Hydro.”

Models such as LifeSim would remove the need to apply different empirical approaches to the fail and no fail scenarios, but would add significantly to the time and budget required for PLL estimates, which is not always justified. This is particularly true for portfolio risk assessments like the project just undertaken by Melbourne Water. Therefore, there is still a need for empirical approaches. In addition, if the industry was to adopt models such as LifeSim for these assessment in the future, guidelines on the assumptions to adopt will need to be agreed upon in order to get a consistent outcome so that assets can be assessed equally. The RCEM make the following comment on programs like LifeSim: “while the numerical modelling approach can be more detailed and can predict traffic and evacuation patterns, it does require a large number of assumptions. In Reclamation’s experience, the selection of key parameters for a numerical exercise requires as much judgment as selecting fatality rates for a given set of conditions and is subject to similar uncertainty and variability. It may also be easier to understand and explain the loss of life estimates from the empirical approach than it would be to understand and explain results from a numerical model. There is no inherent advantage in using a numerical model for most Reclamation dams; however, there are exceptions. Numeric models can however be useful to aid in the estimation of evacuation of highly populated urban areas, where traffic congestion can play a major role" (USBR, 2014).

2 Observations on the current approach

The following section provides some general comment on the current approach to calculating PLL estimates, with a particular focus on their applicability to small dams and/or retarding basins.

2.1 Lack of data

The first thing to note is the paucity of information for populations exposed to "low" DV values (i.e. less than 4.6 m^2/s). From the modelling undertaken for Melbourne Water it was observed that for retarding basins most of the population were only exposed to "low" DV values. Figure 1 shows the 'UK RARS' and the 'No Break Hill et. al.' curves (assuming no warning) together with the data points used to derive the 'fail' scenario fatality curves outlined in USBR, 2014. The yellow diamonds represent dam break events with a flood event (i.e. 'wet day failure'), the green squares represent sunny day dam break events (i.e. 'sunny day failure') and the blue squares represent natural flood events (i.e. events with no dam breaks). Figure 1 highlights the lack of data in the "low" DV range.

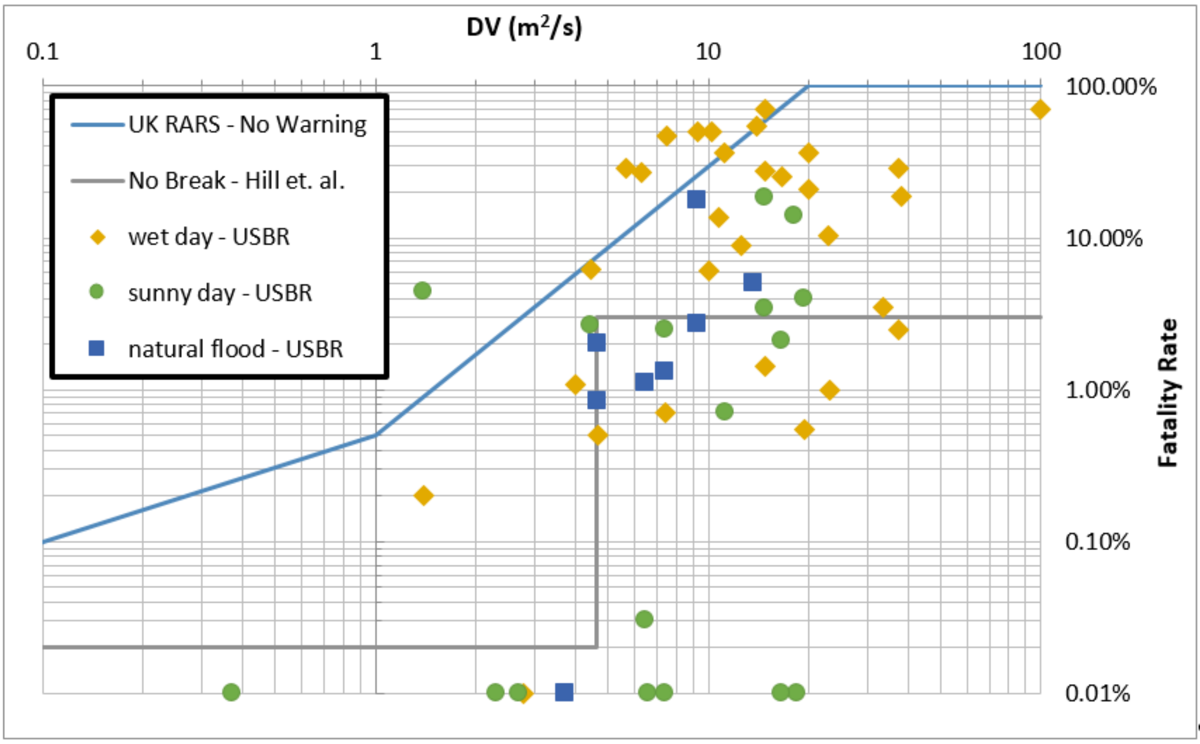

Figure 1 Fatality Curves (derived from USBR, 2014\Brown and Gosden, 2004\ Hill, et al, 2007)

2.3 Non-Dambreak Fatality Rate

As mentioned in Section 1, the need for estimating an incremental PLL means that a PLL estimate is also needed for the 'no fail' cases. As the method stands a building that receives the same hazard (measured by DV) can have a very different outcome in the 'fail' and 'no fail' case. By way of example, referring to Figure 1, if a building is assigned a DV of 3 m^2/s, for the same warning time, then with for the 'fail' case it is assigned a fatality rate of 0.035 and for the 'no fail' case it is assigned a fatality rate of 0.0002. This difference indicates that the PAR is 175 times more likely to lose their life in the 'fail' case compared to the 'no fail' case even though they are subject to the same hazard.

This will most likely lead to some level of conservatism in the incremental PLL estimate, which for these types of assessments is appropriate. However, it may also lead to an overly conservative estimate which could result in large amounts of money being spent on upgrade works that may not be required or certain assets being incorrectly prioritised over others.

The difference between the two fatality rates is largely due to the data used to derive them. Hill et. al. 2007 built on earlier work described in NSW Dam Safety Committee (NSWDSC), which used data from the Dartmouth Flood Observatory (DFO). The NSW Dam Safety Committee work excluded flash floods from the DFO. Flash flood data was rejected based on the fact that “flash floods arrive very quickly, without warning, often with a rolling wave front and people have no time to escape lethal conditions. The lethality of flash floods is similar to that of dam failure floods” (NSWDSC, 2005).

The approach of removing flash floods for large dams where you are trying to distinguish between natural floods and that from failure of a large dam is appropriate. However, according to the Bureau of Meteorology “flash flooding usually results from relatively short intense bursts of rainfall, commonly from thunderstorms. This flooding can occur in any part of Australia, but is a particularly serious problem in urban areas where drainage systems may not cope and in very small creeks and streams.” (BoM, 2016) In general a warning time of less than six hours is generally considered to be flash flooding which covers most of the events we considered for retarding basins as part of the recent project for Melbourne Water.

For this paper all the flood data from the DFO database was extracted and the derived fatality rate was plotted against the Population at Risk (PAR) – see Figure 2. This figure plots the DFO data as grey crosses (excluding smaller or ‘Class 1\Class 1.5’ events, landslides, dam or levee failure and tsunamis - i.e. it includes flash flooding) against the USBR, 2014 data (using the same markers as in Figure 1). Figure 2 shows that there are a number of flood events that have similar or higher fatality rates compared to the dam break events.

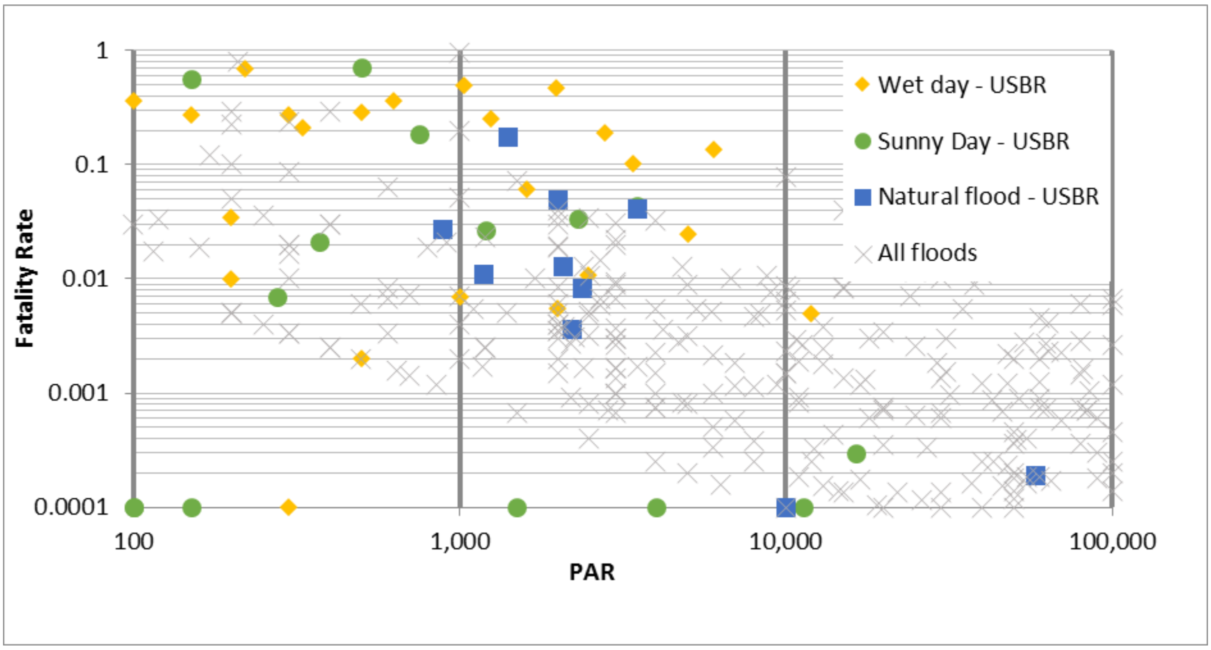

Figure 2 Databases used to Derive Fatality Rates (derived from USBR, 2014\DFO, 2016)

Others, such as Jonkman (2007), have shown that natural floods, and in particular flash floods can be just as or even more hazardous to the exposed population than dambreaks. This is shown in Figure 3, which presents the distribution of mortality rates[1] for different types of floods.

[1] Mortality is the proportion of the population exposed to a particular flood hazard that die. For this purpose, it is important to note that the population is counted after evacuation.

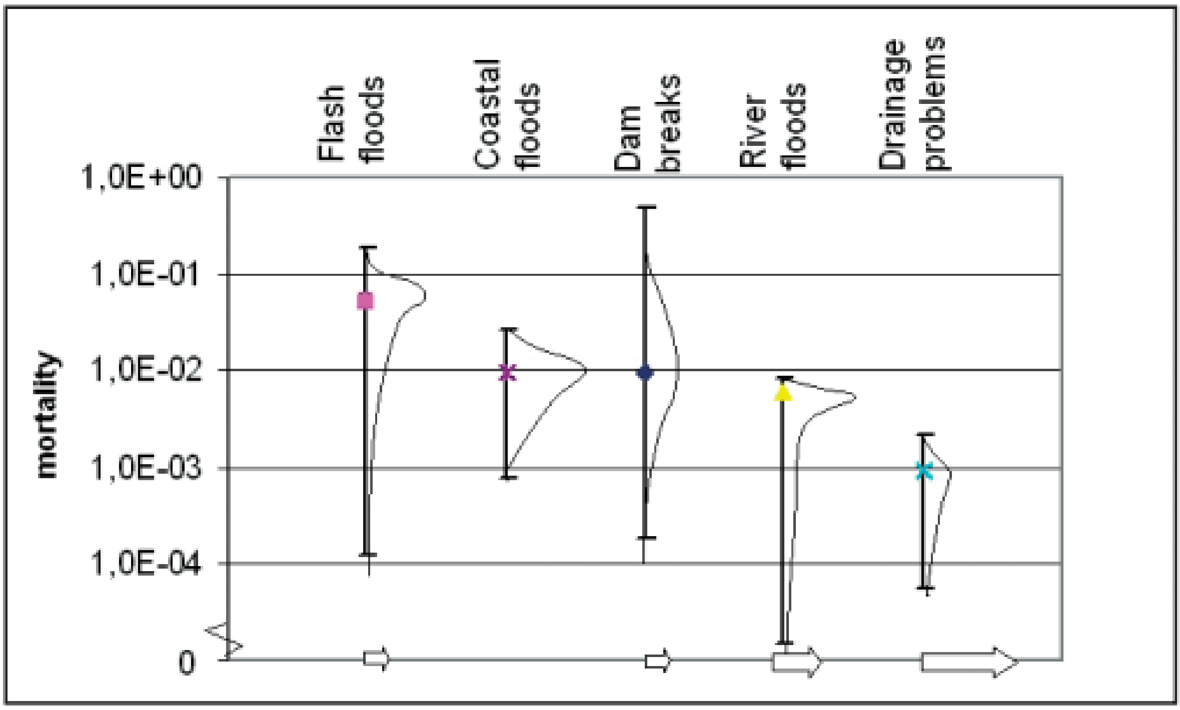

Figure 3 Mortality rate by flood type (arrows represent zero mortality floods) (Jonkman, 2007)

2.3 Application of Fatality Rates to Individual Buildings

For the data used to derive the dam break fatality rates the USBR makes the following comment. “Flood severity is quantified in terms of depth multiplied by velocity of flow, or DV. Although the parameter DV is not representative of the depth and velocity at any particular structure, it is representative of the general level of destructiveness that would be caused by the flooding”. (USBR, 2014).

The use of 2D models has allowed a greater accuracy of assessing the variation of DV across a floodplain. This has often led to a DV at a particular structure being taken and used to select a fatality rate to apply at that location. But as mentioned above the DV is not representative of the DV at any particular structure as the current fatality rates have been derived using an approach in which historical floods (or sections of historical floods) have been assigned a warning time, a representative hazard (DV), a PAR and fatality rate (PAR divided by number of known fatalities), which has been plotted and used to derive a fatality rate curve.

3 Possible Ways Forward

With advances in technology and the availability of information relating to flood fatalities, there is now potential to improve the PAR \ PLL assessment process going forward, especially for small dams and RBs. This section highlights two potential ways to address some of the limitations discussed in section 2, with the intention of generating discussion in the ANCOLD community.

The first issue to address is the lack of data. To overcome this, it is recommended that the industry funds a research project to compile a database of historical floods (including dam breaks, natural floods and flash flooding events) that have two dimensional hydraulic models and known fatality locations to provide a consolidated set of flood fatality data that can be used to refine the currently used fatality rates in relation to flood severity, especially at the lower end of the hazard scale. The new fatality rates derived from this database could then be applied to both the ‘fail’ and ‘no fail’ scenarios, as it would be based on a broader collection of floods. The database could then be improved over time with the commissioning of studies to produce hydraulic models of additional historic events with known fatality locations to increase the data in key hazard areas that have a lack information in the initial database. Even though there will still need to be some assumptions made and interpretations of the data in this approach, using data from this new database will mean that the fatality rates are associated with the hazard at a specific location. To get the most out of this approach, collaboration between the dam and flooding industries, as well as academia would be essential as the data and knowledge each holds could improve the understanding across the board. The cost of this exercise could be justified by the potential saving in upgrade works that could be avoided when these issues are better understood.

In general, from the investigation of the retarding basins undertaken by GHD the UK RARS method appeared to give a reasonable estimate of PLL for the ‘fail’ case. Until additional information is available, as described above, the same curve could be used for ‘no fail’ cases. This is based on the interpretation of **Error! Reference source not found.**, which indicates that when flash floods are included there is not a strong distinction between dam break and flood events. Also most retarding basins have no or very little volume of water stored in them, so in the event of a failure there is not a large additional body of water being released. If, however, a level of conservatism is preferred then the ‘> 60 minute warning’ UK RARS curve could be used (refer to Figure – black line). This approach can be reasoned by the fact that those that are flooded are warned by virtue that they are flooded. Using one of the UK RARS curves for the ‘no fail’ case as well also prevents a large step change in fatality rate being assigned.

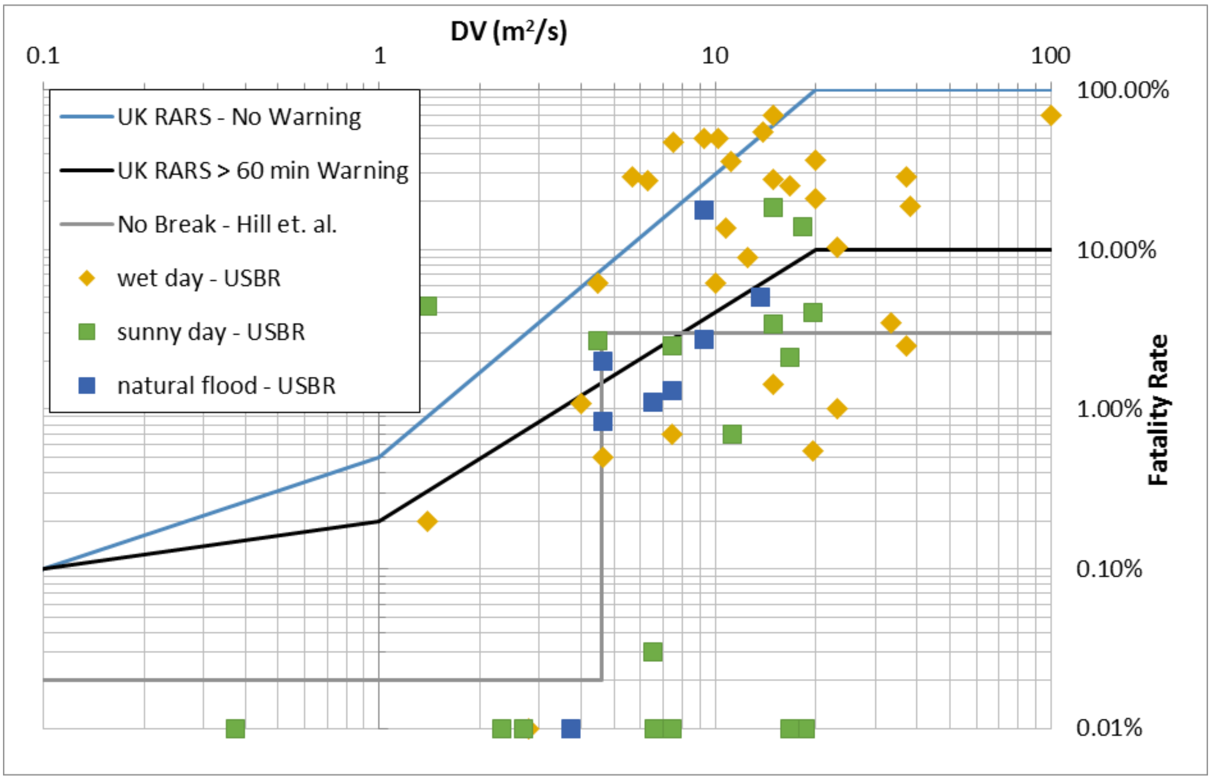

Figure 4Fatality Curves (derived from USBR, 2014\Brown and Gosden, 2004\ Hill, et al, 2007)

4 Example

To compare the impact on the PLL of the interim method described in Section 3, each of the following PLL methods were applied to five (5) example retarding basins of various sizes:

- UK RARS (no warning) for ‘fail’ scenario and Hill et. al. (no warning) for ‘no fail’ scenario;
- UK RARS (no warning) for both ‘fail’ and ‘no fail’ scenarios; and
- UK RARS (no warning) for ‘fail’scenario and UK RARS (with warning) for ‘no fail’ scenario

The retarding basins used were taken from the consequence and risk assessment project recently completed for Melbourne Water. A summary of the key statistics for the five basins used in this report are presented in Table 1. together with the incremental PLL for the buildings.

Table 1 Key Statistics of Basins for Comparison

Basin	Storage Volume (ML)	Embankment Height (m)	Incremental PLL (using Hill et. al.)	Incremental PLL (using UK RARS – no warning)	Incremental PLL (using UK RARS – warning)
1	125	5	0.39	0.37	0.37
2	106	3	0.67	0.53	0.54
3	119	8	2.4	1.6	2.0
4	130	3	0.26	0.26	0.26
5	205	5	0.70	0.52	0.54

The examples shown in Table 1 generally indicates that the results are not that sensitive to the adoption of the UK RARS curve for 'no fail' case. As expected the only time there was a noticeable difference is for Basin 3, which has higher DV's compared to the other basins and therefore sits higher on the UK RARS curve which departs from the Hill et. al. curve.

5 Conclusion and Recommendation

Given the possible way forward described in this report involves additional work and collaboration within the dam and flooding industries, it is recommended that the ANCOLD community adopt the following two stage approach to deliver improvements in the PAR \ PLL assessment process for small dams and retarding basins in the long-term and short-term respectively:

- Fund the development of a database that compiles information on historical floods (including dam breaks, natural floods and flash flooding events) that have two dimensional hydraulic models and known fatality locations to ultimately develop a refined set of fatality curves that can be applied to both the 'fail' and 'no fail' cases. This database and the derived curve could then be improved over time by modelling additional historical events with known fatality locations. It is envisaged that the cost of this work could be justified by the potential saving in upgrade works that could be avoided when these issues are better understood.
- Consider adopting the UK RARS curves for both the 'fail' and 'no fail' cases in the interim before the new fatality curves from above database are developed. Depending on the level of conservatism desired, this could be the 'no warning' curve for both or 'no warning' and 'warning' for the 'fail' and 'no fail' scenarios respectively. This decision would need to be at least consistent across a dam owner's portfolio, if not the industry as a whole.

Considering this, going forward GHD would like to work with the ANCOLD community to progress these approaches to develop a consistent approach that can easily be improved with increasing data in the future.

6 Acknowledgements

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