16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 44

Registration Code: S-W1460983592

QUANTITATIVE PROTOCOLS FOR DECISION-MAKING IN OPERATIONAL EARTHQUAKE FORECASTING

G.Woo[(1)]

[(1)] *Catastrophist, RMS, Gordon.Woo@rms.com*

Abstract

Guidelines are presented here for establishing quantitative protocols for decision-making in Operational Earthquake Forecasting. These guidelines are based on a taxonomy of possible actions that might be taken during a seismic crisis, when an assessment of the probability of a significant earthquake is undertaken on a regular basis. By taking account of the uncertainty in the estimation of this probability, and also in the leverage ratio of mitigated loss to action cost, actions can be decided on the basis of the level of confidence that the benefits of the action do outweigh the costs. This leads to a colour-coded advisory system for taking actions in response to an operational earthquake forecast.

Keywords: operational; earthquake; forecasting; decision; protocols

1. Introduction

In daily life, the general public is commonly exposed to remote uncertain hazards, which would pose a threat to life and property if they were to materialize. Hazard warnings elicit a wide range of precautionary responses, many of which involve comparatively little cost. Air passengers buckle their safety belts during turbulence just in case they may be ejected from their seats. Homeowners in the Caribbean board up their windows with the approach of a tropical storm, just in case it intensifies into a damaging hurricane. Tourists to tropical countries get vaccinations against local diseases.

Most major earthquakes occur without any observed precursory evidence on which to base a hazard warning decision. However, for some major earthquakes, a degree of precursory evidence may be available, identifying a time period of significant probability gain, relative to the background average level. This may arise where a sequence of one or more tremors may be interpreted probabilistically as foreshocks to a damaging earthquake. This may be the situation, for example, during an event swarm. During an extended time period after a damaging earthquake, a significant probability gain of a further damaging earthquake may also develop. The generic term *seismic crisis* is used here to refer to a time period of significant probability gain of a damaging earthquake.

The task of quantifying the probability gain associated with precursory evidence has traditionally been perceived as rather academic, and of no real practical societal use. Seismologists are physical scientists who are trained to aim for rigour and objectivity in their communications with their peers and the public. The lamentable history of failed earthquake prediction shows that seismologists are almost never in a situation where they can confidently state that a damaging earthquake will occur in a specified region, within a narrow time window of a few days, or even a few weeks. Since the probability gain is never sufficient for seismologists to have high confidence in an earthquake forecast, little interest has been shown in estimating the probability gain.

Even though, from the estimated probability gain, seismologists cannot be at all confident that a damaging earthquake is imminent in a specified region, seismic risk analysts *can* be confident, in varying degrees, that various classes of mitigating actions are justified. This key difference in perspective between seismologists and risk analysts underlies the opportunity and challenge behind operational earthquake forecasting.

Cost-benefit analysis is the systematic method which makes rational sense of actions even when event likelihood is quite low – even very low [1,2,3,4]. The use of cost-benefit analysis to justify actions taken in a decision-making process was suggested by Jordan et al. [5] as the International Commission on Earthquake Engineering for Civil Protection, established after the 2009 L'Aquila earthquake. A recommendation of this Commission was that *'Quantitative and transparent protocols be established for decision-making that include mitigation actions with different impacts that would be implemented if certain thresholds in earthquake probability are exceeded.'* Jordan [6] has explicitly referenced the L'Aquila earthquake as a rationale for moving forward more quickly with operational earthquake forecasting.

Traditionally, during past seismic crises, actions have generally not been taken under operational earthquake forecasting. Accordingly, decision makers may be expected to display some reticence and aversion to mandate or advise actions in the awkward circumstances where the benefit-cost ratio is marginally greater than unity, and where the confidence in the estimation of this ratio is not high. The usual mental process of decision-making involves a hasty balancing of pros and cons. This process is informal and unstructured, subject to cognitive bias, and not reproducible. Decision makers need quantitative assistance in addressing the issue of uncertainty over whether the benefits of action really do outweigh the costs.

1.1 Willingness to Pay to Save a Life

From a behavioural perspective, people differ enormously in their risk aversion. People tend to become more risk averse with age. A mother with young children will be much more willing to pay to avoid a hazard than a youth, with a risk-seeking lifestyle and a history of sports accidents. Whilst a youth might be happy to walk home in a lightning storm, a mother with young children would generally prefer to pay for transport home. This need not depend on social status. People also differ in what psychologists describe as locus of control: some take a fatalistic attitude towards risk and question the value of evasive action, whilst others are more ready to take safety in their own hands, and incur costs in the process. Depending on their personal circumstances and psychological characteristics, people have different views on expenditure for risk mitigation.

A wide range of loss mitigating measures can be taken sensibly and rationally during a seismic crisis. In order to assess which out of many possible precautionary measures might be warranted and prioritized, the loss prevented by saving a life has to be expressed in terms of the willingness to pay to save a life. There is no inconsistency between adopting such a concept and sharing the universal humanitarian belief that every human life is beyond monetary valuation. The free public hospital which denies a life-saving drug to a patient because a course of treatment is excessively costly is implicitly acknowledging a limit to its willingness to pay to save a life. There are numerous econometric applications of the concept of willingness to pay to save a human life, which is sometimes referred to as the value of statistical life (VSL).

2. Taxonomy of loss mitigating actions

During a seismic crisis period when there is a significant probability gain for the occurrence of a major regional earthquake, there are numerous possible actions that may be considered, within the context of an OEF. These are most instructively classified within a general taxonomy of loss mitigating actions. The taxonomy of potential actions spans the disaster risk management spectrum from preparatory planning actions to crisis management activities to post-event loss reduction measures.

In contrast with a traditional seismological perspective, where action options have been perceived as essentially binary – evacuate or not, the spectrum of potential actions forms a continuum. At the highest end of this continuum is general evacuation; for which an implausibly large probability gain would be needed. But at the lowest end of this spectrum are actions which should be included as part of routine seismic safety management in an active seismic zone, and hence do not need any probability gain to justify.

Operational Earthquake Forecasts (OEF) may be issued to motivate a diverse range of potential mitigating actions that might reduce the risk of casualties should a major earthquake occur. Most of these possible actions involve the active and informed cooperation of citizens in the region affected. Guidelines for the involvement of citizens should respect key principles which provide a platform for OEF participatory decision making. These principles include the democratic right of citizens to information and choice; the need for basic training and education on risk issues to enable citizens to make more evidence-based decisions; the opportunities for governments to nudge rather than coerce citizens into taking OEF actions; the scope for application of the precautionary principle or its variants; and the over-arching need for decisions to be rational, equitable and defensible.

This taxonomy is comprised of seven general classes of action, all of which aim to make society more resilient against any imminent major regional earthquake, suffer smaller loss and recover more successfully, should an operationally forecast earthquake actually occur.

1. *Actions to increase public situation awareness,* and raise the level of knowledge and understanding about the current seismic crisis;

2. *Actions to acquire supplementary data*, so as to improve both the quality and the quantity of the risk information databases for decision making;

3. *Actions to improve civil protection and societal preparedness* in the event of a major earthquake occurring, so to expedite effective and efficient disaster response;

4. *Actions to reduce regional vulnerability*, so as to lessen the societal impact of any ground-shaking footprint, or of associated secondary hazards such as fault rupture, tsunamis, landslides, fire following earthquake;

5. *Actions to curtail transportation, commercial and industrial activity* which might pose special dangers if an earthquake were to occur;

6. *Actions to reduce exposure in vulnerable buildings*, so as to minimize the population in particular danger.

7. *Actions to transfer financial loss* such as through insurance purchase and mortgage guarantees.

The first three actions are essentially strategic, and mainly involve civic authorities. They aim to inform the public, to acquire better regional data of all kinds to support decision making, and to enhance disaster preparedness. Societal risk is a product of hazard, vulnerability and exposure. Risk can be mitigated through measures to reduce vulnerability, avoid vulnerable structures, or decrease the human and physical assets in the region at risk. These pro-active and potentially costly risk mitigation measures comprise actions four to six listed above. Physical risk cannot be transferred; but financial risk can be. The last action relates to financial market instruments for risk mitigation, including home and accident insurance.

Acting in accord with social evidence is a standard behavioural trait underpinning efforts made by corporations and governments at public persuasion. To answer the key public policy question how people can be helped to make good decisions for themselves, without a curtailment of freedom, Thaler and Sunstein [7] have developed the nudge principle. Advocating a policy of libertarian paternalism, they have suggested ways in which people can be nudged, rather than coerced or obliged, to make decisions that serve their own long-term interests. There are informed and unintrusive ways of achieving this goal. But it takes enterprise and creativity to find viable solutions to the challenge of helping people to make good decisions for themselves. The idea of nudging citizens to act in their own safety interest is popular with democratic governments espousing the principles of participatory politics, and happy to encourage each individual to take the responsibility of being his or her own decision maker. Of course, when danger is associated with a very high degree of certainty, then civic authorities have a clear statutory and moral obligation to act to protect the public. Earthquake forecasting would hardly ever be associated with high certainty, so nudging would be helpful to justify and motivate practical loss mitigation measures. Ultimately every corporation and individual has freedom of choice, and consequently will have to shoulder some burden of responsibility for seismic safety [8], including deciding on mitigating action. The following broad survey of possible actions considers them in an overall cost-benefit context.

2.1 Public Situation Awareness

In any hazard context, situation awareness helps people to make better decisions for themselves, families, neighbours and colleagues. The loss impact of an earthquake would be reduced if there were a regional education campaign to increase public knowledge and understanding of a seismic crisis, and reduce the societal prevalence of ignorance of basic seismic safety procedures. An emphasis on public education is an important element of 'nudge' campaigns. Before individuals can make a sensible choice for themselves and their families, they need information.

It is standard practice for large offices to hold fire drills from time to time so that office workers are familiar with the procedure for responding to an alarm and evacuating their building. As long as these drills are infrequent, not more than once or twice a year, the temporary disruption to office work is not perceived as having an unduly heavy cost burden; rather, it is widely recognized by office managers that the safety preparedness benefits of an occasional fire drill outweigh the work disruption costs.

Similarly, during an occasional seismic crisis in a given region, the organization of an earthquake drill should be recognized as being cost-effective, provided that they are infrequent. If there has been a previous seismic crisis in the past several years, there may not be a need for an earthquake drill. Otherwise it should be positively beneficial in increasing risk awareness. Other methods of disseminating information include special school and adult education classes. Because public education on earthquake risk should happen as a matter of course on a continuous basis, the marginal cost of having extra education during seismic crises should be reckoned as minimal. Formally, the extra education cost might be maintained below some minor fraction of the annual education budget.

2.2 Supplementary Data Acquisition

It is true in almost all circumstances that better decisions can be made if more data are acquired. Even if data procurement may consume resources, ignorance may be even more costly. Supplementary data can improve overall understanding of the regional geography of risk, and reduce uncertainty in the assessment of public danger. Data acquisition to improve decision-making is recognized to be one of the most cost-effective ways of mitigating risk.

During a seismic crisis, it is the customary function of the regional or national seismological institute to increase seismic surveillance with the deployment of a local seismic network. This would be expected even if the region had very low population density. Hence the marginal cost of enhancement of local seismic monitoring should be considered as minimal. In any public emergency, accounting for the size of the population at risk is a prerequisite for informed decision making on public safety. In particular, estimates of the population size in different zones, and at different times of the day or night, are very helpful for gauging the efficacy of alternative safety initiatives, and for refining cost-benefit analyses. To this extent, undertaking a population survey is highly beneficial, and could be undertaken at small cost, using available online databases.

In the aftermath of an earthquake that is known to have caused some building damage, as a matter of course, it would be desirable to undertake a general survey of buildings in the areas where damage has occurred. Normally, such a survey might be conducted by structural engineers over a number of months. If subsequent to a damaging earthquake, the probability gain for another event is substantial, then there should be safety justification for this survey to be expedited. It should be stressed that the purpose of a survey is not at this stage to assess repair strategies; entering a damaged building during an aftershock sequence may be dangerous.

3. Real-time operational earthquake forecasting

Seismic monitoring is a continuous round-the-clock process, rather like meteorological monitoring of the weather. Especially during seismic swarms or aftershock sequences, significant dynamic changes in probability gain of a damaging earthquake are liable to happen potentially at any time. The temporal volatility in probability gain requires protocols to be established for real-time OEF, with advisories on a range of possible mitigating actions issued promptly, in different time frames, as often as is demanded by the evolving seismic crisis situation.

During an actual seismic crisis, there will be numerous possible actions that might be considered and potentially advised. However, there would be only a brief time window for a decision maker to consider them systematically via a cost-benefit analysis. Necessarily, the opportunity to gather additional information and undertake computer analysis to refine the estimation of costs and benefits will also be limited. This situation could be improved if as much relevant information as possible were to be acquired, processed and archived well in advance of any seismic crisis.

Recognizing an intrinsic level of imprecision in estimating the costs of many mitigating actions and the associated benefits in damage and casualty reduction, not to mention the epistemic uncertainty in estimating event likelihood, the most robust and publicly defensible actions will be those justified by making some plausible, sensible and judicious approximations. The art of sound approximation is an essential aspect of all practical hazard modelling in support of decision-making under uncertainty, and is key to the optimal selection and suggestion of OEF advisory actions.

In the immediate aftermath of any hazard event, there are many stakeholders in the public and private sectors with an interest in estimating casualties and damage. Accident and emergency rooms in hospitals need some idea of the serious casualty count so that the maximum number of those with life-threatening injuries can be treated within the vital 'golden hour'. The fire and police departments need some sense of how many fires may break out, and how many people might need to be rescued. Aid agencies and NGOs need to assess short-term aid requirements. If there were only a few types of disaster to expect, highly specific preparedness measures might be adopted. But the possible crisis situations are numerous, and action has often to be decided rapidly and flexibly under time pressure and limited information.

3.1 Benefit-Cost Ratio Guidelines for Civil Protection

To consider the manner in which civil protection decisions can be supported by cost-benefit analysis, denote the benefit-cost ratio as the product of event Probability P and Loss L divided by Cost $C : R = P * L / C$. For practical real-time decision making purposes, the range can be discretized into five coarse bands: less than 1; between 1 and 2; between 2 and 5; between 5 and 10; and above 10. Based on the best estimate made, R can be assigned to one of these bands. Having five bands rather than fewer provides for greater resolution in borderline decision situations where an action may just be warranted.

There is of course significant uncertainty in the real-time estimation of each of the parameters P, L, and C. In contrast with volcano eruption forecasting, earthquake event probabilities are invariably low or very low. Furthermore, from the output analysis of an ensemble of alternative seismological forecasting models, depending on the ambiguity in interpreting the seismological event time series, there may be potentially up to an order of magnitude error either way in estimating P.

The potential error in estimating the dimensionless ratio L / C might also be an order of magnitude either way, given the uncertainties in the number of casualties saved through a risk mitigating action. Even in a single apartment building, the fatality count might differ by a sizeable multiple, according to the extent of building failure or mode of collapse, and its day and night time occupancy. The fact that the costs of mitigating action C are necessarily constrained by available finite financial budgets limits the uncertainty in this ratio from being still larger. The estimation errors for P and L/C are uncorrelated; unlike terrorist attacks, earthquakes do not strike preferentially when the casualty potential is especially high.

Jaiswal et al. [9] outline three casualty estimation methods: empirical, analytical and hybrid. The empirical approach is driven by fatality observations. The analytical approach is based on detailed structural modelling of buildings. The hybrid model is less rigorous in engineering terms, but it does involve estimating the collapse probability of a particular structural type, subject to input ground shaking. In general, whilst there may be scope for use of the analytical or hybrid approaches for some specific important yet seismically vulnerable buildings, the simpler empirical approach is most practical for real-time OEF. For shaking intensity S, the fatality rate $\nu(S)$ is expressed as a lognormal distribution [10]:

$$\nu(S) = \Phi\left[\frac{1}{\beta}\ln\left(\frac{S}{\theta}\right)\right] \tag{1}$$

Denoting the regional population exposed to earthquake shaking S as $N(S)$, the expected number of fatalities in a region is the weighted sum:

$$E(L) = \sum_j \nu(S_j)\,.\,N(S_j) \tag{2}$$

The USGS casualty estimation system PAGER [9] models fatalities using a lognormal distribution, based on a worldwide data study of 4,500 earthquakes. The long tail of this distribution is a consequence of the engineering variability in the collapse dynamics of a mixture of vulnerable buildings of all kinds. For the PAGER alert, the probability that the number of fatalities lies within the range from a to b is:

$$P(a < D \le b) = \Phi\left[\frac{\ln(b) - \ln(E)}{\varsigma}\right] - \Phi\left[\frac{\ln(a) - \ln(E)}{\varsigma}\right] \tag{3}$$

The benefit-cost ratio $R = P * L / C$ is a non-negative function having a probability distribution characterized by a long tail. Taking logarithms, and noting the independence of the three factors P, L, C, the benefit-cost ratio should also be reasonably approximated by a lognormal distribution, such as is widely adopted in engineering safety and reliability analysis. Assuming this two parameter distribution for the benefit-cost ratio, the likelihood that this ratio exceeds unity can be evaluated. Taking the median to be in one of the five designated bands, and assuming here that the order of magnitude possible errors either way in both P and L/R correspond to about three standard deviations from the best estimate, then confidence levels that the benefit-cost ratio exceeds unity can be quantified from the lognormal distribution as indicated in Table 1.

From this table, if R is between 1 and 2, then there is 60% confidence that the benefits of action exceed the costs. This is a borderline modest confidence situation, and is designated by a green colour, the lowest ranking colour as in other hazard warning codes. If R is between 2 and 5, then there is 70% confidence that the benefits of action exceed the costs. This is a moderate confidence situation, and is designated by a blue colour. If R is between 5 and 10, then there is 80% confidence that the benefits of action exceed the costs. This is a high confidence situation, and is designated by a orange colour. If R exceeds 10, then there is 90% confidence that the benefits of action exceed the costs. This is a very high confidence situation, and is designated by a red colour.

Table 1: Illustrative benefit-cost ratio colour-coded decision table

Confidence	**1 > R**	**1 > R ≥ 2**	**5 > R ≥ 2**	**10 > R ≥ 5**	**R ≥ 10**
60%	No action	**Action**	**Action**	**Action**	**Action**
70%	No action	No action	**Action**	**Action**	**Action**
80%	No action	No action	No action	**Action**	**Action**
90%	No action	No action	No action	No action	**Action**

If the estimated R value is large, i.e. greater than 5, then a decision maker can be very confident that action is justified by the benefits outweighing the costs. If the estimated R value is moderate, i.e. between 2 and 5, then a decision maker can be reasonably confident that action is justified by the benefits outweighing the costs. However, if the estimated R is only between 1 and 2, then a decision maker could only have a rather modest degree of confidence. Of course, if the estimated R falls below unity, then there would be little confidence that the benefits would outweigh the costs.

Needless to say, the entries in this table are general guidelines as informative benchmarks to support civil protection decision-making. In any specific crisis situation, the level of risk aversion appropriate for the context would be a matter for the civil protection staff themselves to assess. Thus, an action might be suggested, even though it has just the green or blue code. These two colour codes provide flexibility in an OEF protocol system, allowing decision-makers more opportunity to exercise their own judgement. Too rigid a protocol system would be unduly restrictive. Conversely, there may be some orange or red code actions that decision makers may decide not to recommend or advise. The bureaucracy alone of organizing a set of actions efficiently may strictly limit the number of feasible actions. But whatever the decision, it should be better informed by prior reference to Table 1.

3.2 Benefit-Cost Ratio Guidelines for Citizens and their Families

Whatever directives or advisories there may be from civil protection decision makers, citizens of democratic states will wish to use the information available to exercise their own right to make a choice which affects the safety of themselves and their families. The population of a region threatened by an elevated seismic hazard is far from homogeneous in risk perception. Crucially, there are key psychological differences between people in their sense of risk aversion, and their locus of control in having the power to influence outcomes in their daily lives.

Through informal community self-organization, rather than authoritarian top-down mandate, societal risk from natural hazards can be managed more effectively. Thus, even though civic authorities may have only very limited space to accommodate evacuees, individuals in vulnerable buildings can find a way to stay with neighbours, friends and relatives fortunate to be living in seismically resistant buildings. Particularly for individuals who might be especially risk averse, for personal, family, or professional reasons, an earthquake advisory would be welcomed as additional key information upon which to exercise their own choice of safety risk management. Traditionally, decisions on dealing with natural hazards have not been based on the adoption of formal risk management methods, but rather on the exercise of informal subjective judgements. These are prone to an assortment of well-known human cognitive biases, not least optimism that a damaging event will not happen, or if it does, that it will not harm them seriously.

3.3 Benefit-Cost Ratio Guidelines for Businesses

Where public safety may be at stake beyond the perimeter fence of an industrial plant, civil protection may mandate the implementation of specific risk mitigation measures, during a seismic crisis. The reduction of hazardous inventory levels at a petrochemical plant is an illustration of this. But whatever directives or advisories there may be from civil protection decision makers, business managers will wish to use the information available to promote the safety of their staff and corporate well-being. Thus, irrespective of any intervention from civil protection, risk reduction measures may be justified by internal cost-benefit economics. For example, reduction in hazardous inventory could reduce significantly the corporate loss impact of a fire or explosion following an earthquake. Yet the cost of inventory reduction might be kept low through judicious operational planning.

For some specific high-value assets, e.g. a critical industrial installation, a corporation may already have had a seismic vulnerability and/or risk study undertaken. Such studies are common for nuclear and petrochemical plants, as well as dams. Seismic analyses carried out for a plant could be used as an earthquake engineering basis for a site-specific detailed cost-benefit analysis that could inform decisions during a seismic crisis. Well in advance of any crisis, for a range of earthquake probability values, potential actions could be systematically prioritized. In principle, the uncertainty over the loss-cost leverage ratio L/C should be narrowed by site-specific seismic risk analysis, which would increase the confidence associated with taking any action.

3.4 Loss-Cost Leverage Ratio

Whether for a government organization, corporation or an individual, a basic dimensionless measure of the mitigation worth of an action is L/C, the leverage ratio of the potential loss mitigated by the action to the cost of the action. The loss is expressed in the same currency as the cost. Given that short-term event probabilities are invariably low, a high leverage ratio is crucial for an action to be rationally justifiable. Leaving aside parameter uncertainty, the zone of potential risk mitigation action is indicated by the shaded area in the leverage loss-cost diagram shown in Fig. 1. The smaller that P is, the steeper is the gradient of the L/C line, and the narrower is the zone of justifiable cost-benefit action.

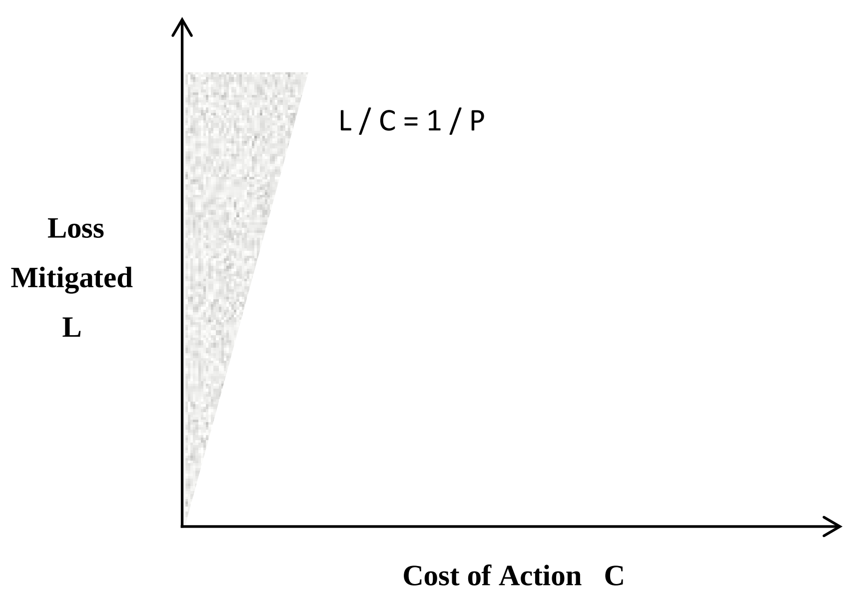

Fig. 1: Leverage loss-cost diagram

In order for the leverage ratio to lie within the shaded zone, the cost has to be kept within quite tight bounds. Thus it is only worthwhile for people to leave their homes if there is a low-cost option for them to stay elsewhere: large scale evacuation would involve a cost well beyond the shaded zone. Many actions involve only marginal additional costs. Even if the corresponding mitigated losses may not necessarily be large, the leverage loss-cost ratio might still be high enough to justify action. Thus bringing forward planned risk mitigation measures is worth consideration, even if undertaking new measures may not. As with terrorism risk, heightened public vigilance is a very modest price to pay to avoid the heavy costs of potential carnage.

It is an adage of disaster management that money spent before a disaster can reduce loss by a sizeable factor. Kelman [11] has conducted a survey of these loss factors, which might be around 4. This is a more compelling argument for flood risk mitigation in heavily flood-prone regions than for earthquake risk mitigation in areas of moderate seismic hazard, where the chance of an earthquake is comparatively low, even if there is a substantial probability gain during a seismic crisis.

Some specific OEF actions targeted at critical industrial installations, such as nuclear and chemical plants, can attain the high leverage in loss-cost needed for their justification, because of the prospect of massive environmental pollution. Otherwise, the focus should be on actions that reduce the level of human loss. Actions that are likely to save lives during strong ground shaking tend to have high loss-cost leverage in the industrialized world, where the willingness to pay to save a life is much higher than in the developing world. This encourages a European focus on the most vulnerable collapse-prone buildings in the region exposed to a heightened seismic threat.

4. Conclusions

With an EEW system, an earthquake has actually happened, its epicentre is known and its magnitude is approximately estimated. An EEW target, such as a school building or railway, is well instrumented, and its seismic response and vulnerability to strong ground shaking are quite thoroughly analysed. Accordingly, compared with OEF, there is much less epistemic uncertainty in a cost-benefit analysis.

Crucially, with an EEF system, an instantaneous real-time decision is required on triggering a risk mitigating action, such as having school-children duck under a table or halting a train. There is no time to review the earthquake data and vulnerability assessment before anybody decides what action, if any, to take. For an EEF, an instantaneous objective algorithm is required: this is the expected loss minimization algorithm described by Iervolino et al. [12]. The optimal EEW decision is to alarm if the expected loss with the warning is less than the expected loss absent the warning.

If only there were hours rather than seconds in which to make a decision, then the epistemic uncertainty in the EEW decision criterion might be scrutinized, and perhaps the decision might be adjusted. In practice, this is impossible with EEW, but it is possible with OEF. Guidelines should not be over-prescriptive; decision-makers need some space to make their own decisions. According to the level of confidence that the benefits of an action really do outweigh the costs, decision-makers are empowered to play an active role in specifying the actions that can be taken to mitigate risk during a seismic crisis. It is therefore suggested that confidence level tables be provided as decision support for OEF quantitative protocols.

4. Acknowledgement

This work was partly supported by European Union FP7 Seventh Framework Program for Research project No.282862: REAKT.

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