Tree Risk Assessments – What Works – What Does Not – Can We Tell?

A review of a range of existing tree risk assessment methods

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Abstract

During the last decade tree risk assessments have become a commonplace activity for many arborists. As part of a Master Degree research project at The University of Melbourne some 23 tree risk methods were accumulated, from these some 15 were further analysed.

These 15 methods were applied to a range of urban trees and situations and sensitivity analysis was used to determine the influence of individual assessment criterion on the output value in each of these models. A further trial was conducted where 12 experienced arborists used eight of these methods to assess eight different trees in varying urban situations; some of these data and observations are reported. Analyses of results indicate that differences exist amongst methods caused by assessment categories types, weighting, and mathematics. Equally, large differences in estimating risk assessment variables were identified amongst arborists.

To some degree, this paper should be considered to be based on preliminary data. The complex relationships and large datasets suggest that some caution should be applied when interpreting the presented results until the all datasets and statistical analysis are fully reviewed.

1 Introduction

Risk assessment of trees is a relatively recent development. Certainly it is difficult to locate much in the literature before the 1970s (e.g., Paine 1971), a few USADAFS papers from the late 1950 and early 1960s exist including Wagener's 1963 seminar paper (Wagener 1963). Little discussion exists even into the 1980s (Evans 1981; Johnson 1981). From an urban tree perspective, one of the earlier publications was Matheny and Clarke's 1994 publication a mere 13 years ago.

If this concern with urban tree risks is a relatively recent development; why the change? Did trees become a greater risk? Was there a sudden increase in the number of tree caused fatalities of people injured by trees?

Whilst it is possible that tree damage related drivers were responsible, no evidence has been found in the literature. The more likely reasons are, firstly the development of what Beck (1992) termed a 'risk society' and secondly the increasing demands from insurance companies for better 'risk management', albeit possibly driven by increasing claims particularly against local government Figure 1 (Trowbridge Consulting 2002).

It is also possible, that it is related to the continuous drive in a techno-scientific society to quantify data and risk.

Tree risk assessments are fundamentally based on a relatively simple methodology, essentially the risk assessment requires inputs derived from:

- is there a hazard (defect) and how likely is it to fail
- is there risk target and how much time is it there
- and finally how much damage could it cause

Typically, tree risk assessment methods have been relatively simple qualitative (subjective) methods using generally simple ordinal rank scores e.g., Matheny & Clarke. Whilst quantitative risk methods have been and still are widely used in many other risk assessment fields, with very few exceptions (see Kenyon 1993) none have been used until very recently in arboriculture. In 2005 Ellison (2005) introduced the probabilistic QTRA (Quantified Tree Risk Assessment) which offers a significant departure from the more traditional approaches, equally during this research a draft probabilistic methodology was developed (TRE QT – Tree Risk Evaluation Quantified). With quantitative methods both the methodology and the underlying processes appear to present issues to many arborists; suggesting that a significant paradigm shift will be required before the industry widely accepts quantitative assessment methods.

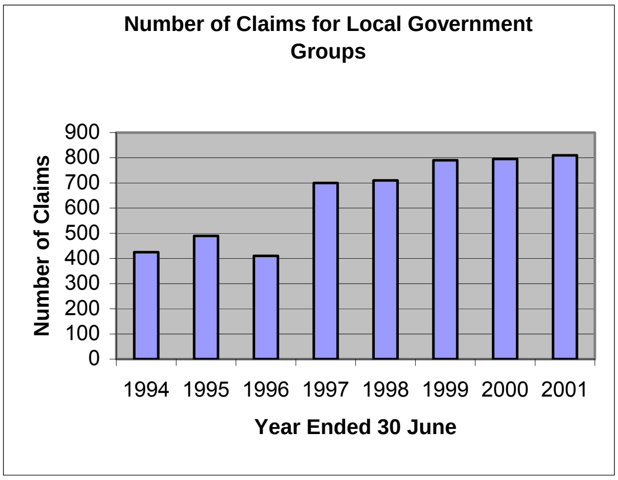


Figure 1 Number of claims for Local Government after (Trowbridge Consulting 2002)

Whilst undoubtedly, all tree risk/hazard assessment methods would contend that they are designed to measure risk in some form; the more important questions are:

- does the method describe all the important elements and relationships (Complete)
- is the method relatively insensitive to assumptions (Robust)
- are the outputs reasonable, believable and verifiable (Credible)
- does it depend on few assumptions, straightforward relationships and few parameters (Simple)
- can the data be gathered, and is it easy and economical to collect (Feasible)
- costs of data collection, preparation, analysis and reporting is reasonable for the type of decision (Economical)
- are the results repeatable by others in the same circumstances (Repeatable)
- does the method measure what it is designed to measure and do so accurately (Valid)

To these criteria we could also add the assessor aspects:

- do we know or understand what we are measuring
- what are the levels of uncertainty
- and what effect does the assessor have on the overall outcome of a risk assessment.

2 Definitions and discussion of definitions

One of the issue that appears to persist is the wide range and variability of definitions used in tree risk assessment. There are significant differences in the definitions of common risk terms used across the world. 'Risk' and 'Hazard' are two words commonly interposed, although the meanings are quite different. An Australian Standard for risk management (AS/NZS4360) was first released in 1995 and is currently in its third iteration (Standards Association of Australia 2004), it contained a range of definitions, hence, it would appear to be logical that these definitions are used. Norris (2005) summarised these definitions relative to tree risk assessment and made other suggestions to standardised terminology used in Australia.

Risk

Risk for the purposes of tree assessments is simply the chance of a specific undesired event occurring within a specified period. Simply put, Risk = Likelihood × Consequences (Standards Association of Australia 2004).

The assessment period is critical as it allows an evaluation of likelihood to be undertaken. All tree risk assessments must be defined by a timeframe.

Hazard

AS/NZS4360:2004 provides a simple definition of 'hazard' as '*a source of potential harm'*, this definition is derived from an international standard (ISO 3534 1993). This definition is similar to that used by Lonsdale (1999) in his '*Principles of Tree Hazard Assessment and Management'*. However, Matheny and Clark (1994) define hazard quite differently, as *'the combination of a failure of tree (or tree part) with the presence of an adjacent target*'.

A tree related hazard will generally be aligned to the defect(s) identified.

Clearly, these different definitions will cause confusion. It would seem prudent to use the definition provided in International and Australian standards.

Risk Target

AS/NZS4360 does not really consider the concept of target; however, it does use the term stakeholder to be mean 'those people who may be affected by a risk'. Stakeholders could include all who may be involved, including the owners or managers of the property or tree.

Target is used in the tree risk assessment literature to mean people or property at risk (Matheny and Clark 1994; Lonsdale 1999). Lonsdale does suggest that target is not a suitable term as it suggests something that is aimed for. The use of the term 'Risk Target' probably overcomes this issue.

It is suggested that the term 'Risk Target' be used to describe those people or property that/who may be affected by the hazard.

Defect

From a risk perspective, a defect is an identifiable fault in the tree. Defects and symptoms are not the same. e.g., decay is a defect, whilst a fungal fruiting body is merely a symptom or indicator of decay.

Trees may have multiple defects, most risk assessment methods propose using the most likely to fail defect as the measurable input for the probability of failure category. This may not be the defect related to the greatest risk, e.g., small deadwood is generally more likely to fail than a large codominant stem, however depending on the consequence and failure likelihood the codominant stem may be a far higher risk. Multiple defects are generally not considered or poorly considered by tree risk methods.

Size of Part

Most tree risk assessment methods use some form of 'size of part' to create a likely damage (consequence) value. However, often the size of part has only a limited relationship to the potential consequences e.g., compare the likely consequence from a 250mm branch impacting a house, car, person or park litterbin.

Equally the 'size of part' range used in many methods is extremely wide, e.g., M&C size 2, ranges from 15cm-45cm, using a simple allometric equations (e.g. Tritton and Hornbeck 1982; Keith, Barrett et al. 2000) calculates that this range covers from 82kg to 1300kg (dry weight).

Size of part criteria should be carefully considered as it is related to probability of damage (consequences). This assessment criteria is one reason why some methods under and overestimate risk (as noted above size of part is not linearly related to damage/consequences).

Likelihood of Failure

A generic description used to describe the overall possibility that a defect will fail within the risk assessment period.

Whilst it is not a difficult concept, in reality it is impossible to do more than apply 'expert assessment/opinion' as no data exists to quantify the assessment, on some sites and with some trees it maybe possible to use history to estimate a predicative value (equally history is not necessarily a good indicator of future performance).

Most methods use a 'number' linked to a descriptor e.g., M&C 'Failure Potential' Low (1), Medium (2), etc., the numbers are ordinal and hence do not represent anymore than at best a ranking.

Quantitative methods use a more precise (although not necessarily more accurate) definition, where the likelihood is described as a point, e.g., 1:100 or 0.01. This approach is difficult for many arborists to conceptualise or accept.

For general use, the term is likelihood is preferred over 'probability'.

Likelihood of impact

Simply the possibility that something of value (the risk target) will occupied the area. An obvious example is people walking under a tree in a park, the number, frequency and total time the area is occupied relative to a given period equals the likelihood of impact. Clearly a building under a tree has a near 100% likelihood of impact, whereas, a person spending 5 seconds walking under the same tree every day occupies the area for 1/17,280 of a day hence the likelihood of impact is far lower.

This category is often misunderstood, with assessors or methods assigning the assessment value based on the value of the target, e.g., it is a playground therefore it receives a very high score regardless that it may be only used for one hour a week.

Many methods provide descriptors for this assessment criterion; however, whilst these descriptors frequently appear initiatively correct, further consideration will demonstrate a range of inconsistencies.

This is an assessment category where the data can often be more accurately refined; e.g., traffic counters are available to assess people, bicycle and vehicle numbers.

Risk Rating/Score

All risk assessment methods produce an output value from the application of the methodology, commonly it is a number, although it can be a descriptor (e.g., low, medium, high). Many methods have different terms for this output value. It could be argued that a risk ranking was defining the output as a value relative to another number, not some absolute point; in reality, all existing tree risk assessment methods' output values are rankings (that is relative to something). This ranking is more pronounced with qualitative methods, e.g., a M&C output (Hazard Rating) is merely an ordinal figure, logically a M&C output of 6 is lower than 8, however, this does not necessarily reflect the risk level. For example, it is possible to have a scenario where the M&C 'Hazard Score' does not reflect risk even from a rank only perspective, e.g., 100mm dead tree branch over a house 3+1+4=8/12 compared to the same over an infrequently used park seat 3+1+2=6/12 (in this method the size of part does not adequately addresses likely injury/damage).

Quantitative methods imply a greater level of accuracy, and mathematically this is probably a reasonable position, however, this implied accuracy is limited by the precision of the input data, knowledge and the underlying assumptions inherent in the method must be understood. For example, QTRA uses the Impact Potential (Size of Part) to quantify 'damage', however this is based on the weight of a tree derived from an allometric equation and scaled from a maximum diameter tree of 600mm, there would be numerous occasions when the possible damage to a risk target (consequences) would be the same over a wide range of the tree part sizes, equally wood density (and hence mass) varies considerably. Scaling from a 1000mm or 400mm base value would create different risk output values.

Hence, risk scores and ratings are valuable but must be understood for what they represent.

Various methods provide guidelines for the risk scores, which leads to a discussion based on the concept of acceptable risk.

Acceptable Risk

Acceptable risk is a point where the overall 'risk' is considered at a level where no intervention or action is warranted, the difficulty is in setting such a level, in reality, in countries using the British Law process, no such point is set, and such considerations are decided by the courts in an adversarial process. However, some broad guidelines do exist.

Perhaps the most contentious or possibly least considered of the definitions used in tree risk assessment is the defining of what is, or is not an acceptable level of risk. Some methods use an 'easy out', and suggest this should be set by the client or based on available budget; in effect suggesting that (all?) identified works should be undertaken based on the priority of risk rating values. Many methods, particularly more recent methods are defining the meaning of the risk scores (at least to some degree), which in affect is defining an acceptable risk level.

QTRA has defined acceptable risk quite strongly by using the concept of a Risk of (significant) Harm (RoH); setting the level at 1:10,000 based on the concept that this a broadly acceptable level of risk found in the community (Ellison 2005). Other methods, tend to place the risk output values into categories, e.g., extreme, high, medium and low.

It would appear senseless to use a risk assessment method that does not attempt to define what an acceptable level of risk is or at least define some form of recommended intervention.

3 Methodology

The overall purpose of this research was to review the methodology and functional performance of tree risk methods, through analysis of the underlying processes, and by reviewing the interactions with a range of assessors and differing situations.

The majority of methods were sourced from the literature, Internet, and from people who had completed a tree risk assessment survey, QTRA was assessed twice because of its use of an infield assessment tool (QTRA Wheel) that had the potential to provide significantly varying results compared to the full test. Two assessment methods were created for this research TRE QT (a quantitative approach) and TRE QL (a qualitative approach).

Three approaches were undertaken to gather the data in this report

- tree assessments were undertaken using a single arborist to applied 15 methods to 15 different trees
- sensitivity analysis applied in two differing approaches
- 12 experienced arborists assessed eight trees using eight tree risk assessment methods.

The two different sets of trees were used for the single arborist and experienced arborists assessments. In both instances these were deliberately chosen to provide a wide range of failure, risk target and consequence scenarios (hence not random).

Sensitivity analyses are techniques for determining the influence that the various input factors have on outputs. Each method was subjected to sensitivity analysis through two different approaches; firstly, a simple one rank or 25% input value change (in both directions) from a rounded mean of each assessment category. Secondly, using Palislade's @Risk software (Palislade 2002) to undertake a Monte Carlo simulation using 5000 iterations (Latin hypercube sampling) and either multivariate stepwise regression or rank order correlation (rank order correlation was used when the R-squared value was below 0.60).

To test the various methods in 'real world' scenarios, 12 experienced arborists either local government or private consultants were asked to assess eight trees using eight different assessment methods. To create a baseline, each arborist was asked to subjectively provide an intuitive risk rating for each tree, scaling from one to ten, with one being insignificant risk and 10 extreme risk.

At the end of each assessment, each arborist was also asked, *"Rank the how well you believe the rating reflects the Risk"* and to apply a score from one to ten, with one being 'Very Poor' and ten being 'Very Accurate'.

Some argument exists in the literature that individuals have an inherent 'risk thermostat' (Adams 1999) and that risk is assessed relative to this risk thermostat. McElroy and Dowd (2007) suggests that one of the traits measured by the simple Ten-Item Personality Inventory (TIPI) (Gosling, Rentfrow et al. 2003) could be used to measure the influence of the heuristic 'anchoring' (Tversky and Kahneman 1982; Tversky and Kahneman 2000). The TIPI scores were compared to mean intuitive risk values from each arborist and the results of each tree risk assessment method.

Fundamentally, the result analyses for the above trials were limited to direct comparison, descriptive statistics, regression, correlation analysis and rank order comparisons. A high correlation was defined as >0.7, whilst a low correlation <0.3.

The fifteen methods reviewed are briefly described in Table 1; the eight methods used by the 12 experienced arborists are marked with **.

Table 1 Methods Reviewed

Name of Method (Coding)	Brief Description, Derivation and Source
Bartlett Tree Expert ** (Smiley 2002) (Bartlett)	Bartlett (Smiley 2002 pg. 27) is a simple two assessment categories summation model (Failure/Potential Defects and Consequences) using ordinal ranked values. The assessment criteria vary in range and number of values. The risk rating scores range from 2-15. Bartlett provides reasonably strong descriptors for each assessment criterion and relies to a degree on the assessor being suitably qualified and experienced. The final risk rating score is quantified in this method with scores being aligned to four categories, Low Risk (<7), 7-9 Moderate Risk, 10-12 High

	Risk, & 13-15 Critical Risk. Detailed in the publication Tree Risk Management (Smiley 2002). The publication is available from Bartlett in the USA and can be ordered via Bartlett Tree Expert's website.
Colorado Tree Coalition** (Colorado Tree Coalition 2004) (CTC)	A qualitative method developed in the US in 2004 by The Colorado Tree Coalition. This methodology was kindly provided freely by the authors. http://www.coloradotrees.org/ A somewhat complex model with two tiers of assessment and several base criteria that can trigger the need for the second tier inspection. However, for this assessment, only the initial risk assessment was analysed. Three fields Tree Species, Potential Target, and Defects Present, are multiplied to create a risk output score. Each of the three assessment categories has different ranges. The output scores range from 1-60. The unique element is Tree Species Index category, where species are allocated to one of five groups ranging from Very Low (1) to Very High Hazard (5). The authors suggest such grouping be made by local consensus. The 'total rating' (output score) is grouped into three predefined ratings, Low (1-14), Medium (15-35), & High (36-60).
Hume City Council** (Hume City Council nd) (HCC)	A highly modified version of Matheny & Clarke's method. Designed by two local consulting arborists in collaboration with and for a Melbourne (Aust.) local government authority. This methodology was kindly provided by the HCC. It is a somewhat complex model with five assessment criteria and a final risk score created by a combination of addition and multiplication. The assessment criteria are Failure Potential, Size of Part, Target Usage, Target Value and Damage Probability, the first four are evenly scored (five values from 0.5 to 4), whilst the Damage Probability criterion is scored in five values from 0.2-1. No definition or quantification of the output score values is provided.
Matheny and Clarke** (ISA) (Matheny and Clark 1994) (M&C)	A 1994 methodology presented in the publication *A photographic guide to the evaluation of hazard trees in urban areas* (Matheny and Clark 1994). A simple three-category summation method. Failure Potential, Size of Part and Target Rating are each scored from 1-4, these are summed to derive a 'Hazard Rating'. The output scores range from 3-12. No definition or quantification of the output score values is provided.
Kenyon 1993 (Kenyon 1993) (Kenyon)	An early quantitative methodology. Phillip Kenyon was a lecturer at Melbourne University; the paper discussing this method was presented at a 1993 conference and was published in the proceedings. It is the earliest tree risk assessment method located that attempted to quantify risk rather than the more usual approach of ordinal ranked values and at the time was from an arboricultural perspective a novel approach to risk assessment. It multiples four fields, the Probability of Failure, Target Value (in dollars), Target Risk Time and a Damage Factor to give a resultant dollar value. Two of these fields have predefined ranges. No definition or quantification of the output score values is provided.
Private 1 (no reference) (Private 1)	A qualitative method developed by an arboricultural business in Melbourne Australia. The developer kindly provided this methodology, however this was provisional on the source and full documentation not being made publicly available. This relatively simple model uses three assessment criteria. The final risk score is created by (Likelihood of Failure × Likelihood of Impact) /2 × Consequences. The assessment criteria are ordinal ranked numbers, they are not continuous and the Likelihood of Failure criterion is a different scale (1, 2, 4, 6, 8, and 10) to the other two criteria (1, 4, 6, 8, 10). The final risk score can range from 1-500. The levels of risk these scores represent are defined.

	1 -125 points = Very Low Risk Tree. 125 – 250 points = Low Risk Tree. 250 – 375 points = Medium Risk Tree. 375 – 500 points = High Risk Tree.
Private 2 (no reference) (Private 2)	A modification of the M&C method. The developer kindly provided this methodology, however this was provisional on the source and documentation remaining confidential. This method has six assessment fields, each field is summed to create a 'Hazard Rating' of 6-24. This method's variation is the additional three categories Wind Alignment, Defect Height and feasibility of Remediation. The 'Hazard Rating' scores are quantified: 5-10 Low Risk 10-16 Moderate 16-20 High 20-24 Extreme Risk
Private 3 (no reference) (Private 3)	A method based on the matrix approached published in the 2004 Australian Risk Standard (AS/NZS 4360:2004). The developer kindly provided this methodology, however this was provisional on the source and documentation remaining confidential. It is a simple risk matrix composed of 5 values each the Likelihood and Consequence categories. A range of descriptors provides guidelines for each category. The two scores are multiplied to derive a risk score. The risk score can range from 1-25. The significance of these scores is quantified as: 1-6 Low Risk 7-10 Medium Risk 11-12 Significant Risk 15-20 High Risk >21 Immediate Risk
QTRA** – Full (Ellison 2005; Ellison 2005) (QTRA)	Quantified Tree Risk Assessment. A recent quantitative method developed in the UK by Mike Ellison, its use requires user licensing. This is a probabilistic method, that multiples 3 assessment criteria to derive an output risk score. The assessment criteria are Probability of Failure, Size of Part (Impact Potential), and Targets. The assessor is require to estimate (quantify) category data inputs, e.g., probability of the defect failing within the inspection period, estimated number of people passing the tree, number of vehicle per day, etc., the 'size of part' is based on fractionising the estimated dry weight of a 600mm diameter tree using data derived from an allometric equation. With this method, the risk score is usually reported as the inverse of the decimal, i.e., a ratio and is termed RoH – Risk of Harm. This range of scores is infinite (depending on the inputs), 0->1000billion QTRA states acceptable risk is any level above a RoH of 1:10,000.
QTRA – Wheel Version (Ellison 2005; Ellison 2005) (QTRA W)	A simple field tool for calculating QTRA risk levels. Ellison developed a simple dial tool to allow quick in field assessments. It is included in the assessment, because the values used in the various categories are not equal and it is possible/likely that the RoH values generated by this tool will be significantly different to the full QTRA assessment method.
Threats** (Forbes-Laird 2006) (Threats)	A qualitative method developed by UK based Julian Forbes-Laird and initially provided by the author, it has since been released via the web. Threats uses three assessment categories, Likelihood of Failure, Target, and Degree of Harm/Consequences, these are multiplied to create an output risk score. This is one of two assessed methods that can create a zero risk score. The 'hazard rating' scores range from 0-20,000, the author does quantify these

	ranges. 0-49 Insignificant 50-159 Minimal 160-349 Slight 350-999 Moderate 1000-2000 Significant 2001-3999 Serious 4000+ Extreme
TRE Qualitative (TRE QL) (method no longer being developed, an outline of the approach is available from the author of this paper for those that maybe interested).	A simplified quantitative method designed for quick field application, it was developed for this research, and hence has not been publicly released. It is based on the same underlying principles as TRE QT, a 'user interface' has been created by separating assessment categories into 7 values (ranges) and making the assessment values summable by converting them to logarithmic scales (hence the risk ranges are mathematically aligned). Risk Scores from 3-500 are possible; these can be converted to probabilities. Acceptable risk is divided into three categories, at risk scores of 200-300 risk is unacceptable and for risk score 170-199 risk should be reduce if practicable, risk scores below 170 are considered acceptable. This method was proposed as a simple field assessment technique, however initial trials with various arborists found that although quick to apply it offered few advantages and was not developed further.
TRE Quantitative** (detailed in this document) (TRE QT)	A probabilistically based quantitative method developed for this research. It has not been publicly released. Its purpose was to align with the Australian Standard of Risk Management (AS4360:2004) definition simply expressed as Risk = Likelihood × Consequences. Three categories are used Probability of Failure (Pf), Probability of Impact (Pi) and Consequences (Co), each is assigned a probability (or ratio), consequence is factionised from the maximum value of the VOSL (value of a statistical life) developed from a review of values used in Australia and indexed by CPI. These categories are multiplied to create a risk score expressed as a probability or ratio, it is also possible to express the risk as a financial value. Acceptable risk is divided into two categories, at risk scores below 1:10,000 risk is unacceptable and for risk score between 1:10,000 & 1:100,000 risk should be reduce if practicable, risk scores > 1:100,000 are considered acceptable.
USDAFS Method 1** (Pokorny 2003) (USDAFS 1)	One of several qualitative methods developed by the US Department of Agriculture Forestry Service (USDAFS), and one of two published in *'Urban Tree Risk Management - A Community Guide to Program Design and Implementation'*. (Pokorny 2003). This method sums the values from four assessment criteria, Probability of Failure, Size of Part, Probability of Target Impact and Other Risk Factors. These categories have differing ranges, and the 'Other Risk Factor' category can be used 'if professional judgement suggests the need to increase the risk rating'. The output – 'Risk Rating' ranges from 3-12. No definition or quantification of the output score values is provided.
USDAFS Method 2 (Pokorny 2003) (USDAFS 2)	The second USDAFS qualitative method found in the publication *Urban Tree Risk Management - A Community Guide to Program Design and Implementation* (Pokorny 2003) This method use two categories Target and Defects (each covers a different range), the scores are multiplied to create a 'Hazard Rating'. This method can produce a zero score and Hazard Rating ranges from 0-6. No definition or quantification of the output score values is provided.

4 Results and Discussion

Due to the large amount of data generated, limited results are presented in this paper. Equally, much of the data is continuing to be analysed, and further results will be available when the full analysis and interpretation is completed.

It is assumed that the primary purpose of tree risk assessments is to measure 'risk'. Hence, it is reasonable to assume that a strong, at least correlative similarity should exist amongst risk assessment methods. Equally, given that people who assess tree risk would be considered 'experts' a high level of inter-arborist agreement should be evident.

Correlation is used widely in this analysis. Correlation measures the association between variables, it is not influenced by the actual values merely the relationship, hence it is well suited to identifying similarities amongst the different methods used. Correlation coefficients range from -1 to 1, a correlation of 1 suggests a perfect association, whilst -1 would suggest a fully negative association; a 0 value suggests no relationship. Importantly, correlation does not demonstrate 'cause and effect'.

Initial review of 15 Tree Risk Assessment methods

A single arborist was used to assess fifteen trees using fifteen different tree risk assessment methods.

Whilst the range of actual scores created varied considerably, upon comparing the mean scores and standard deviation (Table 2) it is apparent that some methods did not scale very widely M&C, Private 2, TRE QL and USDAFS 1, had only a standard deviation percentage around 20% indicating that the risk scores from these 15 trees did not vary widely. Since the TRE QL ratings are based on a logarithmic scale this is not surprising, however for qualitative methods using ordinal scales, this possibly indicates that without guidelines to the risk output scores a single category move could result in significant change to risk whilst the change is not reflected by the minimal change to the output score range.

Matheny & Clarke risk output scores from these 15 trees vary from 4-9, whilst the USDAFS 1 ranges from 5-10 (both methods maximum 12), without guidelines these values possibly mean little. Private 2 is a modified version of the M&C method, its output values range from 13-20 (highest score 24); the author provides guidelines to the risk scores, the descriptors in this method placed 9 scores in the 'Moderate' risk range, 5 'High' risk and one 'Extreme', as comparisons QTRA rates 3 trees as unacceptable risk, and Threats similarly rate three trees above the 'slight' risk level. Interestingly method Private 1 did not rank any tree above 'Low' risk.

Table 2 Means and Standard Deviations from 15 trees

	Mean	StdDev	StdDev %	Output Range
Bartlett	6.53	3.09	47%	2-15
CTC	11.93	6.36	53%	1-60
HCC	16.53	11.49	70%	0.2-64
M&C	6.47	1.30	20%	3-12
Kenyon	10041.37	14703.35	146%	0->4.5million
Private 1	34.93	25.60	73%	1-500
Private 2	15.07	2.22	15%	6-24
Private 3	8.73	3.84	44%	1-25
QTRA	30397746.53	67671005.09	223%	0 – 1:1
QTRA W	10688907.13	21994200.61	206%	1:1 - 1:302billion
Threats	354.67	879.74	248%	0-20,000
TRE QL	175.60	37.68	21%	3-300
TRE QT	9154203.33	18758038.82	205%	0 – 1:1
USDAFS 1	6.53	1.41	22%	3-12
USDAFS 2	2.13	1.41	66%	0-6

The correlation coefficients of the actual risk output values identified a few strong (>0.7) and a few weak (<0.3) associations. Table 3 lists the results, grey bold font cells have correlations >0.70, whilst yellow bold italics cells <0.3. The negative correlations that occur with QTRA and TRE QT relationships exist because in these methods the higher risk scores (closer to 1) are associated with greater risk; this is the reverse of that used by the other methods listed in the table where risk increases as the risk values move away from 1 (hence these are not truly negative correlations).

Generally, only a medium level of association exists between the methods. Correlation of rank ordered risk scores was also undertaken and the results are generally similar (data not reported).

A high correlation was expected, and found to exist between the two different QTRA approaches (QTRA vs QTRA Wheel 0.88). The highest correlation was between QTRA and a method developed for this research (TRE QT), as these methods function similarly this was not surprising, most of the high correlations (>0.7) exist only between the QTRA, QTRA W and TRE QT. Particularly low correlations (<0.3) are found in a number relationships, the lowest between the Kenyon and Private 2 methods. The only 'true' negative correlation was found (-0.05) between Kenyon and Private 2, although effectively it is near zero.

Table 3 Actual Score Correlation

	Bartlett	CTC	HCC	M&C	Kenyon	Private 1	Private 2	Private 3	QTRA	QTRA W	Threats	TRE QL	TRE QT	USDAFS 1	USDAFS 2
Bartlett	1														
CTC	0.34	1													
HCC	0.56	0.58	1												
M&C	**0.71**	0.37	***0.24***	1											
Kenyon	***0.25***	***0.24***	0.55	0.36	1										
Private 1	0.42	0.52	0.51	0.38	0.51	1									
Private 2	0.61	0.58	0.40	0.56	***-0.05***	***0.29***	1								
Private 3	0.64	***0.17***	**0.72**	0.40	0.42	0.41	***0.20***	1							
QTRA	**-0.70**	-0.32	-0.61	-0.38	-0.33	-0.52	***-0.20***	-0.69	1						
QTRA W	**-0.76**	-0.32	-0.63	-0.46	-0.35	-0.49	-0.35	**-0.72**	**0.88**	1					
Threats	0.59	0.39	0.53	0.55	***0.26***	***0.21***	0.61	0.51	***-0.19***	***-0.21***	1				
TRE Qual	**0.73**	0.55	0.59	**0.71**	0.59	0.59	0.40	0.56	-0.66	-0.67	0.63	1			
TRE QT	-0.69	-0.37	-0.62	-0.39	-0.35	-0.54	***-0.23***	-0.65	**0.99**	**0.87**	***-0.21***	-0.69	1		
USDAFS 1	0.57	0.35	0.31	0.63	***0.10***	***0.17***	0.38	0.45	***-0.23***	-0.33	0.69	0.65	***-0.19***	1	
USDAFS 2	0.70	0.56	0.63	0.55	0.33	0.47	0.34	0.63	**-0.72**	**-0.78**	***0.23***	0.65	-0.69	0.54	1

Direct comparisons between different methods are not possible when the scaling and range of outputs vary, e.g., M&C outputs 3-12 whilst Threats outputs 0-20,000 (see Table 2). Hence, rank order values were created from the actual output values, the rank does not represent a risk value, merely the order from the fifteen trees in which the rating appears.

Considerable rank variation was found amongst the methods, e.g., Tree 3 a small *Prunus* 'Nigra' (Figure 2) in a public park was variously ranked from the fifteen assessed trees from the lowest risk rank to the highest or equal highest in several methods (Figure 4). Whereas with Tree 7 (Figure 3) the majority of methods clearly ranked this tree at or close to the highest risk rank (Figure 5). This would appear to demonstrate the effect of variations in the assessment categories or applied category weightings.

Table 4 Tree 3 and Tree 7 assessment details

Tree 3 ***Prunus cerasifera 'Nigra'*** Purple Leaf Cherry Height 6.6m DBH 41cm Growing in a lawn area of a suburban park This tree is Dead	*Defects (Probability of failure - Pf):* The most likely failure is either one of the dead codominant stems failing or the entire tree uprooting. Obviously minor deadwood will also fall from the tree.	*Risk Targets (Probability of impact – Pi):* Few people would directly pass under this tree; the most likely target would be a casual park user picnicking near the tree in summer, or occasional person walking a dog. Failure would be more likely in adverse weather	*Consequences (Likely amount of loss or damage):* The size of likely failures is limited to deadwood ≈25mm, one of the co-dominant stems (≈200mm) or the entire tree.
Tree 7 ***Populus X canadensis Moench f. aurea*** Grey Poplar Height 20.3m DBH 61cm Grown in a grassed area near a shared footpath	*Defects (Probability of failure - Pf):* Tree has major decay at base of tree, large split in trunk and a strong lean in the direction of the path. The most likely failure is of the entire tree	*Risk Targets (Probability of impact – Pi):* Area has approximately 100 walkers/bicyclists pass by each day and maybe 10-20 cars each week.	*Consequences (Likely amount of loss or damage):* A tree of this size will in all likelihood cause a fatality or major trauma to a human, a vehicle would be substantially damaged.).

Figure 2 Tree 3 Prunus 'Nigra'

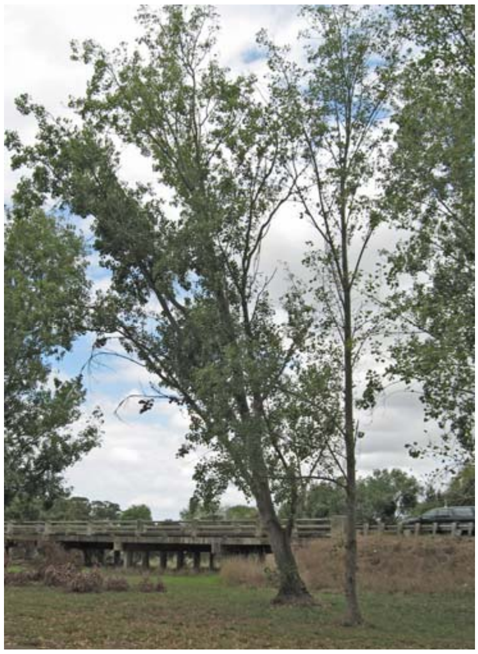


Figure 3 Tree 7 Populus X canadensis

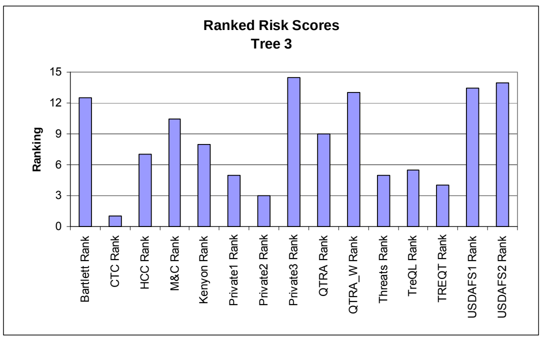


Figure 4 Tree 3 Rank Risk Score (15 is highest risk rank)

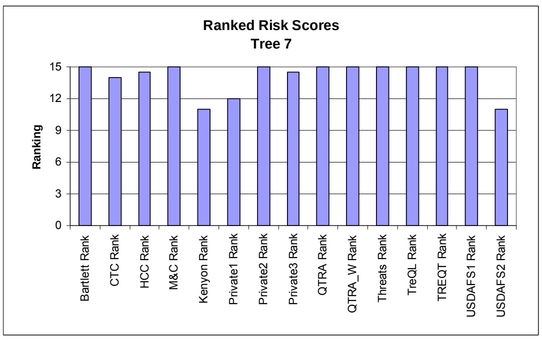


Figure 5 Tree7 Rank Risk Score (15 is highest risk rank)

Some methods provide guidelines to interpret the resultant risk output scores; others provide no real indication of the output values. A qualitative approach was undertaken to allow comparisons to be made amongst methods, a 'risk scale' was devised. Values from one to ten were assigned qualitatively based on the risk scale (Table 5), where possible values were aligned to the guidelines or thresholds provided by the assessment method (e.g. Bartlett). Where these guidelines were not available, the Risk Scale was assigned based on the overall width of the method's risk scaling, e.g., M&C score of 4/12 was designated risk scale rank of 3 or low (because it was only 1 above the minimum possible score), whilst a score 7/12 was designated a risk scale rank of 6 or medium/moderate).

Table 5 Qualitative Risk Scale Values

Risk Scale Values	Designated Risk Level
One	Insignificant risk
Two	Very low
Three	Low
Four	Minor/Slight
Five	Medium
Six	Medium/Moderate
Seven	Moderate
Eight	Highish
Nine	High
Ten	Extreme

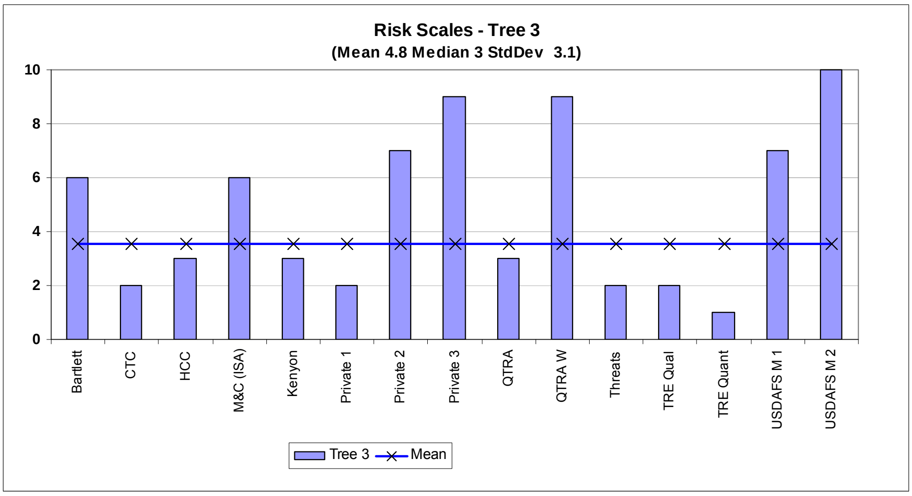


Figure 6 Risk Scales Tree 3

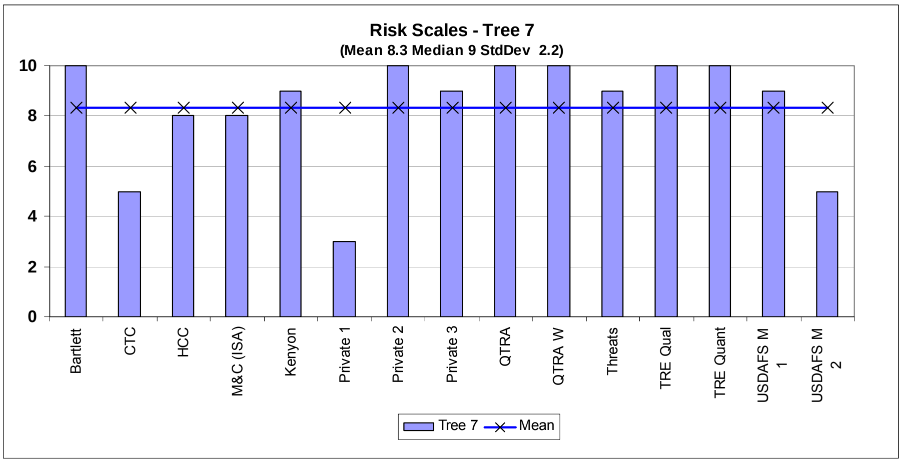


Figure 7 Risk Scales Tree 7

The derived risk scale values indicate that when applied to each individual tree, the reported 'risk' levels varied considerably. For example, Tree 3 (Figure 6) the mean scale was 4.8 ('medium' risk) eight methods designated the risk score as low or lower, whilst three ranked the risk as high or extreme. Whilst Tree 7 had less variation, nevertheless 12 methods rated the risk as above 'highish', two methods reported Medium risk and one Low risk. As similar effect was identified across all assessed trees.

As a single assessor undertook all assessments, most of the assumed and assessed variables should be equal (e.g., defect, estimation of size, site usage, etc.), and bias and heuristics would be relative if not fixed. Therefore, this apparent variation could indicate either poor interpretation or application of some methods or actual variations produced by the mathematical model, assessment criteria, or provided descriptors. To address this outcome, further analysis was undertaken using sensitivity analysis and further 'real' tree assessments using a range of experienced arborists.

5 Sensitivity Analysis

Sensitivity analyses are techniques for determining the influence of each input variable on the model's outcomes. It has been used in this study to provide an indication of the relative influence each assessment criterion (e.g., size of part) has on the final risk score. The more sensitive an input parameter is, arguable the greater precision is required to accurately estimate the value used in the assessment method.

The basic process of sensitivity analysis is to change one variable at a time whilst holding the others constant and to measure the effect on the output score. Two methods are employed in this analysis, a ± one rank or ± 25% change to each category value and a Monte Carlo simulation (where using Latin hypercube sampling 5000 possible variations are applied to each method). The results of these analyses are summarised in Table 6; whilst Figure 8 to Figure 11 graphically illustrate the sensitivity analysis undertaken for the Bartlett method, similar results were generated for all 15 methods.

Table 6 Summarised Results of Sensitivity Analysis

Method	Change to Output of One Rank or 25% Change	Change to Output of Monte Carlo Simulation	Fitted Distribution Curve and Projected Mean
Bartlett	43% change to Failure/Defect 29% change to Consequence	Failure/Defect 82% variance 16% Consequence	Even spread of scores Projected mean 8.5
Colorado Tree Collation (CTC)	13% each category	Species 38% variance Defects 33% Target 28%	Strong tendency to generate lower end scores Projected mean 15.1
Hume City Council (HCC)	25% change with four categories Damage 33%	Damage 36% variance All others 15%	Strongly tends to produce lower end score Projected mean 10.6
Matheny & Clarke (M&C)	17% each category	33% variance all categories	Tends to generate scores towards the centre Projected mean 7.5
Kenyon (1993)	Target Time and Target Value 25% Damage -25% +17% Failure +14% - 57%	Damage 47% of the variance Failure 15% Other categories 11%	Strong tendency to generate lower end scores - logarithmic distribution Projected mean $285,000.
Private 1	33% each category	Failure 32% variance remaining fields for 28% of the variance	Strong tendency to generate lower end scores Projected mean 87
Private 2	8% each category	16% all categories	Tends to generate scores towards the centre Projected Mean Score 15
Private 3	33% each category	49% each category	Tends to generate scores towards lower and centre Projected mean score 9
Quantified Tree Risk Assessment (QTRA)	25% each category	29% each category	Strong tendency to generate lower end scores- logarithmic distribution The projected mean score 0.125 equal to a 1:8 ratio
Quantified Tree Risk Assessment Wheel	Size -90% + 29% Failure -90% + 900% Target -96% + 576%	Target 51% Size 24% Failure 19%	See QTRA Wheel section for discussion

Threats	Impact -33% +67% Target -/+ 25% Failure -75% +525%	Failure 52% Target 20% Impact 3%	Tendency to generate risk scores towards the lower end of the range Projected mean 1100
TRE Qualitative TRE QL	17% each category	49% each category	Tends to generate scores towards the centre Projected mean 150
Tree Risk Evaluation Quantitative (TRE QT)	25% each category	29% each category	Strong tendency to generate lower end scores- logarithmic distribution The projected mean score 0.125 equal to a 1:8 ratio
United States Department of Agriculture Forestry Service Method 1 (USDAFS 1)	13% each category	Failure 39% 20% all others	Tends to generate risk scores centre range scores skewed slightly toward high Projected mean 7.5
United States Department of Agriculture Forestry Service Method 2 (USDAFS 2)	Defect +/- 50% Target -0% +100%	Defect 82% of variation Target 10%	Tends to generate risk score outputs of 0 & 2 Projected mean 2.6

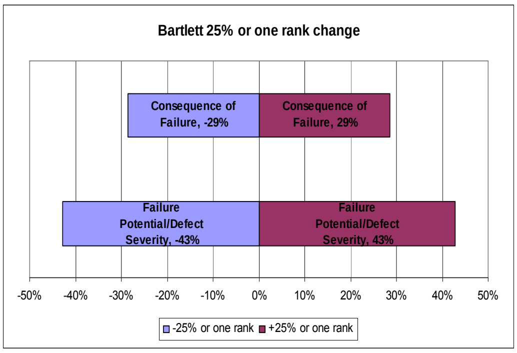


Figure 8 Bartlett - Effect on the Risk Score with a One Rank Change to the Medium Values

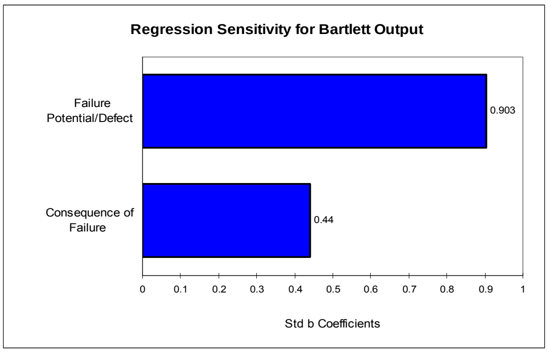


Figure 9 Bartlett – Multivariate Stepwise Regression of @Risk Monte Carlo simulation (5000 iterations)

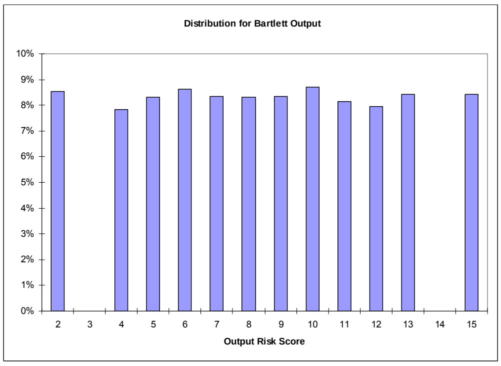


Figure 10 Bartlett – Fitted Curve Distribution of @Risk Monte Carlo simulation (5000 iterations)

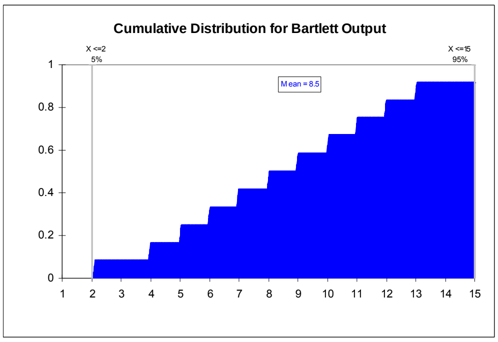


Figure 11 Bartlett – Cumulative Distribution of @Risk Monte Carlo simulation (5000 iterations)

Monte Carlo sensitivity derived variance

Given that risk is defined as a combination of likelihood and consequence factors, it is interesting to review the methods in light of the Monte Carlo sensitivity derived variance. Each method's assessment categories were designated either Consequence or Likelihood (if it was not apparent or did not influence the output it was ignored). The majority of methods appear to weight the likelihood categories more strongly than factors that effect consequence, 10 of the 13 methods more strongly favoured likelihood, whilst two weighted the consequences factors more strongly (Figure 12).

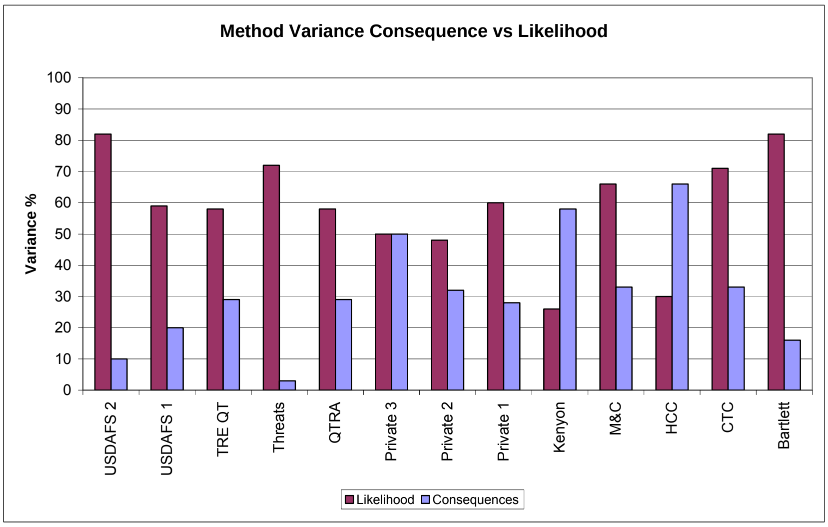


Figure 12 Weighting towards Consequence or Likelihood

Comparison with individual arborist collected data.

To compare the modelled Monte Carlo fitted distribution curve to ‘real’ data, the assessment data from the eight trees assessed by 12 arborists was used; this was a relatively small data set and not randomly derived. Nevertheless, histograms of these data exhibited risk output scores similar to that predicted by the Monte Carlo modelling (compare predictions in *Figure 13*, *Figure 15* and Table 6, with histograms created from the risk output scores created by the 12 arborists’ assessments in *Figure 14* and *Figure 16*).

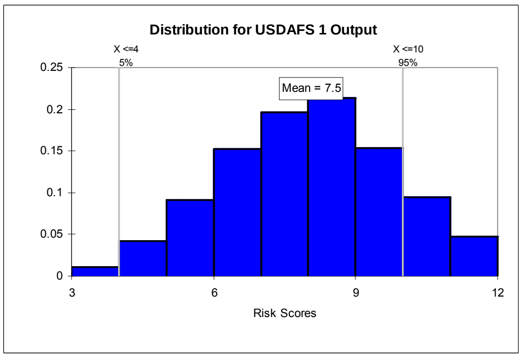


Figure 13 Predicted Fitted Curve Distribution USDAF 1

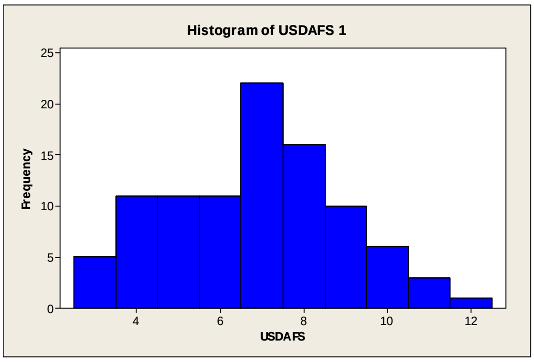


Figure 14 Actual Distribution USDAF 1

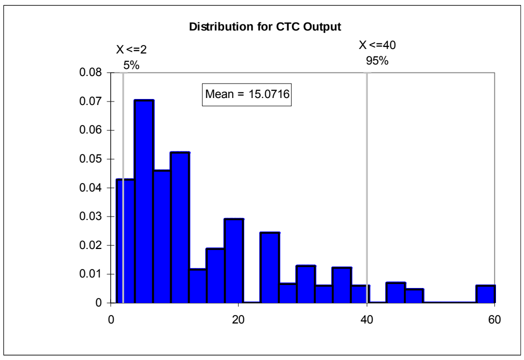


Figure 15 Predicted Fitted Curve Distribution CTC

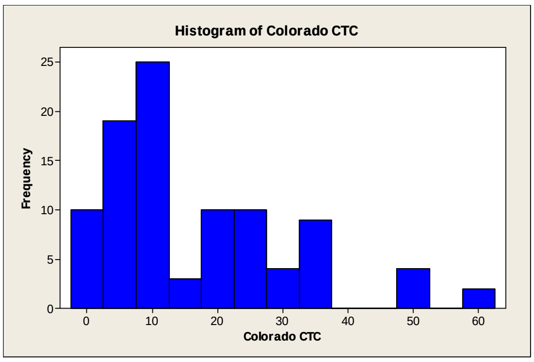


Figure 16 Actual Curve Distribution CTC

Sensitivity Analysis Summary

The various sensitivity analyses demonstrated the large variation in method construction and hence how risk scores are likely to be created. The choice of assessment criteria, scoring range, weighting and relativity, and the mathematics used to combine the assessment criteria will all influence the output scores. Risk assessors and those who develop methodologies should use sensitivity analysis and fitted curve distributions to determine the influence of various components and assess the validity of the model for the desired outcomes.

Independent Arborist Assessments

A trial was undertaken using 12 experienced arborists to assess eight predetermined trees using eight different tree risk assessment methods.

The primary purposes were to compare assessments made by each arborist, and secondly to compare outcomes from each risk assessment method. Hence, it was expected that the results would identify the nature and range inter-arborist assessments and behaviour of risk assessment methods and their interaction.

All arborists had a minimum of ten years industry experience and all were qualified. They came from a range of backgrounds and all were currently employed as senior arborists or similar roles in local government or consulting arborists.

The trees were chosen to provide a range of defect types, target values and potential consequence outcomes. Assessments were made over a period of eight weeks in February/March 2007 (late summer, early autumn).

All trees were assessed for the period of the next 12 months.

The previous trials identified assessment methods that varied significantly in both assessment methodology and risk score output types and values. The eight methods tested were (See Table 1 for more detailed description)

1. Bartlett Tree Expert (Smiley, 2002)
2. CTC - Colorado Tree Coalition (Colorado Tree Coalition, 2004)
3. HCC - Hume City Council (Hume City Council, nd)
4. M&C - Matheny and Clarke (ISA) (Matheny and Clark, 1994)
5. QTRA – Full (Ellison, 2005a, Ellison, 2005b)
6. Threats (Forbes-Laird, 2006)
7. TRE QT - TRE Quantitative (a brief outline is provided in Appendix One)
8. USDAFS 1 - USDAFS Method 1 (Pokorny, 2003)

Any tree risk assessment methodology must be defendable by being:

- robust (insensitive to assumptions)
- credible (outputs are reasonable, believable and verifiable)
- repeatable (results must be able to be repeated by others in the same circumstances)
- valid (measures what it is supposed to measure)

It also must be feasible, economic, preferably simple, provide a transparent methodology, be self-explanatory and mathematically valid.

Assessors can be influenced by various factors including, experience, education, bias, motivation, self-interest, various human errors, heuristics, etc. This trial attempted to reduce some of these influences, only experienced arborists were selected, self-interest and motivation should not have been major influences as all assessments were undertaken without reward or responsibility for assessment outcome. Hence, the major variation amongst arborists was expected to be related to site interpretation factors, heuristics, and possibly errors.

TIPI results

Each assessor undertook the simple Ten Item Personality Test (TIPI) and the scores collated as per the test instructions . Whilst this test is fast and simple it has been compared well with the full personality assessment methods (Gosling, Rentfrow et al. 2003). Of particular interest was the observation by McElroy and Dowd (2007) that one of the traits assessed by this test 'openness of new experience' was correlated to risk taking, with higher scores being related to greater risk taking, and conversely the lower scores being related to risk adverse people.

Comparisons were made between each arborist's intuitive risk rating for each tree and their TIPI score. The correlation coefficient was -0.459 indicating a medium association and a slope that does indicate that the greater the TIPI openness to experience value the lower the initiative risk rating.

Regression analysis also identified this trend (R^2 21.1%), the fitted line plot in Figure 17 illustrates the association, however several arborists are clearly well outside the 95% confidence interval, particularly Arborists D & W. Arb D was more risk adverse than the regression model suggests whilst also being at the lower end of the openness to experience scale, whilst Arb W was less risk adverse whilst having a medium openness to experience rating. This TIPI intuitive risk association is interesting and would be worth further research.

However, this relationship was not consistently associated with the trialled risk assessment methods; the majority had virtually no relationship to the 'openness to experience' rating (data not reported).

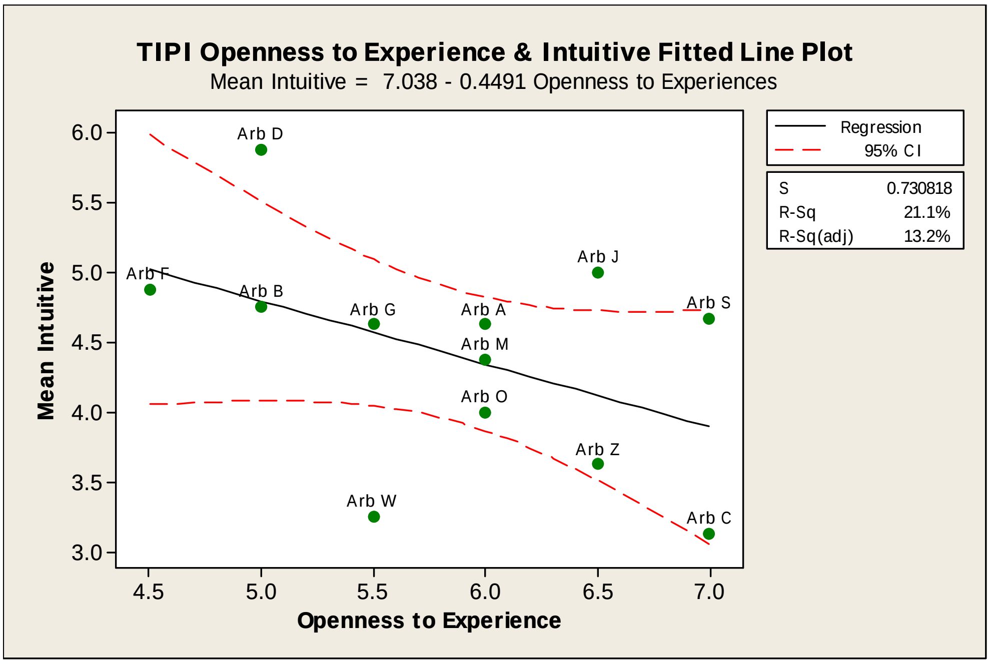


Figure 17 TIPI Openness to Experience Fitted Line Plot

Intuitive Risk Rating Scores

The 12 experienced arborists placed an intuitive risk rating on each tree assessed within the first few minutes of viewing the tree and before any other assessment had been made. The rating was from 1 – 10, with one being described as 'insignificant risk' and 10 as 'extremely high risk', no other guidance was provided.

The range of scores generated for most tree assessments was very wide. Figure 20 illustrates the width of these values, using Tree 7 as an example the range extends from 3 – 9, suggesting low to very high risk. Only Trees 8 & 10 (Figure 18 & Figure 19) appear to have a strong consensus of opinion and these were chosen to provide very clearly boundaries to tree risk assessments (both for differing reasons should rank very low risk).

Whilst, many in the industry would suggest that 'they know a "dangerous" tree when they see one', this sample from 12 experienced arborists would suggest that tree risk assessment may not be as much 'commonsense' as many believe.

Figure 18 Tree 8 **Elaeocarpus reticulatus** ***Sm.***
Common Name – Blueberry Ash
Height *4.3m* **DBH** *7.5 cm*
Landscape Type *Mulched garden bed*
Use under/near Tree *Pedestrians - students, garden visitors, building*

Figure 19 Tree 10 **Eucalyptus camaldulensis** ***Dehnh.***
Common Name - Red Gum
Height 15*m* **DBH** 98 *cm*
Landscape Type *Regenerating bush area*
Use under/near Tree *No foreseeable use, maybe occasional worker*

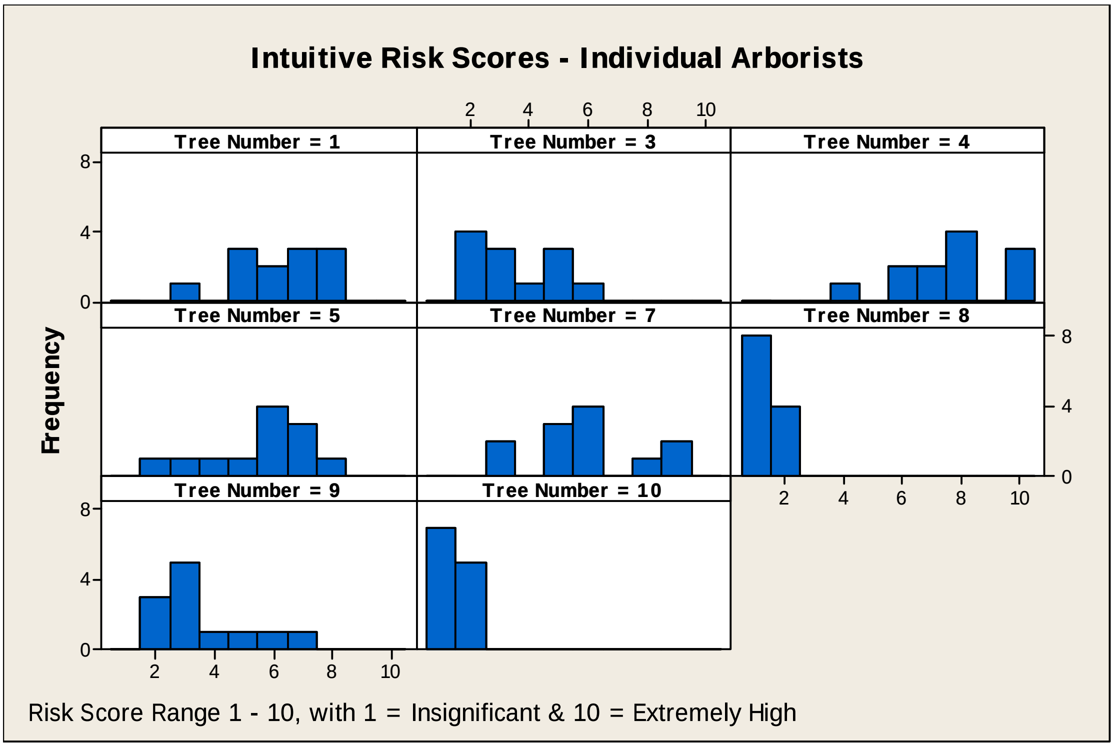
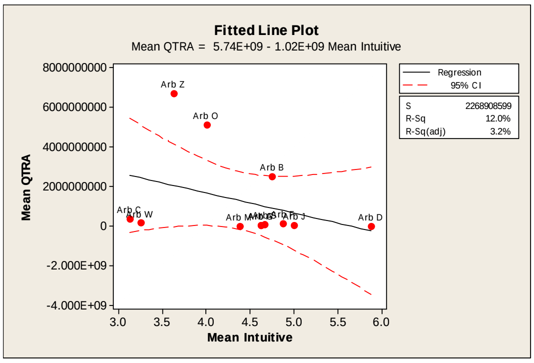


Figure 20 Intuitive Risk Rating Score by Tree Number

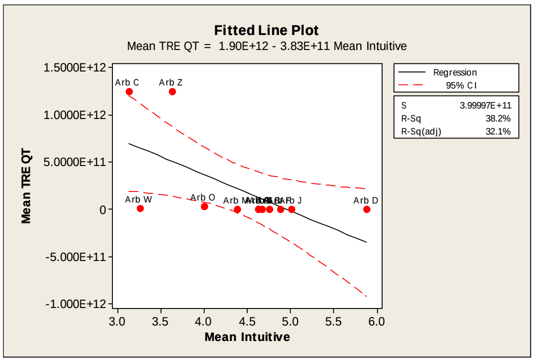
Relationship amongst Intuitive Risk Rating and Eight trialled methods

The mean intuitive ratings were compared via regression analysis with the mean risk scores for each arborist and method. In all instances and not surprisingly, a clear relationship existed between an arborist's intuitive risk rating and their subsequent risk scores created for each method. Figure 21 illustrates the relationships (QTRA and TRE QT slopes are reversed compared to other methods because with these methods the lower risk score is correlated to a greater risk). With exceptions, the lower the intuitive rating, the lower the average risk rating in all methods and vice versa. Of interest are the positions of Arborists C, W, & D; in all fitted line plots these arborists are located at the extremes of the plot ranges.

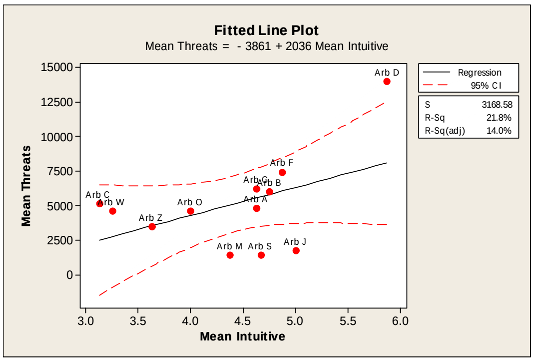
Correlation between the arborists' risk scores and the intuitive ratings agreed with the fitted line plots, showing that generally there were medium to high correlations between intuitive ratings and subsequent risk scores across all methods (Table 7). Figure 22 indicates the range of correlations found with each tree. Table 7 details the correlations, Arb D had the highest mean correlation across all methods and significantly higher than all other assessors (0.82) and the most number of 'highest' correlation for each method, whilst Arb S had the lowest mean correlation (0.43) across all methods and the greatest number of 'lowest' correlation for each method; indicating that Arb S demonstrated a far lower association with his selected intuitive ratings than any of the other arborists.



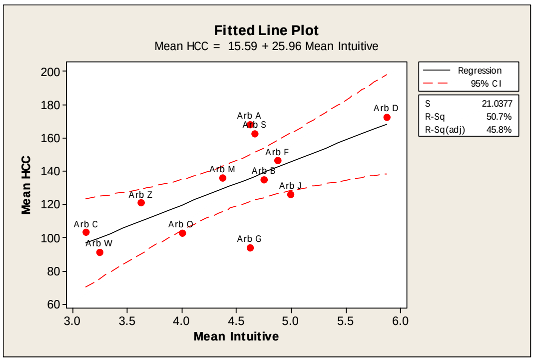
Fitted Line Plot - QTRA



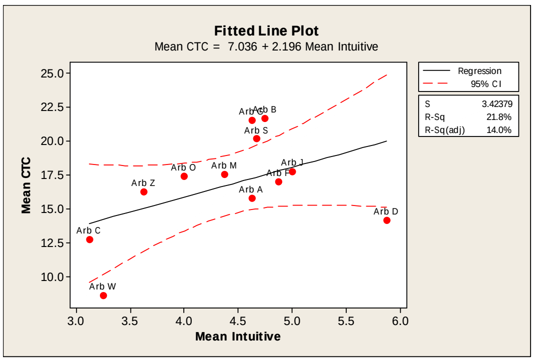
Fitted Line Plot – TRE QT



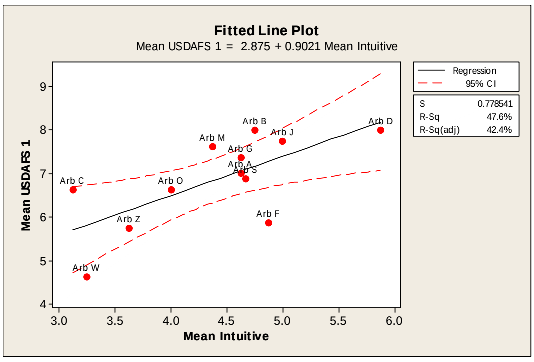
Fitted Line Plot - Threats



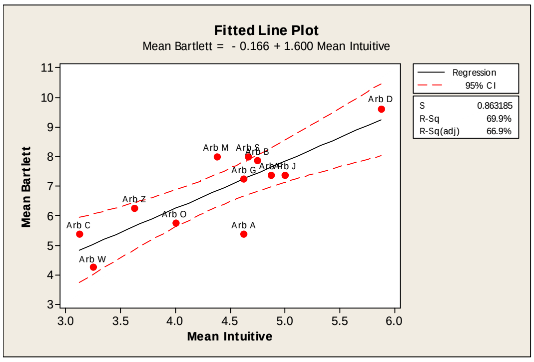
Fitted Line Plot - HCC

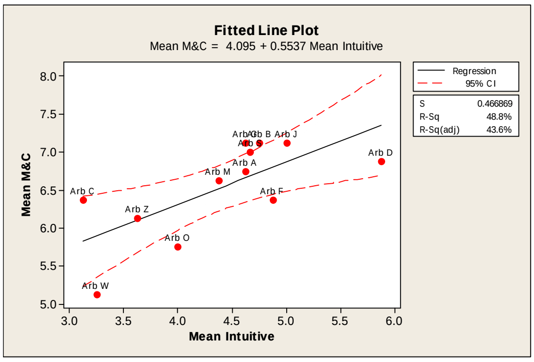


Fitted Line Plot - CTC



Fitted Line Plot – USDAFS 1





Fitted Line Plot - Bartlett	***Fitted Line Plot – M&C***

Figure 21 Fitted Line Plots - Intuitive vs Method

Table 7 Correlations between Intuitive Risk Scores and Actual Risk Score by Method and Arborist Code

Correlations between Intuitive Risk Scores and actuals by method and Arborist Code

	Arborist C	Arborist A	Arborist W	Arborist F	Arborist Z	Arborist S	Arborist D	Arborist O	Arborist G	Arborist B	Arborist J	Arborist M
M&C	**0.39**	0.65	0.56	0.74	0.59	0.42	0.78	0.83	**0.93**	0.84	0.64	0.53
Bartletts	0.85	0.45	0.58	0.74	0.54	**0.25**	**0.95**	0.89	0.75	0.74	0.85	0.64
USDAFS 1	0.78	0.79	0.43	0.76	0.62	0.70	**0.92**	**0.39**	0.72	0.59	0.82	0.76
Colorado	0.81	**0.52**	0.61	0.74	0.84	0.55	0.70	**0.52**	0.68	0.87	**0.93**	0.79
HCC	0.17	0.84	0.85	0.85	0.91	**0.15**	0.89	0.72	**0.92**	0.69	0.75	0.71
Threats	**0.96**	0.43	0.57	0.54	0.13	0.46	0.66	0.85	0.63	0.86	0.53	0.48
QTRA	0.43	0.62	0.69	0.40	0.44	0.48	**0.79**	0.44	**0.29**	0.44	0.67	0.67
TRE QT	0.30	0.58	0.47	0.46	0.43	0.45	**0.87**	0.41	**0.28**	0.44	0.44	0.44
Mean	0.59	0.61	0.60	0.66	0.56	**0.43**	**0.82**	0.63	0.65	0.68	0.70	0.63
StdDev	0.30	0.15	**0.13**	0.16	0.24	0.17	0.11	0.21	0.25	0.18	0.16	0.13

Bold typefaces indicate the high and low correlations for each method

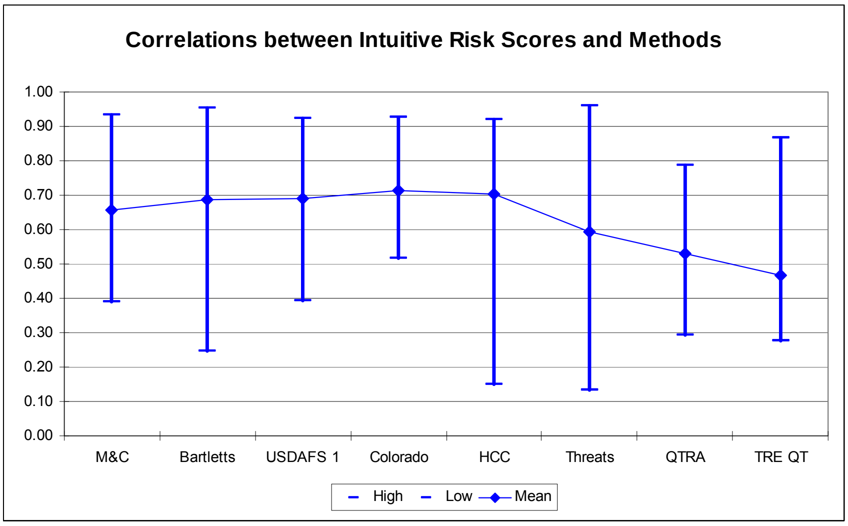


Figure 22 Range of Individual Correlations between Intuitive Risk Scores and Methods

Comparison of risk score generated by independent arborist assessments

Twelve experience arborists assessed eight trees using eight different risk assessment methods. The variances in scores amongst arborists were large, in many cases where a method defined the meaning of the output risk score (e.g., Bartlett & Threats) the arborist assessment output values for the same tree ranged from Low to Extreme Risk.

Figure 23 demonstrates the range of risk scores created using just one method (Bartlett's - the method most assessors preferred see Figure 32), the output value range for most trees is large e.g., Trees 1, 3, 5, 10. Only two trees have a relatively narrow assessment output range (4 & 8).

With the majority of trees assessed, and for most assessment methods, the risk output scores created by the assessors ranged from low to high and sometimes critical. Figure 26 illustrates the huge range of values that can be generated for one tree using QTRA, in this instance from 1:19 to 1:128million, whilst training maybe an issue, QTRA licensed arborists created the lowest and highest values in this assessment. Using QTRA four arborist risk values suggested the risk was unacceptable whilst eight values suggest acceptable risk, using the Bartlett data four values were 'critical', 2 'High', 4 'Moderate' and 2 'Low'. The wide range of values found for this assessment, possibly more reflected individual arborists' beliefs rather than being based on any quantifiable data; highlighting the 'expert opinion' nature of tree risk assessment; a similar wide range of values was found with the majority of trees assessed.

The variation in assessor-applied individual assessment criteria values (e.g., Failure, Target, and Size of Part) similarly appear to vary significantly across all methods. Using Tree 7 as an example, the range for the estimated 'probability of failure' (QTRA & TRE QT) was 1:2 – 1:50,000 (Figure 24), M&C varied by the entire width of the possible values (1-4) (Figure 25), whilst Bartlett's 'Failure Potential' varied across three of the four possible values.

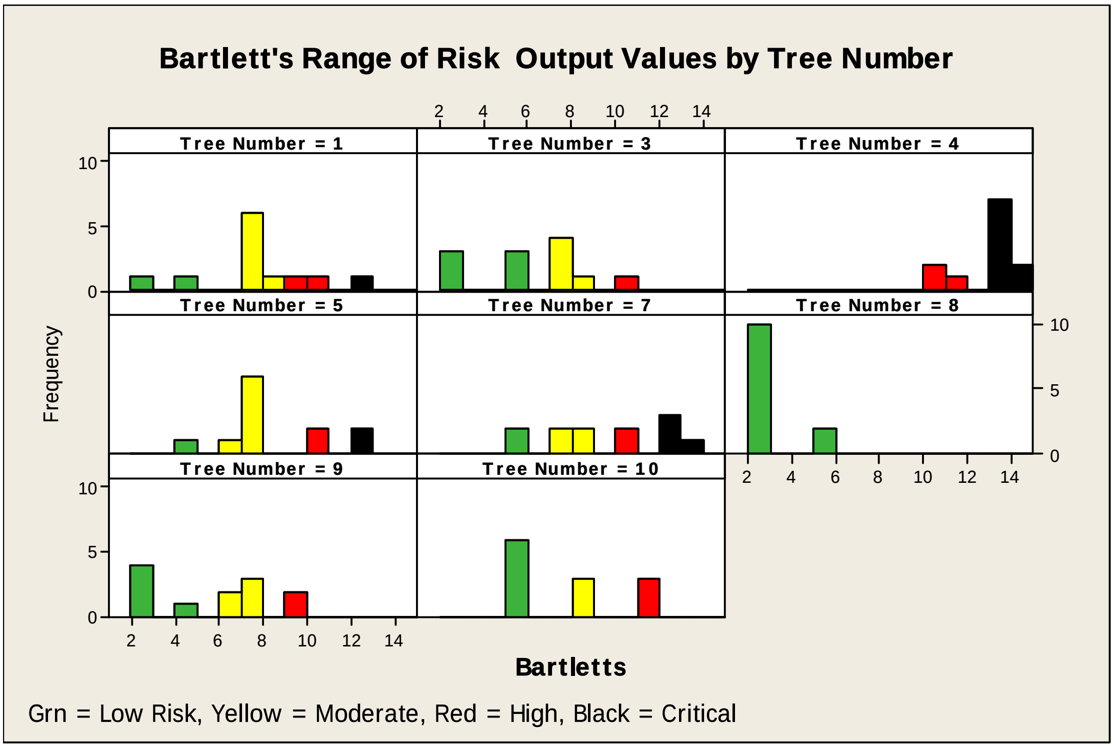


Figure 23 Bartlett's Range of Risk Scores

Table 8 Tree 7 from Individual Arborists Tree Assessments

Tree 7

Eucalyptus cladocalyx F.Muell.,

Common Name - Sugar Gum

Height *25.0m* **DBH** *106cm*

Site Character *Historic Landscape Gardens*

Landscape Type *Mulched garden bed*

Use under/near Tree *Pedestrian, Building*

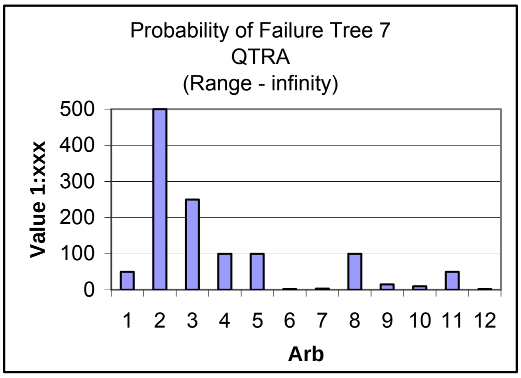


Figure 24 QTRA Range Probability of Failure Tree 7

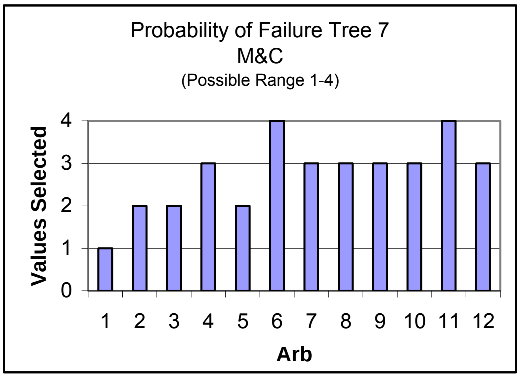


Figure 25 M&C Range Probability of Failure Tree 7

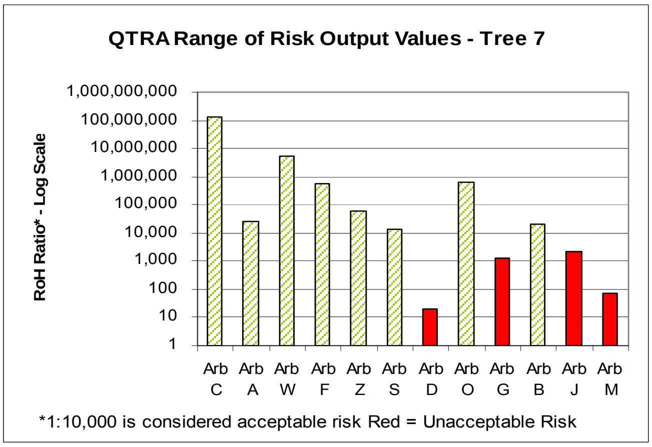


Figure 26 QTRA Range of Risk Output Values

6 Uncertainty

Uncertainty is a term that creates some confusion, fundamentally, for risk assessment it can be defined as *'a consequence of imperfect knowledge or data'*. Uncertainty is not the natural variation that occurs in populations (uncertainty can be reduced with more data or better knowledge, whilst variation remains unchanged because it refers to true heterogeneity or diversity).

Any tree assessment will be composed of a series of estimates and assumptions made by the assessor, accuracy is somewhat implied because virtually all methods use single point values, in all cases these point values will not be accurate.

During this research a tree risk assessment method was developed that attempts to fully encompass the equation Risk = Likelihood × Consequence, as part of the process a technique was developed to at least record uncertainty. Individual arborists were asked to provide a level of confidence around the accuracy in their point estimates. These 'confidence values' were analysed and compared to the associated risk ratings.

Few would argue, and the data reported in this paper would confirm that tree risk assessment is as much 'an art as science'; hence, any assessment significantly relies on 'expert opinion'. Most tree risk assessment methods require the assessor to 'pick a number', some methods qualify or quantify this number with descriptors (e.g., CTC defines houses, playgrounds, schoolyards and courtyards as High Risk). Descriptors have the potential to limit assessor-produced uncertainty; however, paradoxically they can introduce greater inaccuracy by limiting an assessor's opportunity to apply more accurate or site-specific data.

QTRA is a recent quantitative method that implies a high level of accuracy; however, as previously shown (e.g., Figure 24 & Figure 26) assessors vary enormously in their point estimates for the three required QTRA fields, clearly a large amount of inter-assessor uncertainty exist. Equally, few assessors would claim that their point data is any more than an estimate and that the actual figure could be higher or lower. These points will apply to any quantified tree risk method, because of limited data and knowledge, (hence the argument that uncertainty should be part of any tree risk assessment method).

Little accurate data exists in relation to quantification of the three elements that underlie tree risk assessments

- the probability of failure is limited to experience and at best some broad guidelines e.g., VTA (Mattheck and Breloer 1994), stem hollowness ratios, etc, and these guidelines are open to interpretation
- defining whether a risk target is likely to be impacted is again, generally at best, an educated guess, QTRA (Ellison 2005) has attempted to at least provide a method that requires the assessor to quantify their estimates
- the consequence of a failure and impact is in the majority of methods based on little more than conjecture (it is a big tree part – therefore it will cause a high level of damage).

Hence, uncertainty is the biggest factor underlying all elements of tree risk assessments, yet it appears that it is not discussed, qualified or quantified in the tree risk literature.

The most common method of addressing uncertainty is to use ranges rather than point values; no existing tree risk assessment method addresses uncertainty. It is doubtful due to the open-ended nature of most qualitative methods that range values would prove effective (the range of output scores would be too great). It could be argued that some methods e.g., Threats, Bartlett address uncertainty because the output values are interpreted in ranges. The use of ranges increases the complexity of the process, however, the influence of uncertainty should be addressed by any methods that imply or attempt to quantify variables or output scores.

In an attempt to qualify uncertainty (at least obliquely), the risk assessment method developed for this research TRE QT (see Appendix 1) requires assessors to assign a 'Confidence Level' as a percentage value of the confidence their have in the value they allocate to each of the risk assessment categories (see example Table 9). The three Confidence percentages are averaged to create the 'Confidence Level' is used to generate a certainty factor (Cf) and to both quantify the uncertainty the assessor has in the assessment and create a range around the final risk output rating. Hence, the output value is reported as 1:40,000 with a Cf of 80%, this can be taken one-step further and an output range created e.g., the output value would be reported as 1:32,000-1:40,000 Cf 80%. This approach does not directly address uncertainty; however, it does at least qualify the confidence an assessor has in their estimates.

Category	Estimate	Confidence %
Pf	100	90%
Pi	4	80%
Co	100	70%
Risk	**40,000**	**CF 80%**
Range	**32,000**	**48,000**

Table 9 Confidence Factor Example

The Confidence Levels assigned by the 12 arborists varied as widely as the risk score values. Using Tree 7 as an example, the confidence in the Probability of Failure (Pf) ranged from 40-90%, Probability of Impact ranged from 10% to 95% confidence, whilst the Consequence (Co) range was 20-95% (Figure 27). A comparable range was found when all assessments were averaged (Figure 30). The levels of confidence appears to indicate that assessor will acknowledge a level of uncertainty.

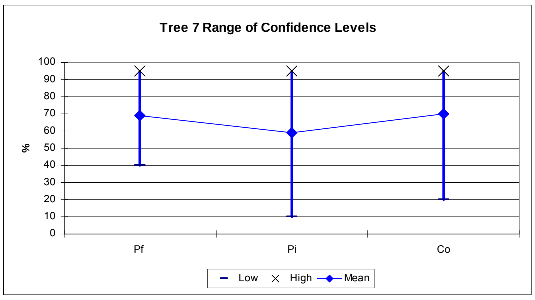


Figure 27 Tree 7 Confidence Level Range

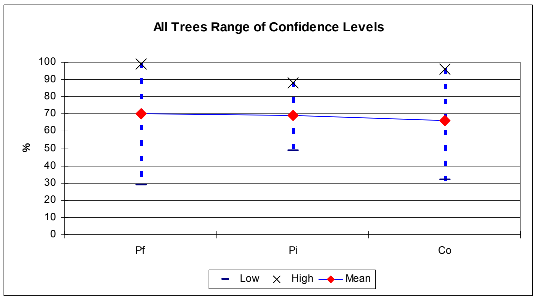


Figure 28 All Trees Confidence Level Range

Interestingly and possibly not unexpectedly, the confidence levels correlate neither with the various category estimates nor with the risk output values. More interesting are the data in Table 9, where it is evident that whilst Confidence Levels (CL%) are variable (range 4-95%) the mean is 70% and arborists regardless of their Probability of Failure (Pf) estimates generally apply high confidence factors, hence it is probably reasonable to assume that most have reasonably high confidence in their assessment skills. The local government arborists mean confidence was higher than that of the consulting arborists (60.8 vs 71.4%), however, this difference was not statistically significant (p >0.5).

Table 9 Top Five Confidence Levels and Probabilities of Failure - Tree 7

	Arb C	Arb A	Arb W	Arb F	Arb Z	Arb D	Arb S	Arb O	Arb G	Arb B	Arb J	Arb M
Pf	1:50,000	1:50	1:250	1:100	1:100	1:2	1:4	1:100	1:15	1:10	1:50	1:2
CL%	95%	80%	80%	79%	50%	60%	40%	50%	75%	70%	80%	80%

Regression of confidence levels and the TIPI 'openness to experience' levels identified an association, this was found in seven of the eight tested trees The R^2 value using the mean confidence level was 21% (Figure 29), the correlation coefficient was 0.459 indicating that some 21% of the variation can be explained by this association.

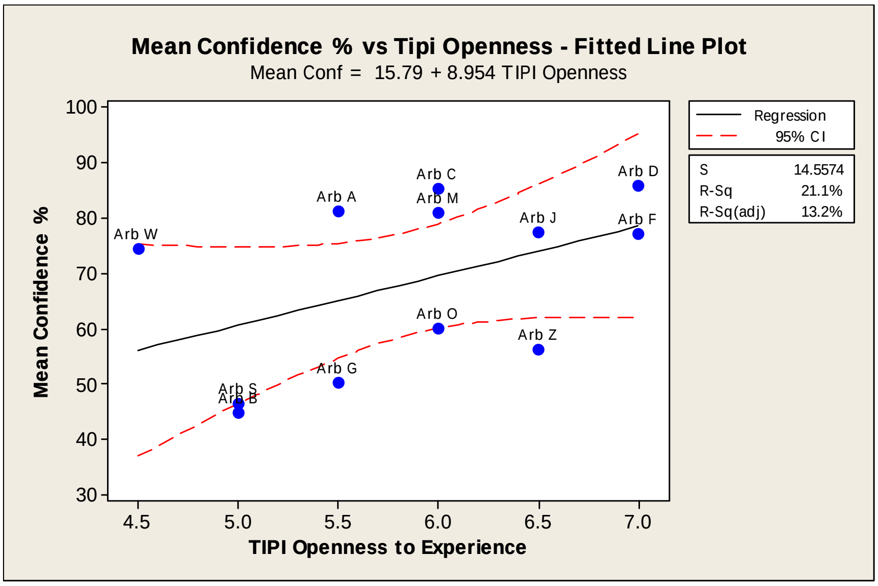


Figure 29 Fitted Line Chart and Regression - TIPI Openness and Mean Confidence in Assessment

Uncertainty surrounding assessments is a major issue given that most if not all tree risk assessment are made with limited data and incomplete knowledge. To improve the validity of any assessment method, uncertainty must be addressed by the method and assessors.

The Confidence Levels identified using TRE QT varied significantly by assessor, no doubt reflecting individual beliefs surrounding the various assessment uncertainties. Whilst this approach does not directly address uncertainty, it does provide an insight and may prove valuable, applicable, and transferable to any tree risk assessment method.

7 How Well it Works – Assessor Opinions

Each assessor was asked to rate how well they believed that each method reflected the risk for each tree assessed.

Based on simple mean overall allocated ratings, the Bartlett method was ranked the method that best reflected the risk that the arborists considered each tree presented (Figure 30), it also had the lowest standard deviation (1.86) and was 0.9 points above the nearest other method, and this was greater than the range across all other methods.

T-Scores were also created to allow for possible heuristic (anchoring) differences; regression of T Scores and actual means had an R^2 0.94, and a correlation coefficient of 0.95, hence suggesting that anchoring was not an issue.

As shown in Figure 30 the 'how well it worked' mean scores did not vary by a large amount, equally no score was particularly high. However, opinion did vary significantly between arborists and this is evident in Figure 32 where the Bartlett range is narrow (suggesting most assessors rated it similarly) whilst M&C, QTRA and TRE QT generated a wide range of opinions. Unfamiliarity with the methods could have produced the wider range of rating found with QTRA and TRE QT, the three QTRA trained assessors did rate QTRA slightly higher than the mean (6.5 vs mean 6.2), equally however, the Bartlett method is unknown in Australia and rated highly.

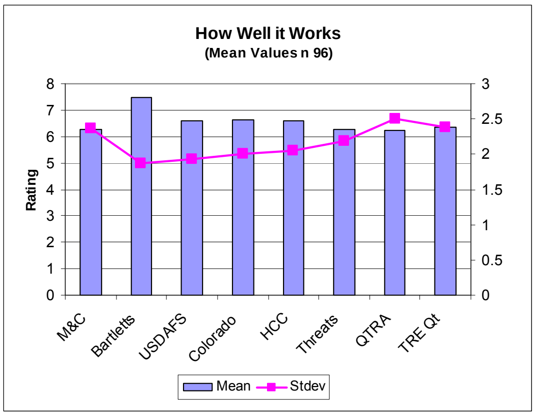


Figure 30 How Well it Works Mean Ratings

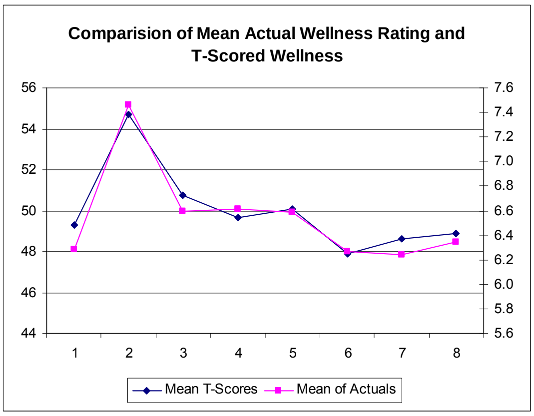


Figure 31 Comparing T Scores to Actual Means

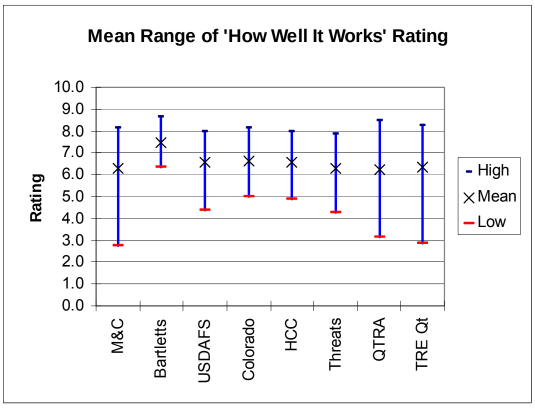


Figure 32 Mean Range of 'How Well it Works' Rating

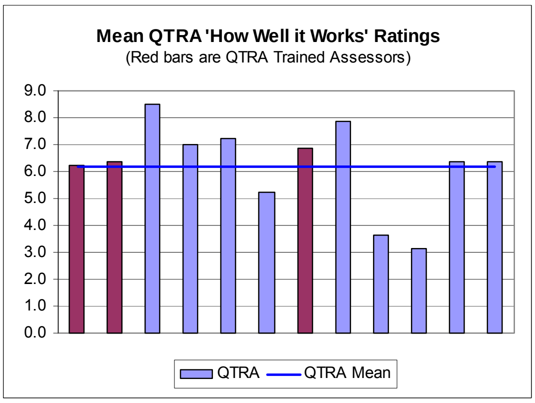


Figure 33 QTRA Range of 'How Well it Works' Ratings

8 Summary

During the last 40 years, physiological, biological and environmental tree knowledge has improved vastly; conversely, tree risk assessment *per se* has developed slowly, with little significant change to the simple qualitative methods developed in the 1970s. This research identified over 25 tree risk assessment methods and that a large number of assessors were developing their own or modifying existing methods. This possibly indicates a level of dissatisfaction with existing methods.

Tree risk assessment has tended to be treated as a valid process that anyone with ‘suitable training’ can undertake. The recent introduction of more quantitative assessment methods particularly QTRA, has raised some questions in relation to the overall validity of tree risk assessments and associated input variables.

Interestingly, given the prominence of tree risk assessment in the industry, it appears that negligible if any research has been conducted analysing the underlying processes and the overall validity of assessments.

Analysis of 15 methods applied to 15 trees identified that different tree risk assessment methods do produce a wide range of output values when applied to the same tree in the same circumstances. The breadth of this variation leads to a questioning of what each method is endeavouring to measure. Clearly, the differing input categories, variable types, ranges, weighting of values, the descriptors used and the mathematics combine to produced differing results.

Sensitivity analysis demonstrated that even a simple ± 25% or ± one rank change can produce very variable outcomes. Monte Carlo analysis identified the weighting and hence importance that each method places on the various assessment categories, with the majority of methods appearing to far more strongly favour the ‘Likelihood of Failure’ aspects over Consequence outcomes. Equally, the fitted distribution curves illustrated the significant influence the underlying mathematics have on the outcome ranges and distributions, and these distribution profiles were confirmed by comparing data collected from the 15 arborists.

The 12 experienced arborists who assessed eight trees using eight different methods, produced the most interesting results. The hypothesis was that experienced arborists would apply similar values in similar circumstances and hence the differences produced by each method would be evident. However, it appears that the differences in arborist applied assessment values to these eight trees across all methods was so diverse that the influence of each method is not obvious and that the variation produced by the arborists is the greatest influence on the risk output values created by each method. This observation was also confirmed by the comparison of ‘intuitive risk’ values that were chosen by the arborists.

The application of a simple ten-point personality test (TIPI) identified a medium correlation between a TIPI derived attribute and the arborists’ intuitive risk values, suggesting that to some degree an individual’s inherent attitude in relation to risk possibly influences their risk assessment.

Uncertainty is a major factor in risk assessments, however, it is largely ignored by the assessment methods reviewed. Uncertainty was obliquely addressed by the ‘Confidence Level’ assessment required by one method, this found that the arborists assessing trees applied a wide range of confidence levels to their assessments, indicative of uncertainty caused by lack of knowledge or data.

Of the eight methods assessed by the 12 arborists, the method that scored the highest value (and by a large margin) in the ‘how well it works’ question was the simple two category Bartlett method, which given that none of the arborists had previously used the method is interesting.

Analysis of the data currently suggests that the assumption of validity, completeness, robustness, and repeatability should be challenged, including the base assumptions, and underlying modelling (particularly weighting and mathematics). Equally, the wide range of assessment input variables chosen by arborists resulted in a wide range of risk output values, which would suggest that individual differences amongst arborists question the current value of risk assessments.

What Works – What Does Not – Can We Tell? Whilst analysis of the data gathered for this research is still to be completed and reviewed, based on the methodology and data analysis to date, sensitivity analysis will identify the weighting of the various components and likely distribution curve of output, however, it would appear that in field tests the inter-arborist variability is such that ‘we cannot tell’ which models or methodology provides the most complete measurement of tree risk.

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10 Appendix 1 A brief outline of the TRE QT risk assessment method developed for this research.

Draft Proposed Quantitative Tree Risk Evaluation Model (TRE QT)

Note: This is a draft tree risk evaluation method, created as part of a Masters Degree research project and as such it has not been extensively tested in the 'real world'. This explanatory document is a draft version intended for those helping with a tree assessment methodology trial as part of the master's research; it is not intended for general use.

Risk assessments should only be undertaken by persons with an adequate understanding of the risk assessment process, this involves far more than identifying tree defects, (refer to AS4360:2004). This document is an explanation intended to assist persons wishing to investigate further the usefulness of the method and to understand the underlying factors, assumptions and processes. If assessors do not understand the underlying logic in the methodology, it is recommended they do not use this system.

Whilst this method use probabilities, it would be rare when assessing tree risk that sufficient empirical data exists to apply truly quantitative probabilities (possible exceptions are with some probability of impacts where long term vehicle or pedestrian counts are available). Hence this method relies on the assessor's skills at applying in most cases a judgemental probability (Cleaves 1994).

This method also addresses uncertainty that exists in assessments. Uncertainty represents partial ignorance or the lack of perfect knowledge on the part of the assessor. Probability is the only way to represent uncertainty regardless of the practicalities in doing it accurately (Daneshkhah 2004).

Short Explanation

The following two pages explain the methodology for this tree risk method, and it is recommended that anyone intending to use the system read the complete document. However, given that many people will be merely curious; this document provides a brief overview.

TRE QT is based on the assumption that tree risk can be evaluated by mathematically combining the Probability of failure (Pf) with the Probability of impact (Pi) and the probable Consequence (Co). This approach is based on the definition of risk assessment as detailed in the Australian Standard AS4360:2004, it is also widely found in the literature and extensively in use by industry.

TRE QT can be used at a basic level for quick easy broad evaluation of risk and is suitable for initial inspections, surveys etc., by applying predefined variables (the probabilities are divided into ranges). Should the initial evaluation identify a potential concern or a potential cost (which can include financial, ecological, historical, environmental, social or political costs) then a more thorough TRE QT assessment can be used to refine the level of risk and uncertainty.

Time is critical, all trees will fail, and it is only with a reference to an assessment period that a risk assessment becomes valid. This method can be used for any period; however, data inputs should be based on annualised data, equally the greater the period the more uncertainty will exists.

Software is being developed using Excel® and for Windows CE® computers, whilst this will allow faster calculations with reduced possibility of errors it will not remove the need for those undertaking the assessments to be skilled assessors of each of the risk criteria categories and will not remove uncertainty cause by limited knowledge or data.

Quantitative Method

The TRE QT quantitative method will potentially provide a significantly more precise risk measurement than qualitative methods. However, similar to any risk assessment method, this method is limited by the quality of the input data and skills of the assessor. The major differences between this method and most qualitative methods are:

- the use of category point values (rather than ordinal values e.g., 1,2,3,4; or high/medium/low)

- the use of consequence as either a financial risk or relative risk against the value of a statistical life (VOSL), most methods use 'size of part' as a consequence category
- an attempt to define uncertainty via the use of a 'certainty factor' to provide a measure of assessor confidence in their predictions and hence provide a risk range rather than a point value (unless the assessor is 100 per cent certain of each input point value)

Whilst it is not an overly complex process, it does require some mathematical calculations; nevertheless, it can be easily automated for field collections. It is important that assessors understand the underlying methodology. Fundamentally, the three assessment categories are assigned a probability (a value between 0 and 1 or a ratio e.g., 1:100); these are multiplied to create a risk output value. This value will range from 0 to 1 or be a ratio e.g. 1:10,000, for easier broader understanding and use, most users will probably use the ratio method (although some simple mathematics will still be required to calculate consequence values). Each assessment category also requires the assessor to assign a confidence percentage based on their estimated probability; this is used to create a Certainty Factor (Cf).

The three risk categories are –

- Probability of failure (Pf) and confidence level % (CF%)
- Probability of impact (Pi) and confidence level % (CF%)
- Consequences (Co) and confidence level % (CF%)

The risk output value is the probability of the event occurring (Pf x Pi) and causing damage (Co), relative to the overall worst case i.e., 1x1x1 =1.

The confidence level percentage indicates the assessor's belief in the point value estimate and the average (mean) of these three confidence percentages is used to create a certainty factor (CF). This CF may be merely expressed as part of the assessment e.g., the risk is 1:20,000 with a 0.85 CF, and/or to create a risk range e.g., the previous values create a risk range of approximately 1:17,000 – 1:25,000.

These risk point values can be easily converted between probabilities and risk ratios (they are reciprocals). For example, a Pf 0.1 (ratio 1:10) x Pi 0.01 (ratio 1:100) x Co 0.001 (ratio 1:1000 of A$2.9mill or $2,900 damages) results in a risk output value of 0.000001 or ratio of 1:1,000,000.

The calculations for Pi (probability of impact) are based on the amount of time exposed over a year divided by the time available within the year. This can be complex, e.g., variables such as vehicle speed, length, tree width, breaking distance, etc., need to be combined to produce a probability.

Pre-calculated tables and spreadsheets are available, these provide for faster calculations, particularly when converting pedestrian or vehicle counts to probabilities, although more precision is possible by calculating actual values.

It is suggested that the usage figures represent average annual usage even when expressed hourly, daily, weekly etc. Terms that provide some precision to the Pi probability are recommended.

- Pedestrians - AAP/hr/day/wk/yr defined as - Average Annual Pedestrians per /hour/day/week/year
- Vehicles - AAV/hr/day/wk/hr defined as - Average Annual Vehicles per /hour/day/week/year
- Fixed hours - (e.g., car parks, or visitors to parks) should be expressed as AAE//hr/day/wk/yr – Average Annual Exposure per /hour/day/week/year

Pf (probability of failure) is merely defined as the likelihood of an identified hazard (usually a tree defect) failing within the inspection period. This is expressed either as a probability e.g., 0.001 or a ratio (1:100).

Co (consequence) is the risk assessor's evaluation as to the degree of injury/damage that would transpire should the failure occur and impact the risk target. The highest value of Co is based on the Australian VOSL (value of a statistical life) proposed by Abelson (2003) and has been indexed to 2006 prices using the CPI All Groups Weighted Average of Eight Capital Cities, provided by the Australian Bureau of Statistics (ABS 2006) the indexed value which has been rounded at June 2006 was A$2.9million. Hence an assessed Co of $29,000 represents 0.01 (1/100th) of the VSOL. This method also allows that Co can be represented as a financial figure, the resultant risk output value then represents a dollar value, (Pi 1:100 (0.01) x Pf 1:10 (0.1) x Co ($29,000) can be represented as a risk score of $29 or 0.00001 or 1:100,000.

Nothing is 'safe'; no one can define a tree as 'safe' or for that matter 'unsafe' without some qualification of acceptable risk. Acceptable risk is a complex subject, and suffice to state that the acceptability of risk is the choice of the owner or manager of the property, however, the concept of acceptable risk does exist within the community and there are some general figures which are often broadly used. For urban tree risk it is suggested that any risk output value closer to one than 0.0001 (1:10,000) is unacceptable, and any risk from 1:10,000 (0.0001) to 1:100,000 (0.000001) be reduced if ‘practicable’. Cost benefit values can be used to define ‘practicable’. Equally, large organisations may choose to use the risk output values to prioritise works based on reducing the greatest risk first, with available budget being the arbitrator of the amount of works completed.

When multiple fatalities are realistically possible, a FN (frequency number) curve should be used to define a different level of acceptable risk. FN curves change the level of acceptable risk relative to the number of people at risk at any one time. Where an acceptable per annum tolerable risk level for an individual may be 1:10,000pa (10^4), for an exposed group of 5 – 1:100,000 (10^5) and over 10 people 1:1,000,000pa (10^6) is suggested.

Uncertainty

Any risk assessment will have a level of uncertainty associated with the assessment. This can be for several reasons; in particular, most tree data will be limited in accuracy due to imperfect knowledge. Using ranges rather than point values for risk assessments is a common method of allowing for uncertainty; however, it significantly increases the complexity of the assessment.

TRE QT attempts to quantify the level of uncertainty, by requiring the assessor t to assign a ‘Confidence Level’ as a percentage value of the confidence their have in the value they allocate to each of the risk assessment categories. This ‘Confidence Level %’ (CF%) is used to generate a certainty factor (Cf – the mean of the three Confidence Levels) used to both quantify the uncertainty the assessor has in the assessment and create a range around the final risk output rating.

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