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Development of inspection systems for estimating the structural integrity of trees: *An overview of sampled tree risk assessment and hazard rating systems*

Utvecklingen av bedömningssystem för besiktning av träds strukturella hållbarhet:
En översikt av utvalda system för riskbedömning av träd

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Foreword

This C-level degree project is written within the subject of Technology as a final report to fulfil the necessary requirements for attaining the level of Bachelor of Science in Landscape Construction and Management through the Swedish University of Agricultural Sciences (Sveriges Lantbruks Universitetet). The course is designed for students to plan, prepare, and exhibit a personalised paper around a chosen topic to demonstrate their ability to complete a standardised project within the allotted timeframe. The project's purpose focuses on scientific method and research as the basis for essay content.

The author would like to thank the faculty for their kindness and consideration during the programme's duration. Their knowledge, wisdom and care are greatly appreciated. Special appreciation is also extended to Klaus Vollbrecht for his consultation and instructional help during the writing of this report.

The paper has been written under the supervision of Anna Levinsson and Annika Wuolo for the Department of Landscape Management, Design and Construction.

Curtis Charles Bellows
Lund, May 2008

Synopsis

Urban tree managers are charged with the responsibility of managing large tree populations while securing a safe environment. A conflict exists between the presence of urban trees and the potential hazards these trees can be to buildings, vehicles, and inhabitants. Determining the structural stability of urban trees for the purpose of maintaining public safety is a chief function of urban forestry.

Various conceptual frameworks, systematised routines, and documentation tools are available to aid managers with tree evaluations and risk assessments. This report maps the historical development of modern structural risk assessment's start in conservation area management and its evolution, and application, into the urban arena.

The report finds that the concept of the *hazard tree* exists only when there is the presence of valuated objects within the tree's area of influence. Thus, urban forestry, with the ubiquitous presence valuated objects such as pedestrians, vehicles, and buildings, has forced risk assessment, and management, to become an occupational responsibility for urban foresters. Events of structural failure resulting in injury and death are statistically low; however the frequency of structural failures increases during extreme meteorological events such as wind, ice, or snow storms. Numerical assessment systems were introduced as a tool for rating individual tree's structural status for the purpose of estimating the risk for failure while standardising evaluation techniques. These same systems are also used to regulating tree populations and validate pre-emptive management.

This report samples four currently practiced tree risk assessment models with accompanying pro forma (protocol) documentation aids. Three systematic identification methods used to organise tree inventories for risk assessments are also examined.

The following systems are presented and accompanied by short analyses pertaining to their area of application:

1) International Society of Arboriculture: A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas (Mathney & Clark 1991)
2) The USDA Forest Service Community Tree Risk Rating System: 7-Step Program (Pokorny 2003)
3) Tree Hazard Rating, Evaluation And Treatment System (THREATS): A method for identifying, recording & managing hazards from trees (Forbes-Laird 2006)
4) Quantified Tree Risk Assessment (Ellison 2005)

The report's discussion applies these assessment systems to a hypothetical situation involving a mature treed avenue along a major city road where the trunk diameter at chest height (DBH) exceeds 75cm. Each calculation's result and consequence is discussed to demonstrate the differences between the systems. The variations between the four assessment systems show that alternative models are available which inflate or deflate mature tree hazard rating.

Sammanfattning

Urbana trädförvaltare är ansvariga för skötsel och underhåll av stora trädbestånd, de är även förpliktigade att säkra stadens utemiljö. En konflikt existerar emellan stadens behov av träd och de möjliga faror de kan utgöra för fastigheter, fordon och invånare som kan uppträda när deras tillstånd försämras. Att fastställa trädens strukturella skick är ett grundläggande uppdrag för trädförvaltaren.

Olika ramverk finns, med arbetsrutiner och dokumentationsredskap, för att hjälpa förvaltare med trädbesiktningar och riskbedömningar. Denna rapport har undersökt de ursprungliga källorna till moderna strukturella riskbedömningar av stadsträd och ett urval av aktuella modeller, system och medföljande dokumentationsunderlag som erbjuds.

Rapporten visar på att begreppet *riskträd* endast uppstår när det finns ett samband mellan de föremål och deras värde, som finns inom trädets påverkningsområde. Denna realitet har gjort att trädförvaltning också bör inkludera kompetens att hantera objektiva riskhanteringsmetoder på grund av ständig närvaro av invånare, fordon och fastigheter. Statistik visar att allvarliga incidenter relaterade till bristfälliga träd är låg, dock ökar svåra olyckor när stormar av olika slag inträffar.

I rapporten beskrivs tre systematiska identifikationsmetoders användbarhet gällande inventering och riskbedömning av stadsträd. Implementering av numeriska bedömningssystem kan fungera som ett standardiserat förvaltningsverktyg för att bedöma och värdera enskilda träds tillstånd med anledning att uppskatta bristfälligheter, reglera urbana trädbestånds tillstånd samt att stödja förebyggande åtgärder. Fyra utvalda bedömningssystem presenteras vilka visar att alternativa modeller är tillgängliga för att öka eller minska riskbedömningsvärdet av enskilda träd.

De följande fyra bedömningssystem för besiktning av träds strukturella hållbarhet presenteras med korta analyser av deras tillämpningsområde:

1) International Society of Arboriculture: A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas (Mathney & Clark 1991)
2) The USDA Forest Service Community Tree Risk Rating System: 7-Step Program (Pokorny 2003)
3) Tree Hazard Rating, Evaluation And Treatment System (THREATS): A method for identifying, recording & managing hazards from trees (Forbes-Laird 2006)
4) Quantified Tree Risk Assessment (Ellison 2005)

I diskussionen appliceras samtliga bedömningssystem i en hypotetisk situation med en äldre allé längs en högtrafikerad väg där stammarnas diameter är över 75cm. Uträkningens resultat och konsekvenser diskuteras, för att demonstrera samtliga bedömningssystems inbyggda egenskaper.

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Introduction

Background

The importance of trees as an integral unit within city planning and management has been recognized since the advent of urbanization. Urban trees and green spaces remain as an essential ingredient of great significance in urban planning for the metropolitan populace (Dwyer, Schroeder & Gobster 1991). These spaces are realized as regulators of temperature, humidity, light, and air movement, while providing aesthetic and spatial structuring to their communities (Miller 1988). Mature urban trees are equated with established public greening policies and operative success of urban greening ideals; the maturity of an urban tree population also reflects an individual community's historical legacy and cultural heritage regarding its green structure, collective identity and shared attitudes (Forrest & Konijnendijk 2005). The benefits of urban tree populations as a recreational, health, social, and architectural resource (Tyrväinen et al. 2005) are widely encouraged and are being continuously developed.

Trees, as biological entities within the urban infrastructure, have predisposed growth habits which can predict characteristic traits and form development essential for planning. Individual trees, and tree groups, are often strategically planted to provide specific functions within a specific urban space. Older trees become encompassed by expanding urban spheres, and have their environments drastically altered from their original states. En route, both tree types, those as a result of urban planning or those previously established as remnants of older land uses, suffer from intensified mechanical damage. The results, created through detrimental development, incurred injuries, and environment changes, create a collection of structural deficiencies (Appendix i).

For managers of urban trees, maintaining routine inspections and inventory checks, to map a tree population's state is an important means for increasing public and property safety within green spaces. Responsibility for urban trees creates agenda dilemmas; managers must balance the need to secure reasonably safe urban environments while conserving tree populations. The task of administering tree populations means that juggling the conflict between safety and conservation are a daily reality and responsibility.

Aim

This report aims to:

- investigate the origins of modern tree assessment
- survey a sample group of systematic identification methods used to organise tree inventories for risk assessments
- survey a sample group of tree inspection systems and accompanying pro forma, in current circulation, used for assessing hazards, risk factoring, and tree status
- analyse and discuss the presented tree inspection systems and practical implications

Delimitations
This report will not discuss:

- detailed structural deficiencies, pathological agents and processes related specifically to singular genera or species
- various mechanical tools available for detailed evaluations of decaying processes and pathogens

The study will be confined to data and literature written or translated into the English language.

Method

This report is based upon a literature investigation of English language material accessed through the Swedish Agricultural University's library and subscription database Web of Knowledge, coupled with internet queries using keywords: tree, hazard, risk, failure, assessment, evaluation, rating, damage, loading. The study's sampled tree risk assessment and hazard rating systems were chosen for the following reason:

- two have American origins (Mathney & Clark 1994, Pokorny 2003); two have European origins (Ellison 2005, Forbes-Laird 2006)
- two allow free access and usage (Pokorny 2003, Forbes-Laird 2006); two are membership affiliated (Mathney & Clark 1994, Ellison 2005)
- three (Pokorny 2003, Ellison 2005, Forbes-Laird 2006) have evolved from the one system (Mathney & Clark (1991, 1994)
- all four collectively present a broad evaluative spectrum and framework for managerial risk assessment of trees
- all four are in current circulation

The sampled rating systems will be preceded by a description of general methods for locating and identifying hazard trees within large populations.

The literature study is based on historicism method to explore the roots of modern tree risk assessment while utilising a pragmatic perspective for the analyses and the discussion. Accumulated information from the researched material was cross-referenced with the author's working experience gleaned from local tree populations in southern Sweden, providing an empirical foundation for reference/source sorting and collection.

Historical Foundations for Tree Risk Assessment

Quality Control within Forestry
The evolution of recreational use of peri-urban forests spawned the need for evaluative systems for maintaining local tree populations while increasing public safety. Quality management of trees has a historical origin in silvicultural product management. Determining the quality of timber products demanded a control system for investigating potentially degraded specimens to ensure high quality product (Lockard et al. 1964). The resulting documentation surrounding the degradation of lumber quality created a symptomatic groundwork for urban tree assessment. The progressive establishment of arboriculture and urban forestry sciences and techniques, coupled with increases in public safety awareness, provided a foundation for modern tree evaluation systems.

Willis W. Wagener
During the 1960's in California, USA, Willis W. Wagener, a 40 year veteran forest pathology researcher, wrote one of the first United States Department of Agriculture (USDA) Forestry Service research papers regarding hazards created by trees from a conservationist context (Wagener 1963). The report studied the problematic nature of conservation and safety from a management perspective, outlining the importance of tree structure to maintain mechanical stability. Wagener presented the common morphological manifestations which indicate structural deficiencies, known biotic pathogens and pests, and a specific hazard expectation list for the local indigenous species. The information was accompanied by a general awareness check-list for assessment and judgement.

The Paine System
Lee Paine was also commissioned by the USDA Forestry Service, Pacific Southwest Research Station to investigate tree incidents which resulted in injury or loss within the California State Park System. The researcher's studies are accredited with providing a data compilation which provided a framework for the quantitative elements within hazard tree evaluation forms (Hickman et al. 1989). An initial assessment pro forma was created in 1971. A following pro forma (Paine 1978), used for data collection, assessed and inventoried trees which had experienced structural failure within the state parks jurisdiction.

The *Report for Tree Failure* form numerically quantified tree failure incidents through a data collection system tailored for coding and automatic processing of the collected information. The form focused on:

- type of failure
- mechanical failure points
- contributing environmental factors
- properties and persons affected
- consequences (cleanup/ rebuilding/compensation with estimated values)
- other site related factors such as time, place, site category, and land ownership

Data collection for the project also provided a basis for eventual qualitative assessments of failure and impact probability, with target valuations, to create numerical hazard ratings (Paine 1978). In the US, individual State commissioned initiatives created local evaluation forms used for tree assessment of forested recreation areas based upon the Paine system.

The Webster Model

Working in another US region during the 70s, Bruce Webster (1978) created a qualitative grading model for evaluation of shade trees (an early designation for urban trees). The system was designed to standardise the judgement criteria for monetary appraisal of urban trees. The assessment model was comprised of six rating categories:

- trunk condition (rating 1-5)
- specie's specific growth rate (rating 1-3)
- structural condition (rating 1-5)
- insect and disease problems (rating 1-3)
- crown development (rating 1-5)
- life expectancy (rating 1-5)

A culminating condition rating 26-23 was considered excellent; 9-6 was considered very poor. General guidelines were introduced to explain how visual observations could be interpreted into the rating model. The Webster Model became the basis for the International Society of Arboriculture's (ISA) *Guide to the Professional Evaluation of Landscape Trees, Specimen Shrubs and Evergreens* (1982), the organisation's monetary tree appraisal manual and forerunner to the current ISA hazard tree recommendations, and pro forma, published in *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas*.

Visual Tree Assessment (VTA)

A conceptual framework for tree assessment was authored by Claus Mattheck and Helge Breloer (1993), in the German version of *The Body Language of Trees*, using scientific theory based on physics. The system stems from a collection of research paper focused upon the structural attributes of trees and the resulting failures associated with mechanical loading (Mattheck, C. & Korseska, G. 1989, Mattheck, C., & Bethge K. 1990, Mattheck, C., 1990, Mattheck, C., Bethge, K., & Erb, D.1993).

The system's premise is ***the Axiom of Uniform Stress***:

> *An optimal structure has a uniform stress over the whole of its surface.*
> (Mattheck & Breloer 1993)

When applying the axiom to tree structures, the statement implies that a tree evenly distributes mechanical stress over its surface to optimise a stable structural form to support biological functioning. Extraneous material is the result of processes to re-establish stress distribution by re-enforcing structurally destabilising internal deficiencies. Bulges, boles, and other superfluous material, can indicate a strengthening response to an internal structural weakness, such as decay.

The major categorisation of visual assessment into biological and mechanical flows allows sequential analysis to follow two separate tracks which, when amalgamated in *Failure Criteria*, will influence the *Decision* process. A negative report from the mechanical flow may be balanced and weighed against a positive biological assessment; an injured tree can have good vigour which will hasten the potential for compartmentalisation and wound closure.

Conceptual Foundations for Tree Risk Assessment

Risk
According to a general definition, risk is exposure to the possibility of injury or loss due to the presence of a hazard or dangerous chance. Risk, in countries such as the UK and the US, has received a judicial definition at the national level (Ellison 2005) often as a result of litigation (Anderson & Eaton 1986). In Germany, if a tree controller suspects internal rot within a street tree, a local court decision has now set a precedence which demands that deeper assessment must be made to determine the residual wall thickness to assess the potential for failure, thereby determining risk (Weber & Mattheck 2005). The legal consequences of managing risk can vary greatly from country to country.

Risk, within a tree assessment context, is concerned with the potential for tree failure where collateral damages can occur over and above a level of acceptable risk. All trees contain a level of risk; all trees have the potential to fail under extreme meteorological conditions (Wagener 1963). Wind, ice and snow storms can place excessive loading on trees which cause mechanical failure. Storm events can cause damage to any tree provided mechanical loading exceeds the tree's capacity to withstand the physical pressures exerted (Sisinni et al. 1995).

Statistics from the UK, concerning tree related injuries, have shown that 5-6 individuals are killed each year by falling trees, creating a risk factor of 1/20 000 000. High-risk defined public areas in the UK experience a failure rate of 1/10 000 000 trees annually (Ellison 2005) showing a low frequency of tree failure related injuries.

Defining Hazard Trees and Targets
According to USDA Forestry Services, a tree hazard refers to any *potential* tree failure due to a structural defect that may result in property damage or personal injury (Johnson 1981). The concept of the hazard tree has developed from the concept of the target. Targets are objects or persons within range of a potentially hazardous tree occurrence such as uprooting and falling branches (Paine 1971, Sharon 1987). Targets, and target areas, are ranked according to their use, value and occupancy. Buildings, with continual occupancy, increase a target's rating value which, in turn, increases the hazard status of a tree. Understanding the potential collateral and legal ramifications of a failure incident connected with targets is essential for determining a hazard tree ranking. The hazard status of a tree is determined and categorised through its accumulated structural deficiencies, environmental pressures, and target ratings.

In 1991 the concept was reformulated by Matheny and Clark who proposed three factors and their interactions in *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas.* Hazard status and rating are defined by:

- failure potential due to structural deficiencies
- environmental factors which may promote tree failure
- the target: persons or object which may be injured or damage due to a tree's failure

Establishing a tree's hazard potential is based upon the presence of a target. Therefore, trees with little contact to human interactions receive no hazard rating and can be freed from evaluation. However, urban and peri-urban environments are under constant target pressures from inhabitants and can be consider for target assessment rating.

Various governing bodies, with trees which pose a heightened risk to public and property safety, have created definitions for policy interpretation:

> *A Hazard is an expected accidental loss resulting from mechanical failure of a tree during current inspection cycle if no control is undertaken.* - Accident Hazard Evaluation and control decisions on forested recreation sites (Paine 1971)
>
> *A tree can be considered potentially hazardous if it is situated in an area frequented by people or is located adjacent to valuable facilities and has defects in roots, stem or branches that may cause a failure resulting in property damage, personal injury or death.* - Tree Hazards in Recreation Sites in British Columbia (USDA Forestry Service 2006).
>
> *A standing tree, either live or dead, having defects, singly or combined, in roots, butt, bole, or limb, which predispose it to mechanical failure in whole, or in part, and which is so located that such failure has a probability of injury and damage to persons and property.* - Peter Gaidula, California Dept. of Parks and Recreation (USDA Forestry Service 2006).
>
> .
>
> A Hazardous Tree is a tree that:
>
> - *has a combination of structural defects and/or disease which makes it subject to a high probability of failure*
> - *has a potential target such as a permanent structure or an area of moderate to high use such as sidewalks or public trails within a tree length and a half of the tree*
> - *is a danger which can not be mitigated through pruning or moving of potential targets.* - The City of Seattle (Seattle 2007).
>
> *The term Dangerous trees is used in respect of those trees which, for one reason or another, may fall either as a whole or in part, and in so doing constitute a danger.* – The Arboriculturalist's Companion (James 2005)

Evaluation Criteria for Assessments

Site

Site describes the physical location of the tree. A site is analysed through the surrounding environment's soil, topography, and climate, both locally and regionally, which have an immediate influence on a tree's development. Evaluations must recognise whether the site is of natural or artificial origins, is influenced by altered water table levels, has confined rooting space, and whether there are physical discrepancies between filling and natural soils. (Mathney & Clark 1994, Pokorny 2003, Harris et al. 2004)

Tree Age and Size
It has been recognised that tree failures increase with correlated increases in age and size. Fast growing trees often have increased failure rates due to porous wood growth (Putz et al. 1983); older trees lose vitality, making them more susceptible to pathogenic invasion and other disorders.

Tree Species
Trees often have distinct failure patterns which are characteristic for their species. These failure patterns according to Harris, Clark & Matheny (2004) are:

- Type and frequency of failure (root, trunk, branch)
- Growth habits
- Structural weak points
- Site conditions contributing to failure
- Management routines contributing to failure

These categories have been used to create *Tree Failure Profiling* (Costello & Berry 1991, Harris et al. 2004), a reference aid which can help in assessment awareness of failure points which should receive extra attention during evaluations. *Tree Failure Profiles* can be made for indigenous and exotic tee populations from a local perspective, using local knowledge and experience of failure incidents, as well as international sources, through data collection.

Systematic Identification Methods: Description and Analysis

In North America, identification methods of hazardous trees have been evolving over time, largely due to the efforts of governing municipal and state bodies' need for effective management of tree populations under their respective jurisdictions (Paine 1971, Johnson 1981, Mathney & Clark 1994, Pokorny2003). Survey timing can be the result of crisis management or scheduled routines. Meteorological catastrophes can happen suddenly which demand a quick response whereas scheduled evaluations are anticipated. The following methods can be preformed in sequential order. Time and labour intensities increase as each evaluation method's level of detailed documentation requirements are amplified.

Urban Target Zoning
To organise prioritising of tree risk assessments, *Urban Target Zoning* provides a means for urban areas to structure inventory and assessment programs. Urban centres categorise areas within their jurisdiction with a risk priority scale according to urban infrastructure, public usage, and urban greening importance and function. Safety and accessibility needs of emergency routes, traffic volumes, and sight or accessibility obstructions are considered, weighed and prioritised.

The ranking system ranges from a three level to a four level system which can be numbered or colour-coded (Table.1). These rankings are based on available resources and area's structural complexity.

Table.1 shows a simplified variation of numerical/colour-coded risk grading systems within Urban Target Zoning (Pokomy 2003, p.24)

4	Very high risk	Red
3	High risk	Orange (Red: three level system)
2	Moderate risk	Yellow
1	Low risk	Green

Tree risk zoning allows for municipalities, institutions, and businesses to colour-code maps for organising, and prioritising, tree plans and budgeting work initiatives.

Analysis
Tree risk zoning (*Urban Target Zoning*) can help municipalities, or organisations, with large tree inventories to prioritise management routines and work initiatives. The system can provide a framework for budget planning, and enable managers to form emergency protocols for crisis management. *Urban Target Zoning* integrates urban greening into the large municipal infrastructure and demands departmental cross-communication.

Windshield Survey
The next method for preliminary analysis of a hazard tree population is the windshield survey. An inspector and chauffeur slowly drive through a designated area to visually scan for defects or signs of hazards (Pokorny2003). The survey enables the inspector to create a quick list of suspected defective, dangerous, or declining trees within the survey area. The method is fast, allowing for quick assessments of high risk areas which also have scheduled walk-by surveillance or low risk areas which need lower maintenance checks. The method can also be effective for categorising streets into risk zones before the establishment of inspection routines.

The method is primarily used to pinpoint higher ranked hazards such as crown dieback and dead branches, poor architecture, and dead trees. It is also used after storms for estimating damages and evaluating potentially new hazard which might have arisen, such as fractures or hanging branches.

Windshield surveys are criticised for not providing more detailed site and target evaluations. Tree defects out of view from the inspector will also not be accounted for, allowing for major hazards to be concealed from the inspector’s report. Recent studies have shown that the windshield survey has had a high success rate at assessing extremely high risk trees when road traffic is at a low volume (Rooney et al. 2005). As traffic increases, distractions affect the inspector’s ability to concentrate on the surveying task.

Analysis
Windshield surveying provides a cost-effective data collection method to observe individual trees and populations between major scheduled inventory evaluations. The method is not recognized as thorough, yet can effectively aid job planning during emergency situations. Regularly scheduled windshield surveys can help managers to maintain a clearer picture of a tree inventories’ health between detailed inventory surveys, since it is effective for noting trees in decline.

Walking surveys
General and detailed hazard assessments are dependant upon investigative inspection. Visual assessment has become the core method for general hazard evaluation of trees. Various walking methods for assessing tree structure have been created to meet the grade of the inspector; from general guidelines for volunteers engaging in inventories to detailed field analyses by professional consultants.

The varying intensities of walking surveys can be used to fulfil a complete failure assessment. Walking surveys are time consuming and can be considered when following a governing, systematic inventory standard. Target areas are designated and prioritised; trees 1.5x their heights from target areas should be investigated with a 360° circling of the tree. Assessments preformed during snow cover miss hidden root plates and other potential problem areas which must be considered to complete a full evaluation.

Analysis
Walking surveys can provide detailed information of individual trees, depending upon the investigator's knowledge and experience. The survey's data collection detail level is dependant upon the chosen pro forma format or evaluator's systematic approach, directly correlated to the assessment's aim and correlated to both time, labour, and financial restraints. The walking survey is the primary methodological approach for a detailed evaluation and assessment.

Hazard Tree Recognition, Assessment, and Management Procedures: Description and Analysis

Tree assessment is an intrinsic part of maintaining successful tree plans. A wide range of tree inspection models are available for performing general or detailed risk-assessments. The following samples are largely based upon cumulative developments in arboricultural knowledge coupled with a progressive refining of assessment technique. Combinations of tree assessment processes, risk potential assessments, and target ratings have developed according to the needs of the information's end-user.

International Society of Arboriculture: A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas (Mathney & Clark 1991, 1994)
This system was created as an aid for professional consulting arborists for assessing hazard trees both municipally as well as privately. Preceding assessment processes largely catered to recreational/conservation areas with indigenous amenity trees. The project was designed to create an assessment technique suited to arboricultural trees with amenity value, located within the urban environment. The process method, and pro forma, summarised and amalgamated the current collective knowledge and progression with hazard tree evaluation. The programme is published and endorsed by the International Society of Arboriculture (ISA) and has the following eight steps:

1. Identify tree
The tree subjected to investigation is found through a survey or, in commercial cases, at the request of a concerned party. Trees within a municipal context are recommended to be on a one to two year *evaluation cycle*, dependant on previous assessment conclusions.

2. Formulate evaluation perimeters

The assessment aim's focus and intensity is decided upon, and is reliant on the investigator's expertise. The extent of the investigation will determine the resources and knowledge requirements. A form is provided which can be used for structuring the assessment.

3. Site Evaluation

The evaluator describes the general topographical, geological, meteorological, and historical factors associated with the subject's habitat. Urban environmental influences are noted along with the management history.

4. Identify the tree's structural defects and affected structural components likely to fail; document size and weight

The evaluation systematically investigates the structural components and mechanical stability of the following:

- Overall tree form and symmetry, vitality, and failure history
- Root structural weakness from biotic and abiotic (mechanical) activities which affect anchorage
- Trunk bark, taper and signs of biotic and abiotic activity and damage
- Scaffold branch structure, formation, signs of biotic and abiotic activity and damage, bark, and pruning history
- Branch structure, formation, signs of biotic and abiotic activity and damage, bark, and pruning history

5. Summarise defects and rank likelihood of structural failure

Identified defects are summarised and documented. The cumulative seriousness, with size and weight estimates, is considered and ranked. Environmental interactions and site evaluation are reconsidered in relation to defects when designating an overall failure rating. Ratings were formerly based on a nine-point system (1991), altered to a twelve-point rating system (1994).

6. Identify target in danger

Targets are defined and ranked according to occupancy and value. Target areas should include all objects and traffic within a circular area; an area which has a radius of 1.5x the height of the evaluated tree.

7. Summarise hazard rating

The hazard rating (Equation.) is a summation of three components which will determine the seriousness of a failure event. Each component has a three point rating system, for a combined total of twelve-points (nine-points 1991) which is the maximum hazard rating. Hazard ratings are often used to prioritise work initiatives.

The following presentation lists the original 1991 and the revised 1994 rating criteria:

Failure potential (3-4 points) ranks the likelihood of failure from structural weaknesses. The rating combines the defects seriousness and the probability and potential of failure.
1991

- 1 - low: minor defects (ex. twig die-back, small wounds healing well)
- 2 - moderate: numerous and/or significant defects (ex. cavities with 30-40% circumference coverage, dead scaffold branches)
- 3 - severe: very dangerous (ex. fruiting bodies or cavities with over 50% circumference coverage)

1994

- 1 - low: minor defects (ex. twig die-back, small wounds healing well)
- 2 - moderate: several moderate defects (ex. cavities with 30-40% circumference coverage, dead scaffold branches)
- 3 - high: multiple, significant defects (ex. weakened branch unions, sign of root breakage, cavities with >40% circumference coverage)
- 4 - severe: very dangerous (ex. fruiting bodies or cavities with over 50% circumference coverage)

Size of defective part (3-4 points) ranks the most hazardous part's size to estimate impact potential.
1991

- 1 - small: (ex. branches < 6-10cm in diameter)
- 2 - medium: (ex. branches > 6-10cm in diameter)
- 3 - large: (ex. crown sections or whole trees)

1994

- 1 - < 15cm in diameter
- 2 - 15-45cm in diameter
- 3 - 45-75cm in diameter
- 4 - >75cm in diameter

Target rating (3-4 points) ranks target objects or zones according to occupancy and value.
1991

- 1 - occasional use: (ex. paths)
- 2 - intermittent use: (ex. parking lots, picnic areas)
- 3 - high use: structures, infrastructure: (ex. houses, powerlines)

1994

- 1 - occasional use
- 2 - intermittent use
- 3 - frequent use
- 4 - constant use

A target rating can be set to zero, if no hazard is present. If no target is present, the tree is not a hazard (Equation.1).

Equation.1 shows the hazard rating equation as first presented within ISA: A Photographic Guide to the Evaluation of Hazard Trees in Urban Area (Mathney & Clark 1991, p.47)

Failure potential	+	Size of defective part	+	Target Rating	=	Hazard Rating

8. Prescribe treatment to decrease hazard

A treatment is decided upon to alleviate the hazard rating, factoring in evaluation cycle routines, the management programme's resolve to allocate available resources, and past rating history. If the inspector suspects other potential problems, not visually apparent during a walking survey diagnostic, an advanced root crown and/or an aerial investigation can be undertaken. Evaluators prioritise moving the target to remove the risk (Shigo 1991) before prescribing a treatment. If a target cannot be moved, a treatment is set.

Analysis

The assessment system and pro forma is primarily designed for single tree evaluations, within a private context or for specific municipal trees of significance. The pro forma is structured, detailed, and time consuming. Evaluation structure occurs from the bottom-up; risk seriousness of defects is reduced as the investigator moves up the tree where static weights decrease. The authors stress that vitality does not equal structural stability; a vigorous crown can hide weakened scaffold branches, root structure, or anchorage. After documentation completion, the investigator has a thorough account of the subject's state which can be filed. The failure rating relies upon professional judgement and interpretation of the point system based upon information found within *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas* 2nd Edition. The 1994 twelve-point rating system change provided greater leeway for evaluators to present more detailed assessments by increasing the hazard gradient's communicative ability through greater numerical flexibility.

The USDA Forest Service Community Tree Risk Rating System:
7-Step Program (Pokorny 2003)

This American system has been published for municipal foresters and arborists to adopt as a standardised process for tree assessment within a large scale urban and peri-urban context. The system condenses the Mathney & Clark system (1994) to encompass larger municipal planning using a simplified assessment pro forma to streamline data collection. The system has the following seven step programme:

1. Locate and Identify Trees to be Inspected

Trees within *tree height:distance* (1:1.5) range of the target area are to be assessed. Even larger and taller trees nearest to the target ratio area should be included. Inspections should be timed when root collars are exposed, therefore inspection during snow cover is not recommended

2. Inspect Individual Trees and Assess Their Defect(s)

Walk-around evaluation of root zones and flares, trunks, stems, branches, and branch unions ensures inspection of the high priority areas. Observed defects are compared with severity levels established within the protocols accompanying manual. The system stresses tree structure over tree vigour. Binoculars are recommended for examining the upper crown.

3. Estimate the Risk Rating for Each Tree

An assessment form is provided with a guideline summary (Appendix ii) and coding system synopsis. Defects are compared with the guideline manual's valuations, and a rating is decided upon using the inspector's local knowledge of tree specie weaknesses and defect propensities (Equation.2).

Equation.2 shows the revised risk rating calculation as found in the USDA Forestry Service Community Risk Rating System. A new category has been introduced to allow for greater inspector influence over the risk rating (Pokorny 2003, p.105)

Probability of failure	+	Size of defective part	+	Probability of target impact	+	Other risk factors	=	Risk Rating

The investigator's responsibility is to establish a risk rating using a three-level system:

- Low-risk rating - defect level insufficient to demand management action
- Moderate-risk rating - defects present which may develop failure potential in the future; defect level insufficient to demand management action
- High-risk rating - defects present which indicate impending failure or have caused failure; defect level sufficient to demand management action

4. Prioritize Highly Defective Trees for Treatment

This step is designed for owners of large tree population or owners which have resource constraints. Ranking of treatment of high-risk trees is prioritised, based on target occupancy and value. Ranking provides a basis for treatment prioritising. Targets nearest high-risk trees are defined, then categorised under a three-level system:

- Frequent use - priority number 1
- Intermediate use - priority number 2
- Occasional or low use - priority number 3

5. Conduct a Public Review Before Implementing Corrective Actions

Inform the public of planned management actions such as pruning or removal before commencement. This will provide an opportunity to explain the decision and to create a local understanding about remedial management actions, reducing the potential for conflict.

6. Take Corrective Action as Soon as Possible on the Highest Risk Trees

Commence with the management action as soon as possible. Prolonging a corrective action can be perceived as neglectful by an informed public.

7. Document the Process: Inspection Results, Actions Recommended, and Actions Taken

Systematically document all steps for archiving.

Analysis

The USDA Forestry Service's 7-Step Program is a systematic approach which considers municipal tree management from preparatory planning and inventory surveying to operative management and documentation. The pro forma is designed for multiple tree structural assessments with a short, conclusive tree rating system based upon a criteria guideline list. Structural defects and corrective activities are coded for efficient structural assessment. Assessment documentation focuses on an individual tree's most pressing problems giving a narrow picture of the tree's state. The pro forma also contains a follow-up category for completed remedial actions.

Tree Hazard Rating, Evaluation And Treatment System (THREATS): A method for identifying, recording & managing hazards from trees (Forbes-Laird 2006)

The Tree Hazard Rating, Evaluation And Treatment System (THREATS), created by Julian Forbes-Laird, is a free release system endorsed by the Arboriculture Association based in the UK. The system's programme is adapted for single tree evaluations and requires rigorous pro forma documentation. The programme assumes that the candidate tree has been chosen beforehand and proceeds with the evaluation programme. The THREATS evaluation programme is comprised of the following three parts with accompanying nine steps:

PART I: TREE INSPECTION RECORD

1. Survey details

The inspector records personal details, when the work was ordered, and the evaluation's reason. Date, time, weather conditions, and customer insights about the tree are documented.

2. Description of tree

Owner, location, specie, age class and size category are recorded. Size category refers to the potion affected by a defect. This can refer to the weight and size of whole tree or scaffold branches, etc.

3. Description of problems

A problem check-list (Table.2), based upon David Lonsdale's defects list (1999), organises the investigation. Each problem has a brief accompanying description and an open box for evaluator observations, or commentary, related to the defect and/or target. The check-list is problem-based and does not necessarily follow tree architecture.

Table.2 shows the deflect checklist accompanying the THREATS' pro forma (Forbes-Laird 2006, p.1)

Defects	Hazards
Altered exposure	Tree vulnerable to windthrow/storm damage due to eg loss of companion
Unstable root plate	Tree at imminent risk of toppling
Root damage	Tree topples. Compare damage with failure criteria: $R:R_{w.}$ Also consider health loss
Root decay (fungi)	Tree vulnerable to windthrow/toppling, possibly without further warning (see 3)
Stem/limb decay (fungi)	Stem/limb fracture causing crown elements to collapse (consider type of decay)
Inadequate stem taper	Failure risk due to eg excessive crown raising or D/h deficiency
Target cankers	Possible weakening/failure of affected area, especially if located on stem 'hot spot'
Exudates	Indication of (internal) disorder; if from lower stem, Honey Fungus infection?
Hollow/rotten stem; cavities; decay pockets	Stem fracture/buckling, causing crown to collapse. Consider *t:r*value
Lapsed pollard	Re-growth epicormic in origin & possibly weakly attached; possible decay at knuckles
Overweight, subsiding, or lion-tailed limbs	Limb failure due to an excess of mass over strength or to end-loading
Bark congestion	Fibre buckling of leaning/subsiding area indicating possible forthcoming collapse
Reactive growth	Member fails if repair (reactive growth) unsuccessful in stabilising defect
Inclusive bark	Fork fails causing leader/limb to fall
Fractured limbs; storm damage	Broken limbs/hanging breaks could fall; crown destabilised: further failures likely
Bark necrosis	Cambium death causing xylem dys-function: affected area dies, decays & fails
Dieback; poor foliage	Dead areas become unsafe. Various biotic and abiotic causes; roots damaged?
Dead wood	Branches fall
Prolific ivy	Possible obscuration of defects and excessive winter sail area
Other/None (specify)	

PART II: HAZARD RATING CALCULATION

4. Failure Scoring

A judgment is placed on the most critical defect(s) found during the investigation. Evaluating the defect's severity should be based on a specie specific knowledge of failure rates and behaviour. The *Likelihood of failure* rating system has been based on a five level algorithmic calculation, increasing failure value exponentially as severity increases (Table.3).

Table.3 shows THREATS' failure scoring range with example defects (Forbes-Laird 2006, p.2)

Score	Likelihood of failure	Example defects
50	Imminent/Immediate	Uprooting; Extreme root loss; Collapsing structure
8	Probable/Soon	Altered exposure; Primary decay fungus; Severe inclusive bark/root loss; Fragile dead wood
2	Likely, foreseeable	Lapsed pollard; Overweight/subsiding limbs; Poor stem taper; Dieback
.8	Potentially with time	Early development of inclusive bark; Robust dead wood
0	Unlikely ever	Tree generally free of defects, or insignificant defects only

5. Target Scoring

Target scoring is based on a six level algorithmic calculation, increasing target value exponentially as occupancy increases. Static targets are rated according to occupancy. Evaluators are to increase target value if unsupervised children, or the elderly, occasion the target area (Table.4).

Table.4 shows THREATS' target scoring with static and dynamic examples (Forbes-Laird 2006, p.2)

Score	Value	Static target examples	Target occupancy examples
40	Very high	Building 24 hour use, railway	Constant vehicular traffic/busy playground
25	High	Building 12 hour use, ≥11Kv power lines	Frequent vehicular traffic/constant pedestrian use
20	Medium	Building/structure occasional use, <11Kv lines	Peak times traffic/intermittent use, eg commuter run
15	Low	Garage, Summer house, Listed wall	Occasional traffic/sporadic use, eg slow country road
7	Very low	Unlisted wall, paving, garden features	Infrequently used access/public right of way/bridleway
0	None	Grass	Hardly ever used, eg remote path

6. Impact Scoring

Impact scoring focuses on potential damages which can be incurred in relation to the defect's size category (Table.5).

Table.5 shows THREATS' consequence scoring based on damage estimates related to the defective parts weight and size (Forbes-Laird 2006, p.2)

Score	Degree of harm and consequences (examples)		Agent: trees, mm, or branches, kg (size/weight for guidance only)	
10	Severe structural damage, vehicles crushed – passenger fatalities very probable	VL	> 750mm	> 500kg
6	Moderate structural/ severe vehicle damage – fatal/disabling injuries likely	L	350-750mm	50-500kg
4	Minor damage/probable disabling/hospitalising injury to pedestrians	M	100-350mm	10-50kg
1	Fragile objects destroyed, superficial/recoverable injury to pedestrians	S	< 100mm	< 10kg

7. Hazard Rating Calculation

Evaluator's *failure score*, *target score*, and *impact score* are multiplied to formulate a sum which can be correlated to an appropriate response (Equation.3).

Equation.3 shows THREATS' multipliable hazard rating calculation (Forbes-Laird 2006)

Failure score	x	Target score	x	Impact score	=	Hazard Rating

PART III: IMPLEMENTATION OF CONTROL MEASURES

8. Appropriate Response

Score ranges are aligned with predefined (recommended) responses to provide evaluators with a critical time-frame window for remedial action planning based on a threat status. The system also incorporates the Beaufort wind force scale (Specification on Land) for re-evaluation actions (Table.6).

Table.6 shows THREATS' equation summation's categorisation with recommended action (Forbes-Laird 2006, p.2)

Score range	Threat Category	Recommended action & Completion deadline	Code
4000+	7- Extreme	Evacuate/prevent access to impact site, emergency call-out of contractors	E
3999-2001	6- Serious	Close site if practical; arrange for work to be completed within 7 days	7D
2000-1000	5- Significant	Arrange for work to be completed within one month maximum	1
999-350	4- Moderate	Remediate within 3 months, reinspect after gales in the meantime (Force 7+)	3
160- 349	3- Slight	Reinspect annually/after storms (Force 10+), expect to schedule work within 2 yrs	12
50-159	2- Minimal	Reinspect within 3 yrs if adjacent to public access, schedule work as required	36
0-49	1- Insignificant	Reassess within 5 yrs if adjacent to public access, schedule work as required	60

9. Work Response

A *control measure* may be indicated by the evaluator providing a line of recommended line of remedial action which can be adopted into a work plan (Table.7).

Table.7 shows THREATS' pre-designed measures for remedial operations. (Forbes-Laird 2006, p.2)

Control measure	Examples
Move/reinforce target	Fence off & post warning signs; relocate benches; reinforce light buildings; re-route paths
Further investigation	Decay mapping to establish significance of defect: set results against failure criteria
Install support	Non-invasive brace to support vulnerable member
Localised pruning	Reduce weight loading on vulnerable limb (including shortening dead branches to retain habitat)
Limb removal	Prune out dead/damaged/vulnerable growth
General pruning	Reduce crown by specified amount
Crown removal	Leave stem as a standing carcass (consider habitat-piling cord wood, preferably in dappled light)
Tree removal	Takedown and fell to ground level (consider stump-grinding as a disease reduction measure)

Analysis
The pro forma is designed for single tree evaluations and is time consuming. Evaluators are guided to document problems occurring around checklist items while categorising and grading severity according to the THREATS valuing system. THREATS' grading system is formulated with sharp numerical increases in severity to encourage more conservative structural assessment conclusions; moderate rating values are 1/10 of the extreme rating value (see Table.6). Failure scoring is radically increased in imminent failure situations; targets are substantially devalued according to occupancy. Threat scoring categories have attached remedial action and re-evaluation deadlines.

Quantified Tree Risk Assessment (Ellison 2005)
The ability to numerically quantify a tree's risk factor has been difficult. A newer evaluation model, *Quantified Tree Risk Assessment* (Ellison 2005) attempts to reconcile risk assessment with probability calculation. The system provides a framework for calculating risk by assigning probability ratings to the three established tree hazard components introduced by Matheny & Clark (1994):

- target value
- impact potential
- failure probability

The system provides numerical *probability ratio* tables for calculating the possibility of a failure occurrence. Probability ratios are based upon an interpretation of statistical data within the given category, where 1/1 (*risk of significant harm*) is the upper limit which predicts an inevitable failure within the year. The system introduces the concept of *acceptable risk* based on the British Health and Safety Executive's (1996) conclusion that 1/10 000 (annual risk of death) is the acceptable limit if the aim fulfils a wider public interest. However, individual users of *Quantified Tree Risk Assessment* are encouraged to decide upon a suitable *acceptable risk* ratio to meet their own interests.

The system draws upon a cost/benefit approach where trees are considered as a positive factor within the urban sphere, providing amenity value and other important functions. The benefits and costs of risk reduction must balance the value of the financial costs, loss of amenity value and other functions.

To establish an upper limit (1/1) for property damage, *the value of statistical life* is used. This value is the estimated cost of human life based upon the British Health and Safety Executive's (1996) valued at £750,000 to £1,000,000 (US$1,387,500 to US$1,850,600).

The Quantified Tree Risk Assessment programme is comprised of the following four steps:

1. Target Value
Targets are evaluated for property values and occupancy. Traffic volumes of vehicles and pedestrians are based upon the amount of time the target zone is occupied during the day, or, in the case of major roadways, stopping distance related to speed limits.

To establish a probability ratio value, the following table (Table.8) for *target value* is used:

Table.8 shows target scoring based on probability ratios created from target frequency and attributed monetary worth in Quantified Tree Risk Assessment (Ellison 2005, p.61)

Target range	Structure (repair value)*	Pedestrian frequency	Vehicular frequency	Probability ratioz
1	(a) Very high value (b)Habitable	> 36 per hour–constant	(a) Motorway (b) Trunk road, built-up and non-built-up areas (c) Principal road, built-up area	1/1
2	High value	10–36 per hour	Principal roads, non-built up-area	1/20
3	Moderate–high value	1–9 per hour	Minor roads, moderate use or poor visibility	1/100
4	Moderate value	< 1 per hour	Minor roads, low use and good visibility	1/500
5	Low value	≤ 1 per day	Minor private roads and tracks (no data available)	1/10,000
6	Very low value	≤ 1 per week	None	1/120,000

*Structure values represent the likely cost of repair or replacement. Very high = £50,001–1,000,000; high = £10,001–50,000; moderate–high = £2,001–10,000; moderate = £101–2000; low = £11–100: very low = ≤£10.

2. Impact potential

Probability of failure is based upon branch weight and impact potential (Table.9). The probability ratio is based on a *dry weight mass(kg)/ branch diameter(mm)* estimate as a fraction of the ratio's limit, set at 600mm (2647kg.).

Table.9 shows impact potential ratio based upon defected part's diameter/weight correlation in Quantified Tree Risk Assessment (Ellison 2005, p.62)

Impact potential range	Size of part (mm diameter) likely to impact target	Impact potential
1*	> 450	1/1
2	251–450	1/2
3	101–250	1/8.6
4	26–100	1/82
5	> 10–25	1/2,500

*Range 1 is based on a diameter of 600 mm (24 in.).

3. Probability of failure

The evaluator is to predict the eventual failure(s). Estimations can apply to the whole tree or to selected parts, enabling varied estimates which can aid management decision making and planning (Table.10).

Table.10 shows failure probability ratio based on the inspector's professional estimate in Quantified Tree Risk Assessment (Ellison 2005, p.62)

Probability of failure range	Probability of failure percentage	Probability ratio
1 Very high	51–100	1/1
2 High	11–50	1/2
3 Moderate	1–10	1/10
4 Low	0.1–0.9	1/100
5 Very low	< 0.1	1/1,000

4. Probability calculation
The collected probabilities are multiplied together (Equation.4) to provide a threat ratio showing the *Risk of harm.*

Equation.4 shows probability calculations based upon multiplied ratios in Quantified Tree Risk Assessment (Ellison 2005, p.63)

Target value	x	Impact potential	x	Probability of failure	=	Risk of harm

Example calculation using Quantified Tree Risk Assessment:
A tree-lined town sidewalk with light pedestrian and bicycle traffic has a series of trees with long, unstable, dry branches <100mm in diameter (Table.11).

Table.11 shows a hypothetical calculation of probability based upon values from Quantified Tree Risk Assessment: light pedestrian/bicycle traffic with dry, unstable branches <100mm in diameter

Target value		Impact potential		Probability of failure		Risk of harm
1/20	x	**1/82**	x	**1/2**	=	**1/3 280**

If the acceptable hazard limit is 1/10 000, the acceptable risk level has been exceeded.

Analysis
The model adds a new dimension to risk assessment by introducing a framework for discussing probability regarding structural failure. Target values and impact potentials can be quantified; however probability of failure relies on qualified professional estimations. Using the model allows the evaluator to create scenarios for the *Risk of harm*. This can provide a basis for justifying management resource needs during budget prioritising.

Result

The literature study has provided the following information:

- Tree assessment has emerged from conservation area management of forest stands and is now being applied for the purpose of providing safe urban and recreational environments
- The concept of hazard trees exists only when there is the presence of a target
- Events of structural failure resulting in injury and death are statistically low
- Structural failure is more frequent during extreme meteorological events
- Failure profiles can be developed for individual tree species
- Risk zoning was introduced to prioritise local work initiatives based on traffic volumes and emergency access routes
- Numerical assessment systems were introduced as a tool for rating individual tree's structural status for the purpose of regulating tree populations and standardising assessment techniques
- Risk equations are based upon, and process the relationship between, the target's value, the size of the defective tree part, and the probability of failure
- Alternative hazard assessment models are available which inflate or deflate mature tree hazard rating
- Tree assessment has now begun to focus on quantified tree management to create cost effective risk assessment systems for population management

Discussion

The development of hazard rating evaluation systems, for the purpose of assessing the structural stability of trees, has stemmed from the need to provide secure outdoor urban environs while maintaining the fundamental principals of urban greening and urban forestry. Each of the sampled systems reflects certain ideological perspectives which can be the result of a cultural attitude towards trees.

The development of the International Society of Arboriculture (ISA) pro forma can be arguably the result of litigation culture's pressures on urban forestry to begin risk management processes. Personal or property injuries can create liability issues for tree managers. Managers should be aware of the local bylaws, governing statutes, and juridical precedence regarding their legal responsibility, in preparation for a failure which might lead to injury and/or damage. Private owners of trees should also maintain a degree of awareness regarding their responsibility. Security issues which result from degraded structural stability often equate to risk assessments which secure their own private property. Assessments should also include neighbouring target areas. As means for anticipating future lawsuits, assessment documentation can show proof of responsible management, even after a failure occurs within a given tree population.

The ISA form presented within *A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas* 2nd Edition (Mathney & Clark 1994) is a rigorous, time consuming pro forma which provides detailed evaluation data. The form has been instrumental for structuring the modern tree evaluation process by organising the evaluator's own cognitive analysis process during tree assessments. All essential categories, necessary for completing a thorough assessment, are presented systematically, incorporating the Visual Tree Assessment (VTA) approach.

Criticism towards the pro forma can be that a single defect may be responsible for a *hazard abatement* recommendation. A large cavity may be responsible for an evaluator's felling decision if the target cannot be moved. Thus, the additional recorded data can be seen as unnecessary, extraneous, and time consuming information collection.

With the ISA system, evaluators have a valuation system from 1-4 for each of the three major categories in the *Hazard Rating Equation* (see Table.2). A mature treed avenue along a major city road may receive the following average rating if the trunk DBH exceeds 75cm (Table.12):

Table.12 shows a hypothetical hazard rating calculation based upon values from A Photographic Guide to the Evaluation of Hazard Trees in Urban Areas 2nd Edition: mature treed avenue with average trunk DBH exceeding 75cm along a major city road

Failure potential		Size of defective part		Target rating		Hazard rating
1	+	**4 (3)**	+	**4**	=	**9 (8)**

Potentially all mature trees of this size can be designated with a *hazard rating* of 8-9 of 12 if located within a densely populated urban area. This rating is a cause for alarm. However, the authors stress that a high hazard rating does not mean standardised treatments. Management responses are specific to each case. The avenue's individual tree ratings could demand increased management routines, such as increased inspection cycles, to continuously maintain and check the tree group's state and needs.

The USDA Forest Service Community Tree Risk Rating System (a modified version of the ISA model) drastically reduces documentation demands, allowing for quick, concise ratings and commentary on the most serious problems which contribute to the overall *risk rating*. The system's four category rating system allows for greater scoring leniency, by including optional evaluation information (*Other risk factors*). Risk rating maximum is 12. The same avenue individuals may receive the following average rating (Table.13):

Table.13 shows a hypothetical hazard rating calculation based upon values from The USDA Forest Service Community Tree Risk Rating System: mature treed avenue with average trunk DBH exceeding 75cm along a major city road

Probability of failure		Size of defective part		Probability of target impact		Other risk factors		Risk rating
1	+	**3**	+	**3**	+	**0 (1)**	=	**7 (8)**

If an evaluator estimates that the avenue's individuals are healthy and without major defects the risk rating can be reduced to 7 of a potential 12, lessening the alarm.

The main conclusion of this type of rating system can be adapted to a Great Storm approach to urban forestry. Tree failure documentation and experiences have shown that the greatest frequency of tree failures occur during storms (Sisinni, Zipperer & Pleninger 1995, Duryea et al. 1996, Rhoades & Stipes 2007, Jim & Lui 1997). Healthy root plates, trunks, and large scaffold branches can experience structural failure during loading from wind, snow, and ice; hence the value 1 for *failure potential* since it is always present.

This can be verified using Quantified Tree Risk Assessment (Ellison 2005) variables (see Table. 10-13):

Table.14 shows a hypothetical hazard rating calculation based upon values from Quantified Tree Risk Assessment: mature treed avenue with average trunk DBH exceeding 75cm along a major city road

Target value		Impact potential		Probability of failure		Risk of harm
1/1	x	**1/1**	x	**1/1 000**	=	**1/1 000**

This probability calculation (Table.14) can be considered both realistic and unrealistic. Traffic volumes decrease during storms, potentially decreasing the probability calculation rating by decreasing the target value (traffic volume). This, however, can not be considered with occupancy structures, such as houses, since individuals seek shelter during such events. From an urban tree manager's perspective, the decision about the acceptability of this probability value will be the result of urban greening policy and social amenity values placed on aging large tree populations.

Since rating systems produce arbitrary values based on the given evaluation scoring system, *the Tree Hazard Rating, Evaluation And Treatment System* (THREATS) (Forbes-Laird 2006) has introduced a system which deflates hazard ratings for mature trees. The same criteria inserted into THREATS (see Table. 4-8) would produce the following rating (Table.15).

Table.15 shows a hypothetical hazard rating calculation based upon values from THREATS: mature treed avenue with average trunk DBH exceeding 75cm along a major city road

Failure score		Target score		Impact score		Hazard rating
2 (.8)	x	**40**	x	**10**	=	**800 (320)**

When interpreted within the THREATS context, the rating's *threat category* is deemed *moderate* (Table. 8); producing a *Hazard Rating* of 800 of a potential 20 000. The failure scoring could even be interpreted to a value of .8, further reducing the hazard rating to 320; the rating's *threat category* would be considered *slight*. System users sense a decreased apprehensive attitude towards the same avenue trees when using the THREATS model. Valuations within THREATS perpetuate and maintain a conservationist attitude, allowing for more flexibility when regarding a tree's hazard rating and eventual remedial actions.

Of the sampled systems, only the USDA Forestry Service Tree Risk Rating System encourages that users adapt and alter the accompanying pro forma templates to meet their assessment needs. The USDA Forestry Service Tree Risk Rating System authors actively encourage tree manager to form specialised perimeter to meet local needs and restrictions. The *risk rating* system is a part of the larger *7-step Program* which also encourages local reformulation to meet local management needs.

THREATS marks a newer arboricultural trend, encouraging a greater protectionist and conservationist approach toward aging urban trees with high amenity value. The system is posted freely on the Arboricultural Information Exchange internet link and endorsed by the Arboricultural Association of Britain. The system represents a structural evaluation model with stronger ecological and socio-historical influences. The scoring system guidelines provide users with a greater sense of security by decreasing the *score range*'s proportional values while encouraging greater active management care in comparison with the ISA system. According to the author, assessment conclusions should:

> "….stratify tree risk such that intervention could be programmed as to urgency, roughly according to: immediate, scheduled and deferred… (by establishing a) defensible hierarchy of response that included phased reinspection."
>
> (Forbes-Laird 2006)

In doing so, risks associated with older trees could be contained through increased management reinspections.

The reinspection demands connected to each *threat category* forces users to increase management routines surrounding scheduled assessments. This can become difficult for managing budgets due to the major time, personnel, and financial needs to maintain such labour intensive, scheduled reinspections. However, increasing reinspections intervals is a viable method for maintaining security around aging tree populations which are highly esteemed.

The Quantified Tree Risk Assessment system is a useful tool for planning and judging tree management needs. Quick calculations can divide urban areas into risk zones and help with work prioritising. Estimates can also be made surrounding how, for example, a crown clearing can contribute to a reduced hazard probability rating (see Table.15). Calculations can also be used to verify or negate suggested management plans when combined with the other sample systems (as presented in Table.18). The author encourages system users to define personalised perimeters which meet local needs, placing operative responsible on urban tree managers and greening policy writers to create municipal, or organisational, definitions of acceptable levels of risk.

Regarding all the sampled systems, quantifiable values can be placed on *part size* and *target value*; every system presents a criteria list for each variable's valuation. However, defining the *probability of failure* is the most difficult of task. The collected evidence during evaluations provides a reasonable basis for deducing a failure probability spectrum; yet exact quantifiable values are not attainable. Most numerical *failure probability* inputs are estimations based on professional judgement within a gradient of risk.

This is the greatest dilemma for urban tree managers. The fact that a failure can happen does not determine when the failure will happen. With the presented data, urban manager are offered ideas and tools for structuring and assessing urban tree populations. How managers use this information is up to themselves - along with the will of those who live daily with their trees. Balancing public safety, conserving aging urban trees, and performing responsible risk management is difficult gamble.

Conclusion

A tree is deemed a risk when there is a target. The urban environment is a place of human activity and interaction; or from a risk assessment view - a group of targets in dynamic flow or static placement. Targets are ubiquitous with varying frequencies and values. According to some interpretations, a tree is deemed a hazard when there is imminent danger of failure, which would harm or damage a target. Others deem that the sheer presence of large trees in urban environment with high target frequencies constitutes an increased potential for hazards and must be treated as such. Hazard levels can be seen along a gradient: from falling twigs, to uprooted trees. Tree assessments are conducted to determine the level of *present* risk and how to respond to the information collected.

Urban forestry management implies a professional understanding of tree species' structural characteristics, habitat needs, and growth habits, along with planning, planting, maintenance, and removal cycles. The positive effects of urban forestry are well established and the need for trees has been widely explored. Yet a conflict exists between the benefits of trees and the inherent risks trees can pose. This has made determining risk, and reducing hazards, a responsibility for managers of urban tree population.

The development of risk assessment methods and systems, and creation of the concept of hazard trees, is the result of collective concern over future tree failure incidents causing injury, death, or sustainable property damages. Failure cases are few; the likelihood of a failure event resulting in injuries and damages are low. However, such extra-ordinary events often receive media coverage, creating a skewed portrait of urban tree management. Awareness of this responsibility is central for all managers; deciding upon vigilance levels of tree assessment routines should be the result of conscious decision-making.

The rise of tree assessment documentation can be related to the need to maintain strict records in the event of a failure occurrence as a preparatory defence for future litigation. Managers are responsible for their inventories and, in many cases, held accountable for failures which occur during their tenure. Failures, from a populist perspective, can be regarded as a result of neglect. Reasonable amounts of risk must be tolerated for a society to function, however it is the manager's responsibility to control the risk factors so that probability of an occurrence remains at a tolerable level.

The information from assessments can aid urban foresters with inventory data about the general state of tree populations to improve regeneration cycles. Using an established assessment system and accompanying pro forma can provide a framework for evaluating tree populations during inventories. Collectively high ratings or scoring from groups of trees can be presented as a basis for an area's renewal through felling and replanting. This is the source of the urban forester's greatest dilemma: mature urban trees which reach their full potential also increase in risk rating.

Estimating the timeframe of a tree's failure is difficult. Most trees will experience structural failure due to a plethora of factors - the question is when? Forecasting failure is a less then perfect science. Newer assessment systems have recognised this by devaluing failure and occupancy scoring (Forbes-Laird 2006). This development adds a conservationist element to urban tree management, which might otherwise consider such ecologically valuable specimens as hazardous. Managers must decide upon how much risk is negotiable if targets are to be jeopardised significantly.

Proper training is critical when performing professional evaluations. Much of tree risk assessment has been based upon the evaluator's educational training combined with their working experience to form an opinion within the framework of a pro forma. This training is translated into an estimation of statistical probability where the investigator must judge likelihood of a failure. Empirical observation can be used to formulate quantitative probability ratios for target values and impact potentials; however, estimating probability of failure, or when the event will occur, adds a larger qualitative judgment.

Aging tree populations are held with high esteem; these members are bound with historical significance, acting as time-markers, indicating past land uses or urban planning ideologies. The tree assessment systems presented show that risk factors increase drastically as cord volumes increase. The heavier the tree, the greater the potential energy stored. Tree managers must be well aware that sudden failure is an important assessment factor; proper pre-emptive planning to prevent excessive storm damage is of the greatest importance.

Trees within the urban space often are subjugated to extremely poor environmental conditions. Habitats are constantly undermined by assorted infrastructural demands. Roads and sidewalks demand suitably designed foundations while other piping and cable channels compete for the subterranean space. Soil volumes are reduced, root systems are severed; crown heights can suddenly surpass anchorage capacity. It is essential that open communication exists between urban infrastructure departments to prevent situations which may result in unforeseen structural weaknesses and risk increases.

Surveys have shown that older tree populations are more susceptible to failure and that failures often follow a species' failure profile. Major decisions surrounding policy attitudes towards an aging tree population can be facilitated using a strategically selected assessment system. THREATS provides a system for evaluating trees from a conservationist perspective, with a scoring system which encourages prudent attitudes towards removal by devaluing any hazard which isn't deemed imminent, such as a partially uprooted tree. Other systems, such as the USDA or ISA systems allow for more liberal perspectives concerning felling by creating higher hazard ratings.

In urban environments, failure occurrences have a relatively even distribution between branch, trunk, or uprooting sources. Branch and trunk structural weakness can often be assessed effectively through VTA. However, many serious problems can be hidden from VTA techniques, the most serious being the root system's structural integrity.

Root decay leads to the most dramatic failures - total tree collapse through uprooting. Many types of root decay exist. Assessing a root system's structural integrity is still an incomplete science. The extent of root decay, or even mechanical root damage, is difficult to discern due to the lack of effective investigatory techniques and suitable tools. Managers must consider these hidden defects, within the context of species' failure profile, when identifying eventual fall zones during assessment.

As the workforce becomes increasingly more fluid, assessment documentation can become a tool for transferring information between professionals about an urban tree inventory's state. Documentation can provide a basis for decision making; inventory development, composition, and status can be viewed over a period of time. As newer exotic species and cultivars are introduced, assessment reports can be used for regional failure profiling to increase awareness and enhance decision making and risk assessment processes among urban tree managers. Failure profile data often exists in the species' country of origin.

Trees draw nature into a highly manufactured, urban arena. Trees, as a biological urban element, are an additional risk incorporated into an already risk-filled environment. The benefits of trees far out weight the risks of trees - when the proper steps toward responsible planning and urban tree management routines are entrenched within a holistic infrastructural framework. Tree assessments, as a part of a larger urban greening programme, can be a valuable tool for maintaining reasonable safety standards while sustaining and renewing one of the most valuable inventories any urban centre can own.

Summary

- The concept and management of a hazard tree largely depends on the tree programmes policy stance and institutionalised attitudes
- Estimating risk combines both qualitative judgment and quantitative assessment
- Urban foresters should be aware of their regional legal obligations and responsibilities for tree inventories under their jurisdiction.
- In the event of a failure, evidence of quality control programmes, regarding urban forest inventories, can confirm and prove responsible management
- Tree assessment recording and documentation can provide a legal basis to prove the existence of systematic quality control programmes
- Rating or scoring systems can provide additional data for long term planning
- Tree assessment documentation can be a valuable tool for professional dialogue in an increasingly fluid workforce

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Appendix

Appendix i

Detection of Structural deficiencies

All trees possess a collection of deficiencies gathered over time through genetic inheritance, pathogenic attack, mechanical injury, or the aging processes (decreased vitality). The following list provides an overview of relevant deficiencies, which are considered during site assessment of trees.

Components

Dead Trees and Branches

Tree decline and death can happen suddenly due to a fatal pathogenic introduction, such as Elm Disease's Ophiostoma fungi, or as a long process of senescent, beginning with branch dieback. Mechanical stresses resulting from wind, snow, ice or children, can exert forces which fracture and break weakened points. Dead trees, and dead branches, loose compartmentalisation mechanisms which prevent or inhibit decay; cellulose, and thereby flexibility, resulting in brittleness. However, a dead tree's or branches' fracture resistance can be increased by saturating resins; more common in softwoods than hardwoods, which provide further structural stability for up to 3 years (Wagener 1963). Certain genera and species are renowned for seasonal shedding of dead branches (branch abscission) to enable wound closure (Dewit & Reid 1992).

Dead branches often do not fracture until decay begins. Their elasticity decreases which increases brittleness and potential for fracture under stress; however being lighter, due to dehydration and absence of foliage, the potential for stress is reduced. Dead branches can remain stably attached if rot is not present. Prompt removal of dead or broken branches over 50mm in diameter is recommended in target designated areas since decay is difficult to recognise from ground but can quickly progress when acquired.

Crown form

Roots, trunks and stems with high, top-heavy crowns are often subjugated to high loading from winds. Thin trunk tapers often experience mid-trunk breakage during heavy loading. End loading of branches due to over extended pruning can increase loading stresses on branch junctions where buckling ruptures and delamination can appear on the underside of branches (Mattheck & Bethge 1991).

Graft points

Grafting points can often show incompatibilities leading to collapse or branch failure at grafting junction.

Co-dominant stems

Many trees, when apical control is temporarily lost due to a terminal leader's damage, can create problematic architectural defects. The loss of auxin regulation can result in competitive leaders or branching, which create a tight V-form branching. The co-dominate junctions have the potential to fuse cambial tissue or to form included bark. Fused cambial tissue allows junction strengthening for long term survival. Included bark is a term used to describe branching that has a weakened union due to two trapped cambial units growing aggressively against one another. Under included bark junctions, splits along the supporting stem can form which can lead to structural weakening and failure. Include bark can begin to appear when branching angles exceed 45^o.

Studies have shown that co-dominant branching with included bark and a branch diameter under 10cm is 20% weaker than co-dominant branching without included bark. Branching diameter over 25cm show a positive strengthening where included bark junction are 14% weaker than non-included unions (Smiley 2003).

Leans

Leans are cited as a key identification factor when assessing tree failure potential. Leans can result from combinations of mechanical factor such as a response to wind loading, degraded soil structures, saturated soils, and root decay. Leaning trees in costal environments, due to prevailing wind over-exposure, indicate that an environmental analysis must consider acceptable establishment trends from a habitat perspective.

Wounds and Decay

Sustained mechanical injuries result in wounds; a compartmentalisation response acts to limit pathogenic attack (Shigo 1997). As entry points for infections and decay, wounded areas may result in open cavities which, depending on size, can reduce the structural integrity around the damaged area. Wounds can be categorized along a gradient correlated to injury size, wound location, compartmentalization success, and target placement.

Fungal bodies (Conks)

Fruiting bodies on trees can often induce brittle decay or internal rot. Specie identification of conks can signify specific internal pathogenic rotting processes. Fruit bodies which indicate extreme structural deficiencies, should be seriously investigated thoroughly.

Cracks and ribs

Visible crack-lines and splits can appear along stems and branches, resulting from internal fracturing of wood fibres due to mechanical loading. Cracks can result from shearing due to bending, torsion due to twisting, and traverse stress causing splitting (Mattheck & Breloer 1999). Cracks reveal a structural weak point and, as wounds, become potential entry points for pathogenic attack and eventual decay. Ribs are cambial protrusion responding to internal cracks. Ribs are a positive response to reinforce fractured areas, indicating the tree’s attempt to reconstitute strength around the weakened crack area.

Swells and boils

Protrusions can indicate structural reinforcement to reassume mechanical strength when compensating for internal decay. Trees can respond with adaptive growth to restore a balance of stress along the stem or trunk. When rot expansion exceeds the adaptive growth, stability can be compromised.

Cankers
A canker is a localised lesion caused by fungal or bacterial attack through wounds. A callus often develops on the area's periphery. Depending on severity, cankers can be an annual or perennial event arising from twig die-back to total tree decline. Cankers can griddle bark circumferences causing the phloem's photosynthetic transfer to stop. Cankers can also provide openings for secondary pathogenic attacks.

Vitality (Vigour)
Vitality is used to describe the tree's overall health and ability to grow, to resist, and to adapt to environmental stresses. Evidence for vigour can be indicated through foliage volume, annual shoot extension, and callus growth.

Historical Uses
Evidence of lapsed pollard and coppice cycles can indicate mechanical branch overloading, included bark, and weakened form.

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Appendix ii

Guide to Risk Rating Codes

(companion guide to the Community Tree Risk Evaluation Form)

PROBABILITY OF FAILURE: 1-4 points

1.Low:some minor defects present:

- minor branch/ crown dieback
- minor defects or wounds

2.Moderate: several moderate defects present

- stem decay or cavity within safe shell limits: shell thickness > 1 inch of sound wood for each 6 inches of stem diameter
- crack(s) without extensive decay
- defect(s) affecting 30-40% of the tree’s circumference
- crown damage/breakage: hardwoods up to 50%; pines up to 30%
- weak branch union: major branch or codominant stem has included bark
- stem girdling roots: <40% tree’s circumference with compressed wood
- root damage: < 40% of roots damaged within the CRR

3. High: multiple or significant defects present:

- stem decay or cavity at or exceeding shell safety limits: shell thickness < 1 inch of sound wood for each 6 inches of stem diameter
- cracks, particularly those in contact with the soil or associated with other defects
- defect(s) affecting > 40% of the tree’s circumference
- crown damage/breakage: hardwoods >50%; pines >30%
- weak branch union with crack or decay - girdling roots with > 40% of tree’s circumference with compressed wood
- root damage: > 40% of roots damaged within the CRR.
- leaning tree with recent root breakage or soil mounding, crack or extensive decay
- dead tree: standing dead without other significant defects

4.Extremely High: multiple and significant defects present; visual obstruction of traffic signs/lights or intersections:

- stem decay or cavity exceeding shell safety limits and severe crack
- cracks: when a stem or branch is split in half - defect(s) affecting > 40% of the tree’s circumference or CRR and extensive decay or crack(s)
- weak branch union with crack and decay
- leaning tree with recent root breakage or soil mounding and a crack or extensive decay
- dead branches: broken (hangers) or with a crack
- dead trees: standing dead with other defects such as cracks, hangers, extensive decay, or major root damage
- visual obstruction of traffic signs/lights or intersections
- physical obstruction of pedestrian or vehicular traffic

SIZE OF DEFECTIVE PART(S): 1-3 points

1. Parts less than 4inches in diameter
2. Parts from 4 to 20 inches in diameter
3. Parts greater than 20 inches in diameter

PROBABILITY OF TARGET IMPACT: 1-3 points

1.Occasional Use:

- low use roads and park trails; parking lots adjacent to low use areas; natural areas such as woods or riparian zones; transition areas with limited public use; industrial areas.

2.Intermediate Use:

- moderate to low use school playgrounds, parks, and picnic areas; parking lots adjacent to moderate use areas; secondary roads (neighborhoods) and park trails within moderate to high use areas; and dispersed campgrounds.

3.Frequent Use:

- emergency access routes, medical and emergency facilities and shelters, and handicap access areas; high use school playgrounds, parks, and picnic areas; bus stops; visitor centers, shelters, and park administrative buildings and residences; main thoroughfares and congested intersections in high use areas; parking lots adjacent to high use areas; interpretive signs, kiosks; scenic vistas; and campsites (particularly drive-in).

OTHER RISK FACTORS: 0-2 points

- This category can be used if professional judgment suggests the need to increase the risk rating.
- It is especially helpful to use when tree species growth characteristics become a factor in risk rating. For example, some tree species have growth patterns that make them more vulnerable to certain defects such as weak branch unions (silver maple) and branching shedding (beech).
- It can also be used if the tree is likely to fail before the next scheduled risk inspection.

Reference source

Pokorny, J.D. 2003. *Urban Tree Risk Management: A Community Guide to Program Design and Implementation.* St. Paul: USDA Forest Service, Northeastern Area. [Online] Available at: http://na.fs.fed.us/spfo/pubs/uf/utrmm/urban_tree_risk_mgmnt.pdf [accessed 2008-04-14].

"The gardener often spoke to the noble family about cutting down the old trees; they did not look well….. But the family did not want to give up the trees…. that was something the manor could not lose, something from the olden times, which should never be forgotten."

- H.C. Andersen: The Gardener and the Noble Family