The Quantified Tree Risk Assessment System
A New Approach to Tree Safety Management

Historically, the arborist has been relied upon to make judgements about the safety of trees. The tree owner or manager's expectation is often that the arborist will provide a definitive opinion as to whether or not trees are safe. Arborists seem to accept this position and often yield to the demands of clients and lawyers by stating that this tree is safe, that tree is unsafe. Would a doctor commit him/herself to assuring you that you will not become ill during the coming year, or an engineer that your car won't be involved in an accident this year? No, of course not, there are degrees of risk associated with tree failure as there are with other health and safety issues and there are degrees of benefit to be derived from trees.

When providing advice, how then does the arborist avoid making unqualified judgements on tree safety? After all, even the most cautious and prudent arborists must provide guidance to clients. Without a method of measuring the comparative risks from tree failure, advice is likely to err heavily on the side of caution and result in tree removal or other remedial measures more often than is actually necessary. If we adopt a probabilistic risk assessment approach and provide a reasonable and justifiable limit of acceptable risk, arborists can give tree managers odds of harm occurring as a result of tree failure and managers can make well informed decisions.

For a tree-failure hazard to exist there must be potential for failure of the tree, and potential for injury or damage to result from failure. The issue that the tree manager should address is the likelihood, or risk, of a combination of these factors resulting in harm, and the likely severity of harm. Tree managers often rely on the subjective judgement of a succession of arborists when formulating management strategies and addressing budget requirements. In turn, the arborist often feels compelled to be seen to be doing something, sometimes recommending work that they consider necessary for the abatement of a hazard but often recommending work just to be seen to be doing something; being seen to fulfil their duty of care. This approach can result in unnecessary cost and the degradation of both the amenity and conservation value of a site, without having first established the risk of significant harm arising from the hazard.

Many tree owners and managers have no policies or procedures for the management of tree safety and react to only the most extreme of hazardous situations as they arise. Others do nothing more than clear fallen trees. At the other end of the scale, some landowners' set large budgets for tree safety management that may be disproportionate to the risks being managed. The Quantified Tree Risk Assessment system (QTRA) presents a new opportunity to apply tree safety management resources to a structured risk assessment program. Starting with an overview of land use and tree distribution classified by gross features such as age and species we can prioritise risk assessments and refine them to greatest effect according to the availability of resources.

Balancing Risk with Benefits

Tree managers work in a climate of increasing environmental awareness, in which trees are greatly valued and yet are potentially hazardous. There is often a need to reconcile different management objectives, especially on sites where old and perhaps structurally unstable trees are present. As trees age, they increasingly develop features that might compromise their mechanical integrity whilst at the same time providing increasingly diverse wildlife habitats and visual interest. Cavities, fissures and decaying wood together with other niches in the tree, provide habitats for many plants and animals. A large proportion of higher value habitat trees occur in rural areas, but it is important to recognise that there are also many such trees on the streets of our towns and in gardens, churchyards and city parks.

Trees confer many other benefits, being essential to our well being and generally enhancing our built and natural environments. Most trees are to some degree hazardous in that they have potential, no matter how limited, to cause harm but the removal of all tree hazards would lead to certain impoverishment in the quality of human life. Therefore, it is necessary to maintain a balance between the benefits of risk reduction and the cost of that risk reduction, not only financially but also in terms of lost amenity and other tree related benefits.

Do we have Reasonable Expectations of Tree Safety Management?

Property owners and managers, from single householders to municipalities, have a duty of care under the laws of most developed countries to ensure that people and property are not exposed to unreasonable levels of risk from the failure of their trees. In the UK, USA and Australia, for example, failure of duty of care in respect of tree safety is usually prosecuted under the tort of negligence (a tort is a law that has developed through court judgements and is referred to as 'Common Law' rather than being written in 'Statute Law').

To provide an adequate defence in the event of harm resulting from tree failure, it is usually necessary to demonstrate that you have acted reasonably in the management of your trees. In most circumstances, to do absolutely nothing is probably unreasonable. Conversely to throw money at tree safety management is usually unnecessary. Tree managers are generally expected to manage risks associated with trees to maintain them as low as is reasonably practicable.

The concept of 'Reasonable Practicability' is embodied in English and Australian statute law. In essence, 'Reasonable Practicability' is the principle of doing as much or as little as a reasonable person might be expected to do in any particular circumstances. If the defendant in a legal action has established that a risk is small, but that the measures necessary to reduce or eliminate it are great, he or she may be held to be exonerated from taking steps to reduce or eliminate the risk on the ground that it was not reasonably practicable to do so. For example, if a fairground ride were constructed to be absolutely safe, there would be little excitement in the ride, so designers of fairground rides seek a balance somewhere between the ultimate in exhilaration on one hand and absolute safety on the other. The level of risk that users of the ride might be exposed to will usually be reasonable in relation to the thrill that they seek from it

In respect of trees, the concept of 'Reasonable Practicability' can be embraced by considering together the degrees of both risks and benefits associated with trees. Lee Paine of the US Forest Service (Paine 1971) wrote, "It is high time we admit that we cannot achieve complete safety – and still provide a desirable product – any more than industry can". This statement captures the essence of 'Reasonable Practicability' and holds true to the present day. It is time to acknowledge that tree safety management should not require us to minimise the risks associated with trees or to make false or unqualified statements such as 'this tree is safe' or 'that tree is unsafe'. Instead, risk of harm from tree failure should be managed at acceptable levels whilst maintaining or maximising the multitude of benefits conferred by trees.

Acceptable Risk

We are constantly exposed to and accept or reject risks of varying degrees. For example, if we desire the convenience of electric lighting, we must accept that, having implemented control measures such as insulation, there is a low risk of electrocution; this is an everyday risk taken and accepted by millions of people.

Having considered The British Medical Association Guide "Living with Risk" (Henderson 1987) and with particular reference to the conclusion "few people would commit their own resources to reduce an annual risk of death that was already as low as 1/10,000", Rodney Helliwell (Helliwell 1990) suggests that 1/10,000 might be a suitable figure to start with as a limit of acceptable risk. The UK Health and Safety Executive (HSE) suggests, "For members of the public who have a risk imposed on them 'in the wider interest' HSE would set this limit at 1/10,000 per annum" (Health and Safety Executive 1996). In the management of trees, a property owner or manager might therefore adopt the 1/10,000 limit of acceptable risk or choose to operate to a higher or lower level.

To put the 1/10,000 probability of significant harm into perspective, table 1 is reproduced from the British Medical Association Guide and illustrates the risk of death (in 1987) from a range of hazards.

Activity	Risk of an individual dying in any one year
Smoking 10 cigarettes a day	1 in 200
Influenza	1 in 500
Road accident	1 in 8,000
Playing football	1 in 25,000
Accident at home	1 in 26,000
Accident at work	1 in 43,000
Hit by lighting	1 in 10,000,000
Release of radiation from nearby nuclear power station	1 in 10,000,000

Table 1. ("Living with Risk", British Medical Association, 1987)

The Quantified Tree Risk Assessment System

The Quantified Tree Risk Assessment system is a probabilistic method of assessing the risk of significant harm from the mechanical failure of trees and expands concepts proposed by Paine (1971), Helliwell (1990, 1991) and Matheny and Clark (1994). QTRA provides a framework for the assessment of the three components of tree-failure risk – Target Value, Probability of Failure and Impact Potential. By first assessing the value or usage of targets upon which trees might fail, tree owners and site managers can establish whether or not and at what degree of rigour tree surveys are required. Where necessary, trees are then considered in terms of both impact potential (size) and probability of failure. Values derived for these three components are then multiplied together and their product is the probability of death or significant harm.

Although it might seem counterintuitive, whether or not trees have significant potential to fail should not be the first consideration. Instead tree managers should consider first the usage of the land on which a tree stands and this in turn will inform the assessment of the trees themselves. Common sense tells us that a large unstable tree located in a remote wilderness might represent a very low risk of harm to people and property but as the interface between trees and human activity becomes more intimate, the risk of harm from tree failure will increase. Harm from trees is measured in terms of loss of life or serious injury, or as monetary loss from damage to property.

The system moves the management of tree safety away from considering trees as either safe or unsafe and thereby requiring definitive judgements of either tree surveyors or tree managers. QTRA is used to quantify the risk of significant harm from tree failure in a way that enables tree managers to balance safety with tree values and operate to a predetermined limit of reasonable or acceptable risk. The system proposes adoption of 1/10,000 as a reasonable limit of acceptable risk from tree failure, although a property owner or manager might adopt the 1/10,000 limit of acceptable risk or choose to operate to a higher or lower level.

Using the Quantified Tree Risk Assessment system, it is possible, not only to identify unacceptable risks, but also to identify the components of the risk, which when adjusted will effectively reduce the overall risk of harm in the most cost efficient or appropriate manner.

Calculating the Risk of Harm

Target Evaluation. A target is anything of value, which could be harmed in the event of tree failure. Target value is the most significant and most easily quantified element of the assessment. Using QTRA we evaluate the nature of the targets within a survey area before the assessment of trees. This approach enables the tree manager to justify the prioritisation of tree surveys and establish the degree of rigour required of the risk assessment.

When working in the field, manual calculation of probabilities is impractical. To facilitate field assessment, a calculator has been developed (Fig. 1) comprising three vanes, which are rotated to select values from predetermined ranges of probability and calculate the product of the three component probabilities. Having assessed the hazard and the target, the three component probabilities are selected from the ranges 1-6 on the calculator and the three vanes are aligned to display the result in a window. The calculator displays the result as an index (one thousandth of the reciprocal) of overall probability, which is termed the 'Risk Index' For example, if the risk of harm is 1/10,000, the Risk Index is 10 (10,000 ÷ 1000 = 10). Alternatively, a digital calculator has been developed for use with tree inventory software.

Weather conditions greatly influence tree failure. A walk through woodland and other recreational areas after a moderate storm will often reveal paths and tracks littered with dead and recently living branches. The same weather conditions might at the same time result in reduced pedestrian access to recreational areas, substantially reducing the risk of harm from tree-failure. Often the nature of a defect is such that the probability of failure is greater during windy weather, whilst the probability of the site being occupied during such weather conditions is considerably reduced, e.g. woodland, park or private garden. People may venture beneath trees during high winds either in the pursuit of recreation, thus voluntarily contributing to their increased exposure harm from tree failure, or out of necessity such as en route from home to a workplace. Even in the latter example, weather conditions may be so extreme that the risk of harm from the failure of not only trees but the collapse of buildings and other storm related hazards is such that to venture out at all would be foolhardy. Conversely, the risk of branch failure in tree species susceptible to summer branch drop increases during periods of hot dry weather when pedestrians might seek shade beneath trees. QTRA includes a facility for considering these scenarios.

Impact Potential. The system categorises impact potential by the diameter of tree stems and branches. An equation derived from weight measurements of trees of different stem diameters is used to produce a data set of comparative weight estimates of trees and branches ranging from 10 to 600 mm diameter. The system uses a fraction of the dry weight of the 600 mm diameter tree in calculating probability of harm. Expressed in this way, a 10mm diameter tree is 1/23,505 of a 600mm diameter tree and a 250mm tree is 1/8.604 of a 600mm diameter tree.

Probability of Failure. Accurately assessing the probability that a tree or branch will fail is highly dependant upon the skill and experience of the assessor. Having assessed the tree, the assessor visualises 1,000, 100, or 10 similar trees in a similar state in a similar environment and estimates how many would be likely to fail during the coming year.

QTRA significantly reduces the influence of assessor subjectivity upon the outcome of the risk assessment and applies a robust structure to the assessment procedure, requiring detailed assessment of the tree only where there is a significant likelihood of unacceptable risk. By first evaluating and mapping both the general nature of the tree population within an administrative area and the range of targets upon which they could fail, the manager of a large tree population can identify the interface between trees and targets, thus enabling prioritization of risk assessments. A post-mature tree population adjacent to a busy urban thoroughfare might require biannual assessment, whereas the same tree population in a remote wilderness might never be assessed in detail. Between these extremes is a range of inspection frequency, which should be applied as appropriate to the situation.
Use of the system without training leads to misapplication of the data. To ensure, insofar as practicable, that the value of the system is maintained through consistent application training and ongoing development through a licensing programme is being developed in the United Kingdom.

Examples

Example 1

A 25.0 metre high, mature pedunculate oak (*Quercus robur*), stem diameter 900mm, in a low use area of woodland with no regularly used paths within 30.0 metres but with members of the public occasionally entering the target area. This is a mechanically unstable tree with extensive heartwood decay within the main stem and primary branches. A large opening extends to 30% of the stem girth from ground level to a height of 1.5 metres. The residual stem wall averages 100mm thick and exhibits ongoing longitudinal cracking. The crown of the tree contains extensive large diameter dead wood.
The most significant part likely to strike the target area is the stem or part of the crown with the weight of the whole tree behind it.

	Target Value		Impact Potential		Probability of Failure		Risk of Harm
Probability Ratio	1/120,960	x	1/1	x	1/1	=	1/120,960

The absence of structures and the very low level of public access indicate that detailed assessment of the tree is not essential. If it could be established that pedestrians are 10 times less likely to visit the woodland in very windy weather, when failure is most likely, the overall probability of harm could be reduced to 1/1,209,600 or less.

Example 2a

(before remedial action)

A mature beech (*Fagus sylvatica*) overhanging a minor road of moderate use. The crown of the tree contains long unstable dead branches up to 100mm (4") diameter. The most significant part likely to strike the target area is dead branchwood up to 100mm diameter.

	Target Value		Impact Potential		Probability of Failure		Risk of Harm
Probability Ratio	1/72	x	1/82	x	1/1	=	1/5,904

To reduce the risk to a broadly acceptable level an overall probability of 1/10,000 must be achieved. Removal of all dead wood is unnecessary. Removal of dead branches greater than 50mm (2") diameter overhanging the target should reduce the risk to an acceptable level. See example 4 for a method of considering dead or otherwise degraded trees and branches. We might also consider the reduced mass of the dead branches (see example 3).

Example 2b

(after remedial action)

	Target Value		Impact Potential		Probability of Failure		Risk of Harm
Probability Ratio	1/72	x	1/450	x	1/1	=	1/32,400

Example 3.

A mature sycamore (Acer pseudoplatanus) with a dead branch of 250mm dia. overhanging a thoroughfare with pedestrian occupancy of 9 per hour. The most significant part likely to strike the target is the 250mm dia. dead branch

	Target Value		Impact Potential		Probability of Failure		Risk of Harm
Probability Ratio	1/72	x	1/8.6	x	1/10	=	1/6,192

However, by shedding subordinate branches, the dead branch has degraded to less than half of its original mass. To reflect a mass reduced to 50% or less, the Risk Index 6.19 is multiplied by 2 to produce a revised Risk Index of 12.38 (Risk of Harm 1/12,380).