Frequency and costs of park and avenue tree failure in the Netherlands

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Marinus van Haaften

Preface

Besides considerations concerning the amount of research in this field, I am very interested in this topic. Eventually starting with a Bachelor minor in January 2013, this thesis developed into a major Master thesis (AEP–80433) and ended in August 2013. I would like to thank both my supervisors dr.ir. M.P.M. Meuwissen from the chair group Business Economics and dr.ir. C. Gardebroek from the chair group Agricultural Economics and Rural Policies. I am also thankful to ir. J. Kopinga from Alterra Wageningen for sharing his knowledge and insight in this field.

Marinus van Haaften
Studentnumber 800107291100

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Chapter 1 Introduction

1.1 Urban tree damage

For centuries trees are planted in urban environments. The growth conditions in urban environments differ from the natural conditions. The advantages and costs from park and avenue trees are often presented in cost-benefit analyses (McPherson et al., 2005; Soares et al., 2011). These costs are restricted to tree maintenance and include sometimes re-pavement costs. Less attention has been paid to disadvantages of trees in urban areas concerning tangible and personal adverse events. Concerning the tangible adverse effects, although several technical solutions have been developed for and applied to these adverse effects, most practical experiences are published in test reports (Östberg et al., 2011). One of the problems is the interference of roots in sewer pipes of which some studies reported the costs and extent of this interference (Östberg et al., 2011; Randrup et al., 2001b). Publications on frequency and costs of intrusion of tree roots in drains and other pipes are scarce. Another disadvantage is the conflict between tree roots and pathways, curbs and roads (Arhipova et al., 2007; Kopinga and Meyboom, 1995; Lucke et al., 2011; Morgenroth, 2008) and the costs of this damage (McPherson, 2000; Randrup et al., 2001a). A similar event happens on cemeteries where graves dilate because of tree roots (Caneva et al., 2009). And although the pushing up of pavements by tree roots provides increased risk of personal injuries by stumbling, statistical data on this subject are lacking. Damage is not only restricted to street pavement, sidewalks and curbs, also buildings exhibit cracks in the walls. Especially the foundations of old buildings are vulnerable towards tree activity, while newer buildings experience, continuous amendments in the soil moisture due to near-located trees, especially in the summer and on shrinkable soils (Navarro et al., 2009a; Navarro et al., 2009b; Satriani et al., 2010). These foundation problems caused by tree roots are, in a limited way, subject of investigation (Roberts et al., 2006) and accompanied by a limited number of publications on the associated costs, particularly of the last 10 years. Regarding the personal adverse effects, there are reports on the (rates on) run-off-road collisions on trees with or without injuries and fatalities which were mainly due to a driver's failure (Caltrans, 2010; Mok et al., 2006; Wolf and Dixon, 2007a, b). When it comes to (lethal) injuries due to tree failure there is only one study known from the UK which provides a frequency of personal damage, referred to in some articles (Lonsdale, 2007; NTSG, 2011). Also here, financial data on the associated costs of these adverse effects, are lacking. There are 2 studies known which mention the effect of wind and trees on property damage after extreme weather conditions (Duryea, 2011; Soares et al., 2011), but don't describe how dangerous these trees can be by themselves. The only investigation on the prevalence of fatal injuries in the UK reported that from 1998 to 2003, on average 6 deaths a year occurred due to tree failures which yield a risk of 1 in 10,000,000 persons (Adams, 2007; Lonsdale, 2007; NTSG, 2011). It includes fatal injuries related to tree failure associated with a high wind speed, but excludes fatal injuries related to work safety conditions and occupational associated accidents.

1.2 Risk assessment

In the Netherlands, risk management is common practice in the public area[1]. Playground equipment is assessed every year to ensure safety and minimize risks of injury. Acceptable levels of risk are defined for most infrastructural elements such as playgrounds, streets, pavements and urban furniture. A universal definition of risk does not exist. Aven & Renn define risk as: "Risk refers to uncertainty about and severity of the effects and consequences (or outcomes) of an activity with respect to something that humans value" (Aven and Renn, 2010). Risk assessment is a method for assessing the impact, occurrence and the consequences of events involving products or systems with hazardous characteristics (van Duijne et al., 2008). There are three criteria for a proper risk assessment (van Duijne et al., 2008): risk assessment should include a thorough analysis of the hazardous effects, requires an unambiguous method to estimate the risk level of a particular risk scenario, and needs adequate risk evaluation which requires comparison of risk judgments including various risks (see Appendix I).

The many different procedures to assess risks can be classified by qualitative, quantitative and hybrid methods. In this study, risk is approached quantitatively in a mathematical relation by using historical data on accidents (Marhavilas et al., 2011). A well-known quantitative technique for operational hazards is the risk matrix approach of the US Department of Defense[2] for managing risks in the field of Environment, Safety and Occupational Health (ESOH). This method is based on a formula for calculating the quantified risk of a hazard. The risk is calculated by multiplying the effect of an event (E) with the probability factor (P) (Defense, 2000; Henselwood and Phillips, 2006; Marhavilas et al., 2011).

$R = P \cdot E$ or more formally $R = \sum_t^T [L_i, P_i]\,,\ i = 1, 2, \dots, n$

The probability factor (P) signifies the chance that an event happens (Defense, 2000). The likelihood of the adverse effect (E) denotes the most likely effect of a potential event like tangible damage or personal (fatal) damage. This damage expressed in the claimed and paid compensation denotes the severity of injuries and damage. The weight of these parameters is obtained from collected information from stakeholders in the field. Which involvement is important as they are supposed to know the nature and consequences of the events (Marhavilas et al., 2011; Reniers et al., 2005). The collected information should answer three questions: What can go wrong, how likely will it happen and what are the consequences if it does happen (Kaplan and Garrick, 1981)? The first question will be answered by a literature search on scientific articles and jurisprudence whereas the last two questions are based on information retrieved from several other sources as well, like operators and managers in the field, insurance companies, municipalities and European Tree Technicians.

[1] See the Dutch law on playground elements: Warenwetbesluit Attractie en Speeltoestellen

[2] Due to the arms race in the 50s and 60s between world powers like the US and the former Soviet republic a System Safety Program was developed from military programs by the US Department of Defense and US Aerospace to improve safety and system survivability. MID-STD-882 series have introduced a way to achieve acceptable risks through a systematic hazard analyses.

1.3 Urban tree risk assessment

Current methods to identify risks of tree failure are based on biological and mechanical studies which are supplemental to one another. From the biological field, the condition of a tree can be assessed by the development and morphology of the tree crown. Research in this field dates back to the 1890's. In the 1970's the amount of research in this field diminished. The German researcher Roloff has described and categorized the specific branching patterns of a large number of tree species (Roloff, 2001), which is used in The Netherlands to assess the condition of trees although this method is rather rough. A healthy tree is supposed to have more vitality to compensate infected spots in its structure by producing new tissue. On the other hand, mechanical studies focused on the mechanical structure of a tree by looking to the stability and the severity of fractures. The purpose of these studies was to recognize dangerous trees to prevent damage and injuries, with the first publication about tree risk management in 1963 (Wagner, 1963). Methods developed in this early period were based on biomechanics, site conditions such as geomorphology, hydrology and soil conditions, and visual anomalies of trees. Several decades later, Shigo (1984) examined the development and structure of decay in trees whereas Smiley and Fraederich (1992) investigated the strength loss from decay (Lonsdale, 2007). In the 90's, several other researchers developed simultaneously methods to investigate the structure of trees (Wassenaar and Richardson, 2009):

- Visual Tree Assessment (Mattheck and Breloer, 1994)
- Photographic tree hazard evaluation (Matheny and Clark, 1994)
- Static Integrated Assessment (Wessolly, 1995)
- Integrierte Baum Analyse (Reinartz and Schlag, 1997)
- Quantified Tree Risk Assessment (Ellison, 2005)

Tree failure and the ways to detect this are widely reviewed in the literature (see § 3.1). Methods to identify potential tree failure, the so-called Tree Risk Assessment methods which describe how to assess possible risks technically, are getting steadily more acknowledgment worldwide, and are nowadays mainly used in Europe (Wassenaar and Richardson, 2009). Regarding The Netherlands, Visual Tree Assessment is widely used the last 17 year which in practice often results in a mix of the methods described above.

Regarding tree risk management, we have to identify the potential risks due to tree failure on damage or possible injuries, assess the probability of those risks and identify the financial consequences (Ball, 2007). The first step is to determine the extent of risks due to tree failure. Mortimer and Kane encourage a systematic evaluation of each possible factor that influences tree failure to ensure consistency and objectivity (Mortimer and Kane, 2004). Recent articles in arboriculture seek alignment with the standardized approach for calculating risk, where tree failure is evaluated on the basis of frequency times its consequence (Ball, 2007; Lonsdale, 2007; Manning et al., 2002; Norris, 2005b). In addition, "the size of the defective part that would fail and the value of the target" could be added to this formula as exposure factor (Ellison, 2007; Mortimer and Kane, 2004).

To avoid risks because of tree failure, determining the current risk is not enough. Governmental organizations often develop a tree risk management plan to prevent tree failure. A definition of tree risk management is obtained from (Pokorny et al., 2003):

> tree risk management "should focus on the prevention and correction of hazardous tree defects, and provide a written, systematic procedure for inspecting and evaluating potentially hazardous trees and correcting them" before they become unacceptable risks.

Despite several other articles about tree risk management, no further definitions were found in literature. The aim of tree risk management is an on-going debate (Ellison, 2007) in which some researchers state that tree risk management should not seek to minimise the risk of damage or injuries due to tree failure. According to Ellison, tree risk management should balance damage and benefits of risk reduction of tree failure (Ellison, 2007) whereas Ball et al. described risk management as a process of making decisions on risk assessment based on economics, social considerations, legal requirements and policy issues (Ball, 2007). In several countries tree management plans base the assessment of trees often on designated risk zones, where the highest risk zones are those zones with the highest density of people (shopping areas, Town Centre, et cetera) and the shortest response time in case of emergency.

In the Netherlands, as a result of jurisprudence, tree owners are obliged to carry out regular maintenance of trees and also to check for externally visible defects (Visser, 2009). The frequency of this assessment is based on the age of the tree, often in combination with the degree of public safety, the characteristics of the species and the nature of the defect. This obligation has the purpose to prevent damage and accidents due to tree failure. From my personal experience, the cost of assessing a tree has a current market price between € 1.50 and € 3.00. When trees are known to be dangerous, the legal responsibility of municipalities obliges them to investigate these trees more closely. The associated assessment costs can vary from about € 80 to several thousands, depending on the immediate environment, the age of the tree and the localization of the defect on the tree. However, some municipalities do not perform tree risk assessments. The reason behind this is that the costs of damage caused by tree failure are less than the assessment costs. They ignore their legal duties and ignore the personal and tangible damage that can occur to their inhabitants. The importance of this issue is highlighted by the current debate on the standardization of the current visual tree assessment (VTA). The VTA method is applied by some municipalities in The Netherlands for already 17 years in a non-standardized way. However, due to the scarcity of the associated statistical data on tree failure, a baseline measurement is impossible.

1.4 Problem statement

Although the current tree risk policy in The Netherlands has the aim to avoid risks, however, it is currently unknown how large the risks caused by tree failure are. Current cost-benefit analyses in the field of tree risk management are lacking data on this subject. Hence, there is a uncertainty about the potential safety of trees along avenues and in public areas and the limited available financial data diverts the attention disproportionally towards financial advantages of trees. This information from the literature and the current practice in The Netherlands direct us towards the following problem statement: Current evidence about the frequency and the costs of tangible and (fatal) personal adverse effects of park and avenue trees in The Netherlands is limited and hampers a solid cost-benefit analyses.

1.5 Aim of this study

The aim of this study is to determine the risks on tangible and personal adverse effects of park and avenue trees in the literature and in current Dutch practice. The risks are defined as the product of frequency multiplied by its effect.

Personal damage:	is derived from the frequency of tree-related fatal and non-fatal injuries and its related costs.
Tangible damage:	are derived from the frequency and costs of tree-related damage on immovable and movable assets.

1.6 The scope of this study

In areas where forestry is carried out as an industry, tree related fatal and non-fatal injuries are often registered by the prevailing ministry. These occupational accidents and injuries result from forestry or tree maintenance activities and occur also in urban areas. Occupational (fatal) injuries are not included in this study. The focus of this study is on (fatal) injuries which strictly happen due to failure of trees in urbanized areas.

Cases of damage caused by trees, where side effects play an important role are also excluded from this research. Whether there is a side effect or not, depends on the question: does tree failure occur due to natural processes or is it a result of human interaction. Regarding infrastructural networks, this is an iterative discussion whether or not the tree (root) is the first or secondary cause of damage. A similar debate appears on cemeteries where relatives of the deceased often plant trees, which is affirmed by cemetery managers to foster the ravages of time. The same accounts for leaves, cones and fruits falling from trees causing damage to cars or slowing down the traffic flow. Common tree risk assessment methods are primarily based on damage purely caused by trees and do not take into account tree environment. In addition, regular tree risk assessments do not pay attention to these issues unless public safety is at risk. Moreover, jurisprudence obligates to tolerate common tree inconveniences (falling leaves, cones and fruits) which seasonally occur or due to extreme weather conditions.

Despite ignoring the cases of tree failure mentioned above, it still leaves us with a grey area. This grey area includes (monophagous) insects that survive only thanks to a specific host or species and cause damage or injuries. A well-known example is the Oak processionary caterpillar, whose caterpillars in the larval stage spread bristles, which cause irritation, allergic reactions and other physical discomfort. This Oak processionary caterpillar survives only because of the oak. Larvae of several other butterflies can cause comparable situations. Even though these insects do not contribute to tree failure and thus are not part of tree risk assessment methods. These bugs are often reported separately during a tree risk assessment because of occupational law and are not included in this research. Branches on the road due to a storm are also excluded from this research, because it fuels the ongoing debate on who is responsible to keep ways free of obstacles.

Chapter 2 Materials and methods

2.1 Relevant data sources

The data on material damage and personal injuries caused by park and avenue trees were collected from organizations and experts in the field as summarized in table 1:

Table 1: Origin of statistical data

	Source	Type of statistical data	Region	Timespan
1.	Jurisprudence	Data on (im)movable property and injury damages	Netherlands	1960-2012
2.	Municipalities	Data on (im)movable property and injury damages and costs	Province of Utrecht Municipalities ≥ 100K inhabitants in the Netherlands	1969-2012
3.	Road authorities	Data on movable property and injury damages and costs	Province of Utrecht Netherlands	2007-2012
4.	European Tree Technicians, arboriculturists	Data on tangible and injury damages from research reports	Netherlands	2007-2012

This research covered most municipalities and all road authorities in the Province of Utrecht, almost all municipalities with more than 100,000 inhabitants as well as the national road authority of the Netherlands. It was not possible to approach other municipalities and road authorities due to the limited time span. However, jurisprudence are more easily available and therefore collected for the Netherlands in total. The organizations addressed for this study did sometimes register damage or (lethal) injuries. This meant that in some situations committed employees collected data based on a local template (Appendix II). The results obtained from these data were compared to the situation in other countries as far as data and literature of (current) simultaneous research allows.

2.1.1 Dutch jurisprudence

The liability of inhabitants in natural circumstances and the independency of the judiciary are two principles that underlie the Dutch legal system and legalized jurisprudence as source for this study.

The Dutch law system is based on Roman law, which in principle states that the one who causes damage is responsible to pay the costs. With regard to natural circumstances, each person has to bear the damage he suffers, unless this damage follows negligence or carelessness of other person(s). To prove liability in case of damage or injury, trials are often conducted. Under the administrative law which include tree fell licenses, judges apply a marginal review. These cases do not included damage due to tree failure. A marginal review means that a judge examines whether the authorization to provide the license in a given case is reasonable, but don't examine the content of the decision itself.

Due to the separation of powers, jurisprudence is regarded as an independent source of information which provide us an overview of the situations that occurred due to adverse effects of trees. Besides certain exceptions, it is possible to appeal for a court ruling, in which a higher court again rules on the conflict. This can lead to duplication in the number of incidents that occurred.

Only relevant jurisprudence is digitally published and general accessible. Relevant meant that a case is unique and not judged before or when application of general principles or law leads to a new interpretation of the law. This means that only a limited amount of lawsuits is published. Non-relevant jurisprudence is stored in a km long archive and publicly accessible for a manual search. This makes topic related searching in not published jurisprudence a time consuming process. In the months February and March 2013, a search in the Dutch jurisprudence digital database was manually performed by screening the key word 'tree' in all jurisprudence. The search was limited to the period 1997-2013 because there was no digital library on jurisprudence from before 1997. Duplicate cases were filtered out. The references of selected jurisprudence were crosschecked for other relevant reports. The libraries of the two specialized Dutch attorneys were also consulted over the period 1965-2013 to detect relevant jurisprudence on tree failure from the non-digital Dutch jurisprudence archive. From the period before 1965, only two individual cases were available in these non-digital libraries which dated back to 1870 and 1940 and therefore not included.

2.1.2 Dutch municipalities and road authorities

Under the Dutch Civil Code, article 5, article section 20, sub f, owners of land are responsible for their own assets and for with the land united plantings, hence for damage due to trees on their assets. Municipalities and road authorities are thus owners of large amounts of avenue and park trees and therefore an appropriate source for this study. In addition to the legal obligation to (regular) maintenance and monitoring of visible defects, both municipalities and road authorities, and face responsibilities or even payments for damages or injuries due to tree failure.

Data on incidents of or claims due to tree failure were collected from 3 main groups of municipalities and 3 road authorities whereby the included claims did not result in lawsuits.

The group of municipalities consisted of the 26 municipalities of the Province of Utrecht, the consisting 27 municipalities with a population of over 100,000 inhabitants and the inter-municipal study group on trees (ISB). The 3 road authorities consisted of the Waterschap Stichtse Rijnlanden, the Provincial Council and Rijkswaterstaat.

The inter-municipal study group on trees (ISB)[3] consist of members from several Dutch municipalities which consulted each other regularly on tree risk assessment policies. Due to the small overlap with the data from the municipality Utrecht, duplicate cases were filtered out. The includion of the large cities guarantee a relatively high number of traffic movements compared to the number of trees in public parks and along avenues.

2.1.3 European Tree Technicians and arboriculturists

In the Netherlands, about 50 companies provide advice on tree technical matters. European Tree Technicians are qualified experts in the field of arboriculture and obtain their title and education from the European Arboricultural Council established in Bad Honnef (Germany). Apart from European Tree Technicians, almost all companies in the Netherlands in the field of tree care

[3] Intergemeentelijke Studiegroep Bomen

were approached for information on the frequency and damage (tangible and personal) due to tree failure. Natural hazards fall often outside the scope of liability unless there has been negligence. To determine whether tree failure could have been foreseen by owners, European Tree Technicians are often consulted. Since the amount of companies is limited it was easy to approach all the companies and request for information on their consulting activities. Some companies sent several cases on damages and injuries while other companies hesitated to do so for liability reasons. European Tree Technicians who worked in a specific municipality, were asked to comment on the data provided by that specific municipality. The data of the municipality of Amsterdam seemed to unfit reality when compared to the data of other municipalities. Several European Tree Technicians and the municipal tree consultant of Amsterdam itself suggested that the data of this municipality were incomplete. The reason for this flaw seems to be associated with the fact that the administration is divided in several district councils, which did not always register data of tree failure. Hence, the municipality of Amsterdam showed a very low frequency of tree failure, which seems highly unlikely. This becomes even more clear when we consider that in Amsterdam elms were very common, a species susceptible to elm disease and prone to deferred incompatibility of graft – rootstock combinations.

2.2 Risks compared in literature

To calculate the risk on tree failure, two components are important: the frequency (denoted by P) of tree failure and the effect (denoted by E) caused by tree failure.

The probability is often displayed as a fraction of the population size. However, two ministries in The Netherlands expressed the probability as the risk one runs by participating in activities based on a frequency of this activity instead of the frequency as a fraction of the population size (V&W and VROM, 2003). The use of the population based probability lead toa smaller risk. The probabilities presented as a fraction of the population size for cancer, cardiovascular diseases, lightning, road accidents and total external causes of death for the year 2010 are shown in tables 2 and 3.. Cancer and cardiovascular diseases are involuntary and internal causes of death, while lightning is an involuntary and external cause of death. Road accidents are external and voluntary cause of death whereas the total external causes of death contains voluntary as well as involuntary risks. Tree failure can be seen as an external risk that is both voluntary (participation in traffic) and involuntary (lightning). We were not able to retrieve data on tangible damage of these 5 causes of death because these data were not registered by the Dutch authorities (Davidse, 2011; Wijlhuizen et al., 2012).

Table 2: Baseline data probability factor in 2010

Cause of death	The Netherlands		United Kingdom		United States	
	Number of deaths	Source	Number of deaths	Source	Number of deaths	Source
Cancer	42,396	CBS	157,275	Cancer Research UK	569,490	American Cancer Society
Cardiovascular diseases	38,897	CBS	179,000	British Heart Foundation	600,000	Centers for Disease Control and Prevention
Lightning	2	CBS	3	(Elsom, 2001)	29	National Weather Service
Road accidents	650	CBS	deaths 1,850	Department	32,885	U.S. Department

			injured 22,660	for Transport		of Transportation
Total external causes of deaths	5,748	CBS	17,201	Office for National Statistics	180,811	Centers for Disease Control and Prevention
Number of inhabitants	16,574,989	CBS	62,261,000	Office for National Statistics	308,745,538	United States Census 2010

Table 3: Probability of death per person in 2010

Cause of death	**The Netherlands** Probability / person	**United Kingdom** Probability / person	**United States** Probability / person
Cancer	1:391	1:396	1:5,465
Cardiovascular diseases	1:426	1:348	1:515
Lightning	1:8,287,495	1:20,753,666	1:10,646,398
Road accidents	1:25,500	1:33,655	1:9,389
Total external causes of deaths	1:2,884	1:3,620	1:1,708

Like tree failure, flood risk is, beside lightning another natural risk in the Netherlands. Regarding the Dutch flood risk management, geographical demarcations are used to define the flood risk per region which varies from 1:1,250 to 1:10,000 years (Brouwer and Vellinga, 2007). In addition, national law request regular risk assessment and maintenance to prevent a flood. Likewise, national law request companies with hazardous substances to perform regular risk assessment and maintenance to establish the local individual risk should never rise above 1:100,000 (Ale et al., 2011). Both ministries of V&W and VROM state that the assessment of these external risks should be based on the as-low-as-reasonable-acceptable-principle (ALARA)(V&W and VROM, 2003).

Regarding the effects of damage, as being the likelihood expressing the severity of injuries and damage, these are divided into four levels which form the basis of most classification matrixes on governmental and business level, since the US Department of Defense published its risk matrix (Defense, 2000). Some researchers add one or two levels to this risk matrix or change the definitions of the separate levels to fit the data best. Different industries use different classification boundaries (see Appendix I) within the risk matrix. The European Commission described these 4 levels in the latest edition of the guidelines for the management of the Community Rapid Information System 'RAPEX' (Commission, 2009; van Duijne et al., 2008) and in a commission staff working paper for risk assessment and mapping guidelines for disaster management (Commission, 2010). RAPEX exchanges information on serious risks to the health and safety of citizens of European Union Member States.

2.3 Tree risks compared in literature

To get an overview of all (unpublished) investigations in this field the members of the Council of Representatives of the International Society of Arboriculture were contacted, who represent each a different organization or country. During the collection of data, it was confirmed by researchers in the field of arboriculture of the individual countries that from Denmark, Italy, New Zealand and Slovakia no statistics are known on damage or injuries. Some researchers came up with additional unpublished articles.

2.4 Risk analyses

From the different data sources, a probability was obtained and differentiated towards a frequency and an effect. The frequency of tree failure is defined as cases per year and the effect is expressed in damage (€) per case over the reported timespan as displayed in figure 1 and table 4. The effect is further distinguished into an average claimed compensation and paid compensation per municipality. Not from all cases were the costs known, therefore the averages for claimed and paid compensation are calculated over the cases where the costs were known.

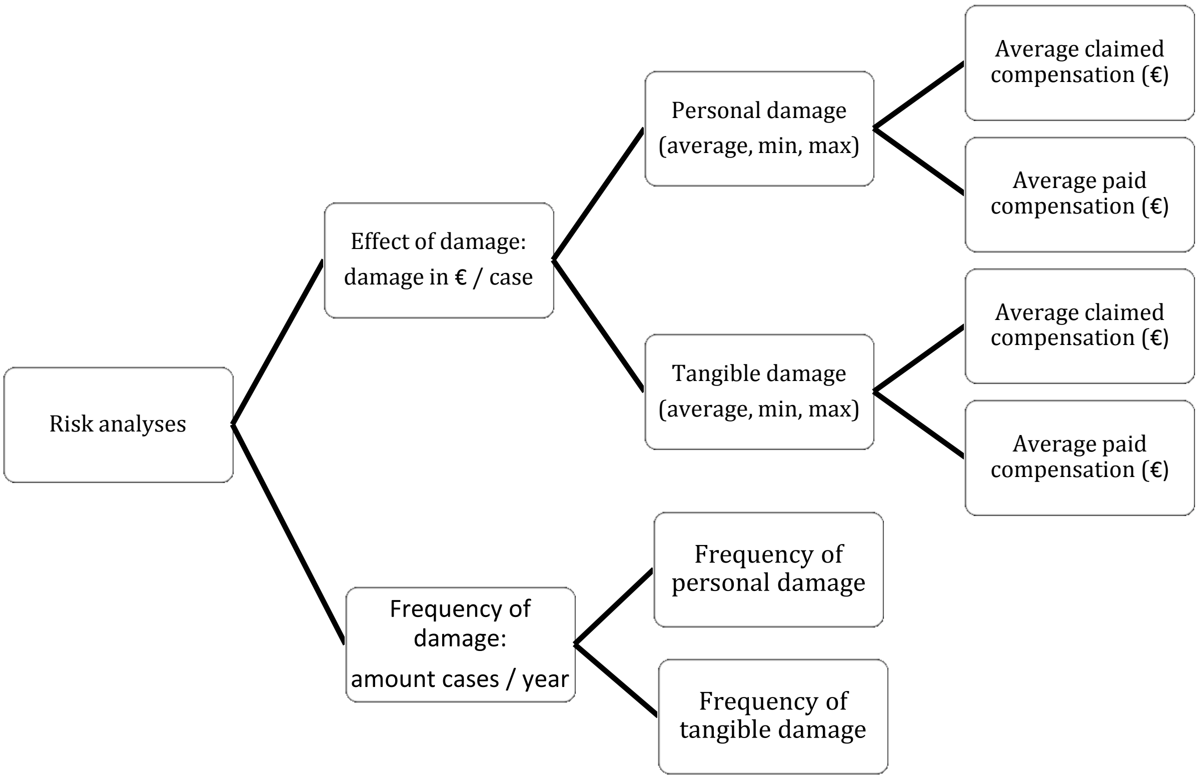

Figure 1: Risk analyses differentiated in effect and frequency

To compare the frequency of tree failure in the different municipalities, beside timespan, average annual inhabitants, average population density and the number of trees were used as indicator shown in table 4. Governmental organizations often provide the risks per inhabitant. Currently, worldwide tree management often prescribe a higher frequency of inspection for areas of intensive use, indicated by the amount of traffic or by a higher population density per km². Tree technicians, however, are often more focused on the (potential) failure of the individual tree. As illustrated by table 4 (column 2 and 3), the timespan of reported cases of tree failure differed from municipality to municipality. Dead trees are often replaced by new trees, which makes the number of trees less or more equal within a timespan.

Table 4: Indicators of tree failure frequency in Dutch municipalities

Municipality	Timespan of reported cases of tree failure	Number of years[1]	Average annual inhabitants[2]	Average population density[2]	Trees
Alkmaar	27/10/2002-31/12/2012	10.18	93,531	3,222	46,000
Amersfoort	18/1/2007-31/12/2012	5.95	143,864	2,290	68,000
Amsterdam	7/1995-31/12/2012	17.50	741,478	4,496	360,000

Apeldoorn	2008-2012	5.00	155,866	459	60,000
Bunnik	01/01/2009-31/12/2012	4.00	14,449	391	10,000
De Bilt	2/8/2006-29/1/2013	6.49	42,026	634	25,000
Ede	27/10/2002-18/4/2013	10.48	107,072	336	65,000
Emmen	2002-2012	11.00	108,831	323	102,000
Groesbeek	1/7/1988-29/8/2009	21.16	18,792	431	6,500
Groningen	26/4/2001-31/12/2012	11.68	182,188	2,312	75,000
Haarlem	25/04/1997-31/12/2012	15.68	148,205	5,045	55,000
Haarlemmermeer	2009-2012	4.00	143,037	801	63,310
'X'	2009-2012	4.00	28,727	490	21,000
Maastricht	11/2/2004-31/12/2012	8.89	119,821	2,110	35,000
Nijmegen	9/6/1969-31/12/2012	43.56	153,404	3,002	54,740
Rotterdam	03/04/2000-31/12/2012	12.74	595,700	2,880	152,000
s-Hertogenbosch	25/11/2006-31/08/2012	5.76	138,130	1,639	73,000
Venlo	01/01/2001-31/12/2012	12.00	93,803	1,013	64,000
Wijk bij Duurstede	13/3/2012-14/2/2013	0.92	23,050	486	14,000
Zeist	20/4/2011-31/12/2012	1.69	61,029	1,258	35,000
Zoetermeer	1997-2012	16.00	114,940	3,282	40,000

1. This denotes the timespan between the first date of reported tree failure until the last date of the reported tree safety control period.

2. Source: CBS; both categories represent the average criteria over the years of the timespan of reported cases of tree failure.

2.5 Statistical analyses

The probability distributions defining the risk of tree failure are computed using the @Risk software. Municipalities provided the most detailed data on which a Monte Carlo simulation was applied. Unfortunately, the partial complete data from road authorities and European Tree Technicians hampers a statistical analysis. The data were to limited to perform a proper analyses. After applying Maximum Likelihood estimators each column ended up with its own probability distribution. A Poisson distribution was generally assumed as probability distribution for the data, where the mean was taken as the lambda parameter. The mean fitted the data better than estimators of other probability distributions, like for instance a triangular distribution based on the minimum, maximum and most likely. When other probability distribution were performed, they all resulted in higher statistical values. To estimate how likely the adverse effects of tree failure were a Latin Hypercube (default setting) was performed for the risk (P x E) on tangible damage. The choice for tangible damage only, is made because of lack of data on personal damage. Monte Carlo uses the Central Limit Theorem with the standard error of the mean of the input distribution, entirely random. This means that samples can be drawn from anywhere within the input distribution. However, it fits the data more when samples are obtained from areas where a higher probability of adverse effects is more likely. Latin Hypercube stratifies random samples (taken from each interation), causing that the input distribution is very closely matched. The samples reflect more precise the distribution of values of the input probability distribution.

Table 5: Stochastic (Poisson) distributed variables in @Risk

Variable	Description	Parameter
Jurisprudence	Frequency of lawsuits and paid compensation	Minimum, average, maximum
Municipalities	Average frequency all municipalities and claimed and paid compensation	Minimum, average, maximum
Road authorities	Frequency of claims	Average
European Tree Technicians	Frequency of cases of tree failure	Frequency

Chapter 3 Results and Analyses

3.1 Reported risks in literature

Articles on tree failure are limited. Literature that discusses risks of tree failure without reporting or analyzing data is defined as qualitative articles. Table 6 provides an overview of the published qualitative articles on tree risk management and associated fields. A more extended version of table 6 is presented in Appendix III. In addition to table 6, we found also some governmental documents and tree master plans that emphasize the prevention of risks through systematic and regular inspections of trees, but these reports were not enclosed due to the absence of qualitative data. Remarkably, in Germany, there seemed to be no data or articles available on tangible or personal damage due to tree failure, according to several German experts.

Table 6: Overview published qualitative articles

Qualitative articles	Country	Tree management	Tree risk assessment methods	Liability	Risk analyses	Education
(Norris, 2005a)	Australia	x				
(Manning et al., 2002)	Canada		x			x
(Adams, 2007)	Great Britain	x			x	
(Ball, 2007)					x	
(Eden, 2007)			x	x		x
(Ellison, 2007)			x			
(Fay, 2007)			x	x	x	
(Lonsdale, 2007)		x	x			
(Britt and Johnston, 2008)		x		x		
(Boddy, 2009)		x				
(Brown and Fisher, 2009)		x				
(Forbes-Laird, 2009)				x		
(Bennett, 2010)				x		
(NTSG, 2011)		x				
(Barrell, 2012)		x		x		
(Hong Kong Government 2012)	Hong Kong		x			
(Wagner, 1963)	United States	x				
(Paine, 1971)		x				
(Anderson and Eaton, 1986)		x		x		
(Costello and Berry, 1991)			x			
(Edberg and Berry, 1999)		x				
(Pokorny et al., 2003)			x			x
(Mortimer and Kane, 2004)		x		x		

Articles which reported the frequency or damage (tangible or personal) of tree failure were defined as quantitative articles and outlined in table 7.

Table 7: Overview quantitative articles

Quantitative articles	Country	Reported frequency	
(Dunster, 2012)	Canada	2008: 3 deaths, 4 injured	
(Adams, 2007)	Great Britain	1998-2003: on average 6 deaths / year	
(HSE, 2007)		Annual 5–6 deaths of which 3 in public spaces.	1 in 10 million trees in areas public use cause death 1 in 20 million inhabitants suffers a death due to tree failure 1 in 150 million for all trees in Great Brittain cause a death.
(Ball and Watt, 2009)		1999-2008: 65 deaths, 12 injured	1 in 10 million inhabitants
(Dunster, 2012)		2008: 5 deaths 2009: 9 deaths, 8 injured	
(Dunster, 2012)	India	2009: 6 deaths, 11 injured 2010: 21 deaths, 25 injured 2011: 28 deaths, 34 injured	
(Hong Kong Government 2012)	Hong Kong	2011: 1 death	
(Dunster, 2012)	Philippines	2010: 11 deaths, 8 injured 2011: 12 deaths	
(Blom, 2013) unpublished	Sweden	2007: 196 injured 2008: 121 injured 2009: 106 injured 2010: 92 injured 2011: 119 injured	
(Schmidlin, 2008)	United States	1995-2007: 407 deaths, 73 houses damaged	
(Johnson, 1981)		1965-1980: 45 (fatal) injuries	
(Dunster, 2012)		2008: 44 deaths, 6 injured 2009: 63 deaths, 52 injured 2010: 75 deaths, 96 injured 2011: 118 deaths, 124 injured	

Most of the quantitative reports described the frequency of tree failure and related tangible or (fatal) personal damage whereby only in two cases a comparison was made with the population or tree density. Regarding the frequencies reported by Dunster, one important remark has to be made. The number of reported incidents was based on information retrieved through Google which may suggest an underestimation of the real frequency of (fatal) injuries due to cultural differences, technological integration and development, and political influences.

3.2 Dutch jurisprudence

Cases of tree failure obtained from the Dutch jurisprudence which were organized at the date that the actual adverse effect happened. Generally, the date of the court decision occurred a few years later. For each 10 years, the frequency and effect of damage are presented in table 8. Because of the lack of data on personal damage (except for one case), only tangible damage is displayed. The digital search led to a selection of 8 lawsuits of damage and injuries which arose due to tree failure. The search in the libraries of the two specialized attorneys identified 52 additional cases of damage or injuries due to tree failure. One double counted incident was removed from the selected lawsuits. Of note, several attorneys had the impression that the total number of cases regarding damage due to tree failure in court is higher as presented in table 8.

Table 1: Frequency (average, minimum and maximum) and tangible damage of tree failure in lawsuits

Jurisprudence	Overall mean[1]	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010
Frequency / year[2]						
Tangible cases	1.20 (n=60)[3]	0.60 (n=6)	1.10 (n=11)	0.70 (n=7)	1.70 (n=17)	1.90 (n=19)
Personal cases					0.50 (n=5)	0.20 (n=2)
Tangible damage / case						
Average (€ x 1,000)	8.94 (n=23)	0.15 (n=2)	2.84 (n=6)	1.05 (n=2)	4.24 (n=4)	17.15 (n=9)
Minimum (€ x 1,000)	0.13	0.13	0.28	0.88	1.99	0.40
Maximum (€ x 1,000)	61.27	0.16	10.16	1.21	7.82	61.27

1. From 1961 until 2010.
2. In one case of personal damage, data is available: 12-02-1997 after a tree fell on a car, € 19,080 was paid for compensation of tangible and personal damage.
3. In 44 cases trees tumbled, 15 represent falling branches. From the 44 cases of tumbling trees, 16 cases concerned property damage, 28 concerned damage on vehicles.

Table 8 indicates an increase in the number of lawsuits and indicates an increase in the amount paid for the damage. In 38% of the Dutch jurisprudence, the financial extent of damage was disclosed and graphically displayed in figure 2. In all cases where damage due to trees occurred, the permit was released and ratified by the court. In all selected cases of lawsuits, damage occurred due to tree failure, although the financial extent of the damage was not mentioned in 36 cases.

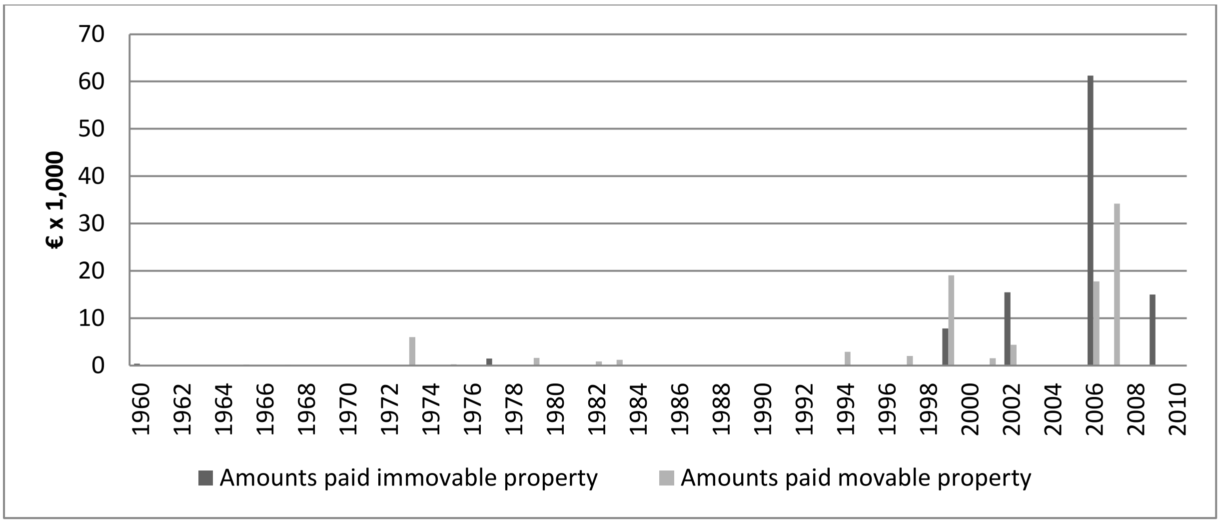

Figure 2: Average paid compensation per case of tangible damage over 1960–2010 in jurisprudence

3.3 Municipalities

The 21 municipalities reported a total number of 1,560 cases of tree failure of a total of 1,424,550 trees, over a self-selected period varying from 1969 to 2013. Cases were differentiated by the frequency of personal and tangible damage per year (see table 9). This frequency presents the annual probability that one inhabitant of the total citizens of a specific municipality experiences tree failure. For reasons of completeness the data of Amsterdam is displayed. Municipality employees mentioned that the number of complaints relating to trees or tree failure increased the number of incidents that is related to damage or (lethal) injuries due to tree failure.

Table 2: Frequency (average, minimum, maximum) of personal and tangible damage per municipality

Municipality	Total cases /period[1]	Frequency (cases /year)	Personal damage /year[2] (%)	Tangible damage /year (%)	Case /inhabitant /year	Case /inhabitant /km^2/year	Case /tree /year
Alkmaar	32	3	0%	100%	29,740	1,025	14,627
Amersfoort	58	10	3%	97%	15,286	235	7,225
Amsterdam	20	1	10%	90%	720,767	3,934	349,945
Apeldoorn	37	7	0%	100%	21,063	63	8,109
Bunnik	2	1	0%	100%	21,674	587	15,000
De Bilt	24	4	4%	96%	11,862	172	7,057
Ede	32	3	0%	100%	35,050	110	21,278
Emmen	153	14	0%	100%	7,825	24	7,334
Groesbeek	29	1	3%	97%	14,203	315	4,913
Groningen	98	8	2%	98%	22,162	276	9,124
Haarlem	57	4	0%	100%	40,771	1,388	15,131
Haarlemmermeer	38	10	0%	100%	15,057	85	6,665
'X'	9	2	0%	100%	12,768	218	9,334
Maastricht	109	12	1%	99%	9,859	173	2,880
Nijmegen	172	4	2%	98%	39,539	761	14,109
Rotterdam	426	33	0%	100%	17,902	87	4,568
s-Hertogenbosch	44	8	0%	100%	18,095	215	9,563
Venlo	128	11	0%	100%	8,792	95	5,999
Wijk bij Duurstede	6	7	0%	100%	3,533	75	2,146
Zeist	17	10	12%	88%	6,895	126	3,954
Zoetermeer	76	5	7%	93%	25,902	691	9,015
Average (excl. Amsterdam)	77	8	2%	98%	18,899	336	8,902
Minimum	2	1	0%	88%	3,533	24	2,146
Maximum	426	33	12%	100%	40,771	1,388	21,278

1. This column displays the number of cases of tree failure within the timespan of reported cases of tree failure as presented in table 6.
2. Nature personal damage: Amersfoort – cuts and abrasions to the face and near the eyes; Amsterdam – death of a baby, broken shoulder blade; De Bilt – minor head injuries; Groesbeek – minor head injuries; Groningen – death of an adult, abrasions; Nijmegen – minor leg injuries, abrasions (2x); Zeist – minor head injuries, knee injuries; Zoetermeer – abrasions (2x), knee injuries, 2 cases unknown.
3. Data on the municipality of Amsterdam is, due to incompleteness, left out from the calculation of the overall mean, minimum and maximum..

When we make a sub-group analyses of the municipalities that reported over several decennia, like in Dutch jurisprudence the frequency indicates an increase over time.

Table 3: Average frequency per year in each decade

Municipality	1971-1980	1981-1990	1991-2000	2001-2010
Nijmegen	2.10	3.60	4.00	8.70
Groesbeek		1.33	1.20	1.44

Haarlem	1.50	6.30
Rotterdam	28.00	35.70
Zoetermeer	3.00	5.10

Table 4: Average annual claimed compensation per year in each decade

Municipality	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010
Nijmegen	196.53	174.20	826.78	1,341.26	1,524.54
Groesbeek			621.68	567.17	1,605.68
Haarlem				995.16	1,935.70
Rotterdam				5,217.90	2,512.97
Zoetermeer				1,014.82	725.39
Overall mean	196.53	174.20	724.23	1,827.26	1,660.85

Table 5: Average annual paid compensation per year in each decade

Municipality	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010
Nijmegen	196.53	174.20	868.83	1,341.26	1,524.54
Groesbeek			794.12	567.17	1,605.68
Haarlem				n.a.	n.a.
Rotterdam				6,955.48	1,777.25
Zoetermeer				1,014.82	712.06
Overall mean	196.53	174.20	831.48	2,469.68	1,404.88

The paid and claimed compensation displays an increase up to the year 2000, after which the compensation declines again.

Also the effect of an individual tree failure case was analyzed. Financial details on tangible and personal damage were clustered in claimed damage and compensated damage. For each cluster, the overall mean, minimum and maximum are displayed in table 10. The average amounts of claimed and compensated damage were calculated over the number of cases per municipality as far as the data were known. This results in differences in the number of cases between claimed damage and compensated damage. The effect was calculated over all cases of each municipality.

Table 6: Personal and tangible damage (€) per municipality

Municipality	Personal damage		Tangible damage	
	Average claimed compensation (€)	Average paid compensation (€)	Average claimed compensation (€)	Average paid compensation (€)
Alkmaar	n.a.[1]	n.a.	1,243 (n=14)	1,243 (n=14)
Amersfoort	500 (n=1)	n.a.	1,754 (n=49)	3,724 (n=13)
Amsterdam	n.a.	n.a.	1,752 (n=4)	1,752 (n=4)
Apeldoorn	n.a.	n.a.	1,036 (n=38)	1,313 (n=13)
Bunnik	n.a.	n.a.	n.a.	n.a.
De Bilt	n.a.	n.a.	1,346 (n=15)	1,773 (n=3)
Ede	n.a.	n.a.	1,180 (n=7)	1,180 (n=7)

Emmen	n.a.	n.a.	n.a.	n.a.
Groesbeek	993 (n=1)	993 (n=1)	940 (n=17)	971 (n=16)
Groningen	n.a.	n.a.	1,821 (n=72)	1,071 (n=57)
Haarlem	n.a.	n.a.	1,725 (n=42)	n.a.
Haarlemmermeer	n.a.	n.a.	n.a.	818 (n=27)
'X'	n.a.	n.a.	898 (n=5)	898 (n=5)
Maastricht	3,000 (n=1)	3,000 (n=1)	881 (n=31)	881 (n=31)
Nijmegen	112 (n=1)	112 (n=1)	1,026 (n=59)	1,026 (n=59)
Rotterdam	n.a.	n.a.	2,670 (n=298)	2,215 (n=176)
s-Hertogenbosch	n.a.	n.a.	1,540 (n=27)	n.a.
Venlo	n.a.	n.a.	n.a.	1,083 (n=18)
Wijk bij Duurstede	n.a.	n.a.	1,156 (n=2)	1,156 (n=2)
Zeist	589 (n=2)	589 (n=2)	677 (n=4)	677 (n=4)
Zoetermeer	908 (n=1)	908 (n=1)	773 (n=26)	773 (n=26)
Average	1,017	934	1,336	1,328
Minimum	112	112	12	0
Maximum	3,000	3,000	75,000	36,340

1. n.a. = not available; n = frequency of tree failure causing known damage

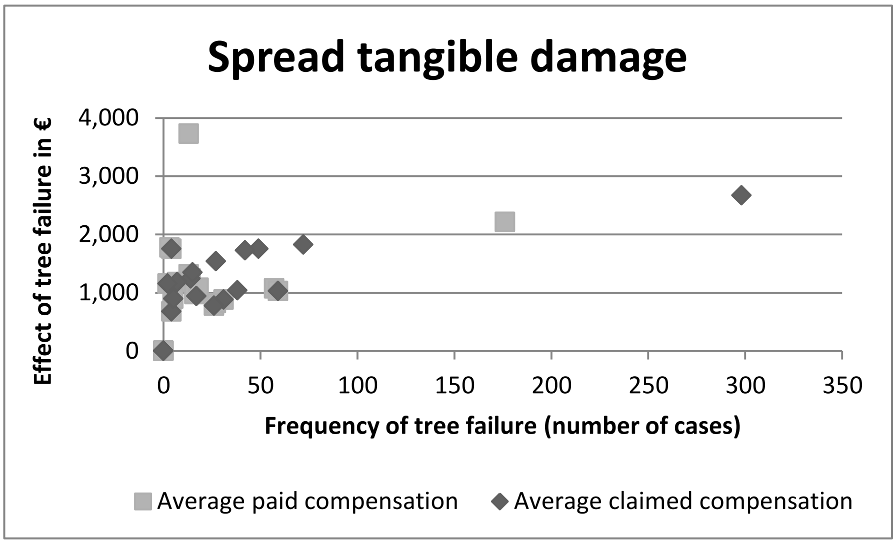

Figure 3: Distribution of Effect and Frequency of tangible damage

The distribution of the effect distinguished in average paid and claimed compensation of the selected municipalities is displayed in figure 3. Sometimes the paid compensation was higher than the claimed compensation. This was mainly because of the number of cases of which the paid compensation was known, was smaller and the payments on average higher. The frequency of these cases of tree failure of which the paid and claimed compensation was known, therefore differs from the frequency in table 8. Clearly most averages from each municipality fall between the upper boundary of € 2,000 and the lower boundary of € 500. The cases where the frequency and effect were zero, signified cases where the data was not available.

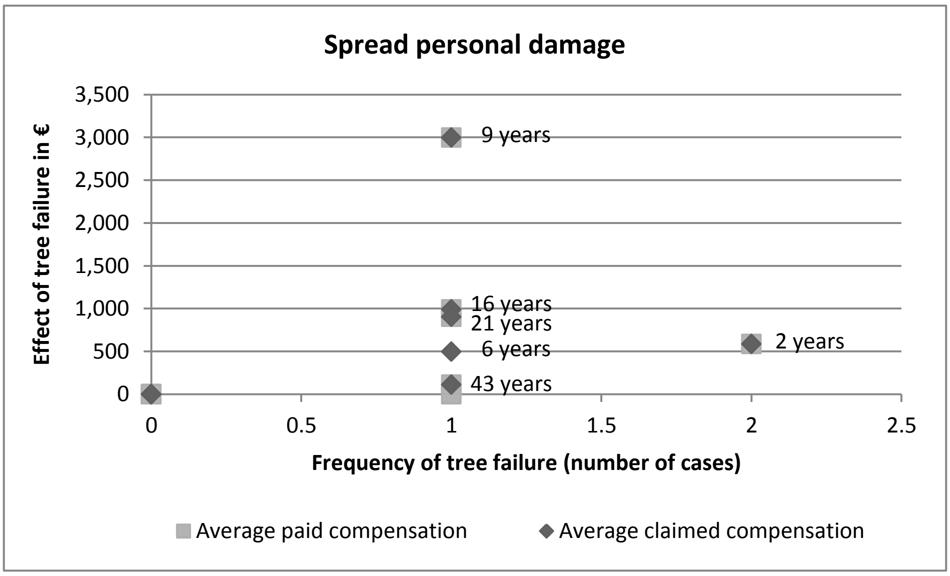

Figure 4: Distribution of Effect and Frequency of personal damage

The distribution of personal damage was limited by the frequency instead of the effect. The cases where the frequency and effect and were zero, are cases where no data was available (figure 4). For each case of tree failure the timespan in which the first and the last case occurred is given. Figure 4 indicates clearly that one case of personal damage per timespan in which tree failure occurred, seems common among municipalities. The municipalities Bunschoten and Montfoort could not provide data on this topic due to absent registrations. The municipalities Utrecht, Enschede, Baarn, Stichtse Vecht and Rhenen had data on cases of tree failure, but were not able to provide data within the study period.

3.4 Road authorities, European Tree Technicians and Arborculturists

The national road authority in The Netherlands – Rijkswaterstaat – provided data on cases of tree failure on highways, waterways and in recreational areas as shown in table 11. These results were partial obtained from individually responding employees and partial based on the registration of annual claims presented by national road authority.
Data obtained from European Tree Technicians and arboriculturists originated from all over the Netherlands. One case concerning personal injury was recorded by the national road authority and European Tree Technicians and is reported in table 11.

Table 7: Frequency and average effect of tree failure

Year	2007	2008	2009	2010	2011	2012
National road authority						
Frequency	1	5	3	6	7	8
Personal damage[1] (%)			33	33		
Tangible damage (%)	100	100	67	67	100	100
Average claimed damage (€ x 1,000)[3]	0.50	3.56	3.05	2.46	1.89	2.34
European Tree Technicians						
Frequency	2	1	3	5	2	6
Personal damage[2] (%)			33		50	
Tangible damage (%)	100	100	67	100	50	100

1. 2009: 1 person injured, 2010: 1 hospitalization of adult due to injuries, 1 death of adult.
2. 2009: 1 adult injured, 2011: arm and hand of child permanently damaged, 1 adult injured.
3. The average claimed damage only accounts for tangible damage.

3.5 Analyses of frequencies and effects

The frequency is based on all reported cases, no matter financial data was known or not available. From the cases where financial data were available, the calculated average effect was interpolated for the cases of tree failure where financial data was unknown. The multiplication of frequency with effect provides the probability per year as presented in table 12. This table indicates the annual presumed costs which a municipality on average faces due to tree failure, subdivided into the average costs per inhabitant and average costs per tree.

Table 8: Deterministic scenarios of annual costs (€), 10,000 iterations in @Risk

Probabilit scenarios	Probability	Mode	Standard deviation	5th percentile	95th percentile
Frequency / year	8	7	3	3	12
Frequency / year / inhabitant	19,260	19,253	139	19,032	19,488
Frequency / year / tree	9,152	9,134	96	8,994	9,309
Claimed tangible damage	1,336	1,335	37	1,276	1,397
Paid tangible damage	1,328	1,326	36	1,268	1,387
Probability of tree failure (P) / year / case					
Claimed tangible damage	10,688	7980.000	3,716	4,176	16,644
Paid tangible damage	10,624	9177.000	3,690	4,125	16,575
Probability of tree failure (P) / year / inhabitant					
Claimed tangible damage	0.069	0.069	0.002	0.066	0.073
Paid tangible damage	0.069	0.067	0.002	0.066	0.072
Probability of tree failure (P) / year / tree					
Claimed tangible damage	0.146	0.143	0.004	0.139	0.153
Paid tangible damage	0.145	0.143	0.004	0.138	0.152
Probability / year / case in court					
Frequency / lawsuit / year	1.00	1.000	1.019	0.000	3.000
Paid tangible damage / lawsuit / year	9.00	8.000	2.990	4.000	14.000
Paid damage	11,505	0.000	4,888	2,336	18,704

The probability per year denotes the output of the probability distribution. The 5th and 95th percentile show the value below which 5 or 95 percent of the damage of all cases of annual tree failure can be found. With the assumption that the focus will be on the presumed paid damage of each municipality, the average payment for damage due to tree failure was € 11,505 when it came to a case in court. Since municipalities know they are likely to face costs of tree failure each year, this can be taken into account when forecasting next year's budgets.

Table 12 shows that the average annual expenditure per inhabitant for compensating tangible damage was on average € 0.069, with a minimum of € 0.066 and maximum of € 0.072 as shown in figure 5.

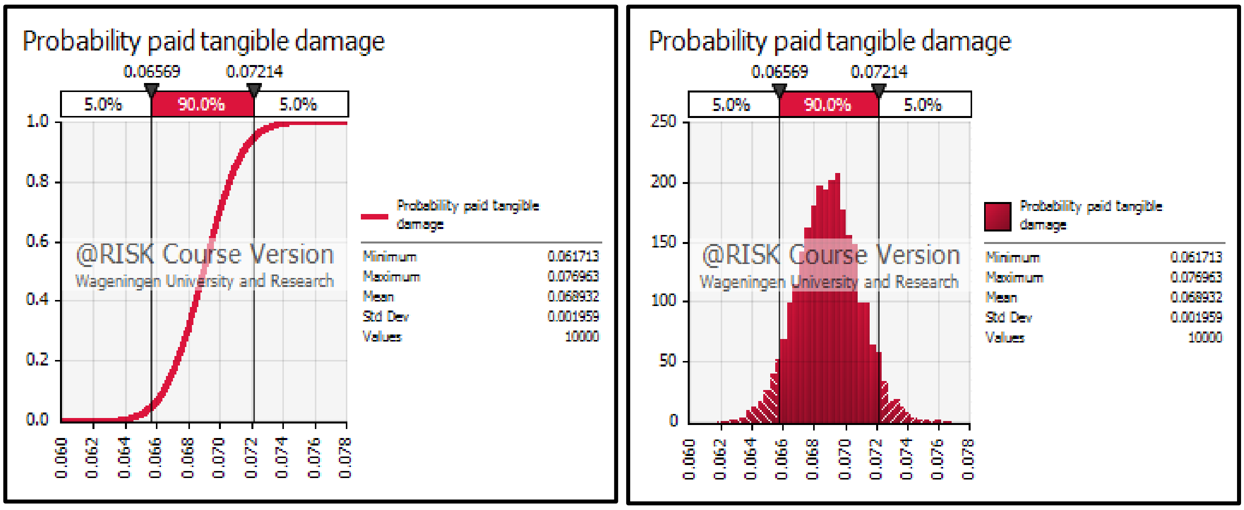

Figure 5: Probability distribution annual paid tangible damage / inhabitant

With the assumption that figure 5 provided a 95% probability without uncertainty, the average annual expenditure per case for each municipality would be € 1,380 based on 20.000 inhabitants.

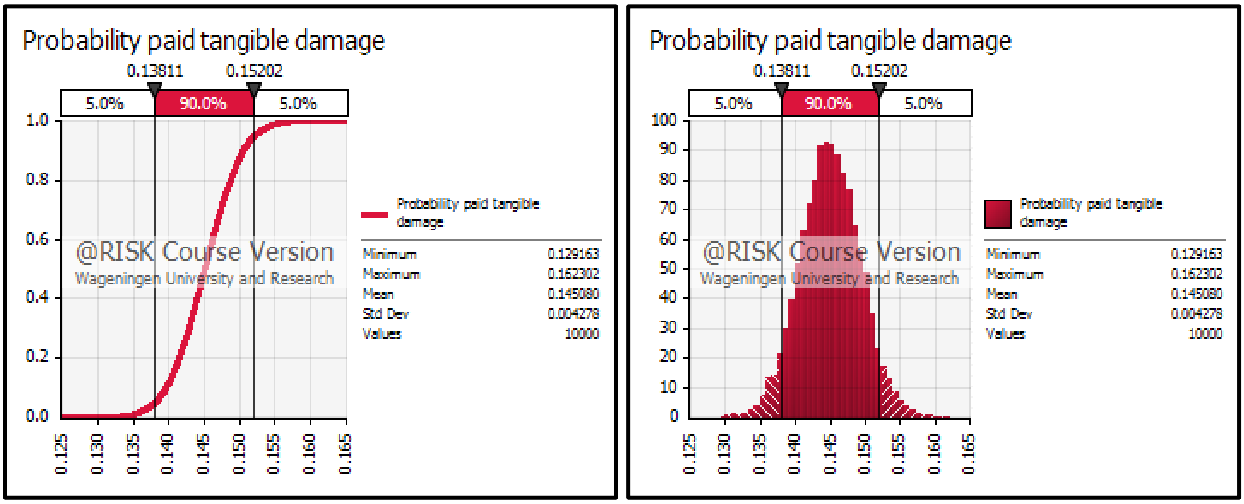

Figure 6: Probability distribution annual paid tangible damage / tree

The presumed expenditure per tree paid for compensating tangible damage is on average € 0.145, with a minimum of € 0.138 and a maximum of 0.152, clearly shown in figure 6. Also here, the average annual expenditure per case for each municipality would be € 1,232 based on 8,500 trees.

4. Discussion and recommendations

4.1 Quality of the data and analyses

4.1.1 Availability and sensitivity of the data

This paragraph discusses the availability and sensitivity of the different data sources.

Jurisprudence: The data on lawsuits concerning tree failure seem to indicate an increase in number of cases and in the amount paid for the damage. However, only in 38% of jurisprudence the extent of damage is disclosed. There seems multiple possible explanations for these increases. First, consulted lawyers specialized in tree failure collected more cases of tree failure over time and therefore may receive more referrals from colleagues. Second, older trees showed more failures and may cause more tangible or personal damage. And third, there is an increase in number of legal aid insurances. It also might be that there is a growth in number of civil works along roads and in public areas, whereby damage to tree roots is caused by cranes and shovels. Damage to the roots always results after some time in dead branches. Public awareness of the principle that the causative pays, can certainly contribute. Besides the number of cases, the amounts to which the defendants are sentenced to pay, also reveal to rise over time. The sums paid on immovable property in the year 2006 show a spike of € 61,270. However, even after removing this spike the paid amounts for compensating damage still seem to grow over the years. The following question arises: does this also signifies an increase over time in the number of adverse effects on tree failure or does it just show that more attention leads to more awareness and registration. It is known that the numbers provide an underestimated picture. This might partly be due to the selection of sources: published jurisprudence and specialized lawyers. Published jurisprudence is only a minor part of the total jurisprudence in the Netherlands, whereas specialized lawyers only collect data with regard to their own clutter.

Municipalities: The rather short periods (5 to 10 years in the past) over which municipalities reported cases of tree failure makes it hard to analyze trends. Like Dutch jurisprudence, the average frequency per year in each decade seems to indicate an increase in the numbers of tree failure. The average claimed and paid compensation also increase up to the year 2000, after which it declines again. From the 21 municipalities the data denote that annually 1:18,899 inhabitants experienced adverse effects due to tree failure. This is somewhat more frequent than the frequency for every inhabitant of the Netherlands of experiencing a road accident, which occurs to 1:25,500 inhabitants. The municipalities of Haarlem (1:40,771) and Nijmegen (1:38,317) clearly excel in the lowest risk per inhabitant. The municipalities of Wijk bij Duurstede (1:3,533) and Zeist (1:6,895) clearly represent a higher risk per inhabitant. Data on the municipality of Zeist displays a significant higher amount of personal damage as compared to data of other municipalities for which we could not found a reason. Questions might be asked to what extent this data between the individual municipalities is comparable. By checking incidental newspaper articles for some municipalities an attempt was made to determine the accuracy of the supplied frequency of adverse effects. In all cases it turned out that the cases reported in the newspapers were not incorporated in the data from the municipality, especially when personal damage (deaths, injuries) was involved. Municipalities did not report serious accidents and deaths, which might partly have occurred because the claims due to tree failure are based on the claims they get. Privacy reasons also could play a role here. In this research only municipalities responded who own large amounts of trees, but there are also municipalities in the Netherlands which don't have trees at all or have hardly any trees. Two other precautionary comments can be made on the results from municipalities. First the present sample size (21) is not a representative sample of all municipalities in the Netherlands (426). This makes it hard to draw conclusions on different frequencies between municipalities. Second, most reported cases are based on the number of claims due to tree failure. The cases of damage that are dealt with by mutual agreement, without coming to a claim, are not included. This means at the same time that the number of reported cases is an underestimation of all cases of tree failure in reality. Nevertheless, the overall mean of the 21 municipalities does indicate the size of the risk for municipalities with trees in the Netherlands. Apart from the frequency the effect is designated by the compensated amount. The differences between claimed and paid compensation arise from different reasons. A higher amount on average for paid compensation than claimed compensation often indicates a high number of unjustified claims. A large quantity of smaller incorrect claims for compensation diminishes the average claimed compensation per case. Where a higher amount on average for claimed compensation than paid compensation often indicates that claimed compensation is partly paid.

Road authorities and European Tree Technicians: The data from the national road authority "Rijkswaterstaat" provides information on the frequency and effect (damage/ case in €) of tangible damage on highways. Some damage is processed in projects (deducted from contractors), which never comes to a claim. So the current frequency is an underestimation of the real situation. It does yet provide information on the probability of claims due to tree failure. The response of European Tree Technicians was rather low; less than 1% of all companies delivered data. Only one case was reported twice of all reported cases. This means that the reported cases did add useful information. However because the total number of reported cases is very small (19) and corresponds to municipalities which did not participate in our study, it is impossible to base conclusions on the reported cases. But the European Tree Technicians could also provide information on outliers which showed up in the data of municipalities. This led to the determination that the reported frequency of the municipality of Amsterdam was incomplete.

4.1.2 Results related to literature on tree failure

The current discussion on tree risk management in the field of arboriculture is dominated by qualitative articles. There is no other research known that systematically investigated how much damage of tree failure. Some studies report personal damage expressed in the frequency of tree related deaths and injuries. Except for Great Britain these studies were often not based on statistics kept by governmental or professional organizations, but on qualitative descriptions instead. However, also for Great Britain the figures do not match each other where one study mentioned that 1:10,000,000 inhabitant (HSE, 2007) experiences tree failure and another study mentioned that this applies for 1:20,000,000 inhabitants (Ball and Watt, 2009). Based on the current figures from Dutch municipalities the chance that an inhabitant experiences (fatal) injuries is 1:1,286,028 and the chance that someone experiences death caused by tree failure is 1:2,127,551. This is much lower as the reported chances in current literature.

4.1.3 Results compared to other risks

Although Schlechter and Reniers both described and defined levels for the chemical industry, the classification boundaries of both articles were different whereby only Schlechters' approach was based on the industry itself(Reniers et al., 2005; Schlechter, 1995). Reniers provided a more general overview of the risk analysis approaches and used the risk matrix as a component to build a new framework for risk analysis called HAZWIM (HAZop analysis, What–If analysis and the Risk Matrix). Distinctive industries use different classification boundaries for likelihood and probabilities within the risk matrix which advocate for a sectorial related assessment of risks due to tree failure (see Appendix II). However, some technical complications may arise such as differences in the development of trees, in climatological influences and in the tensile and bending strength of wood. Risks should therefore be presented in a uniform risk matrix on tree failure where the probability on damage is presented as risk parameter based on geographic conditions.

The risk of tree failure expressed as 1:18,899 inhabitant per municipality is also comparable to the risk of experiencing a deadly road accident, which is 1:25,000. It is for sure that this risk is larger than the risk on experiencing an accident with hazardous chemical substances which should never rise above 1:100,000. The risk of a flood in the Netherlands is 1:1,250 years, which is a much smaller risk as the risk on tree failure. These three risks, however are subject to legislation contradictory to tree failure. The current obligation of executing tree risk assessments for municipalities is based on general principles of justice. There is no specific law nor decree that obliges municipalities to execute a tree risk assessment, like there is for other risks. Preventing inhabitants from a flood or an experience of chemical hazardous substances are legally prescribed by decrees or law. A decree to oblige municipalities to execute a tree risk assessment is highly recommendable given the many trees along roads. The information derived from this study may be helpful in answering policy questions concerning the risks of trees in urban areas. For example, policymakers has to think about the question whether there is structural damage (in)directly caused by trees and whether (fatal) injuries happen and, if yes, to what extent? Furthermore, they have to think about the public risk and the acceptability of this risk. Finally, is it useful to keep a record on (fatal) tree-related accidents expressed in financial terms and in terms of health and safety risks?

4.1.4 Analyses of effects and frequencies

At the initial stage of this explorative study when data is incomplete or absent, the uncertainty is partly determined by means of a distribution. The choice of a probability distribution has a large influence on the outcome of the risks (e.g. Poisson versus Triangular). One can question to what extent the effect and frequency can be multiplied with one another, because in a lot of cases the frequency failed financial data. Theory can in those cases provide arguments to support the way of causality and the variables that are taken into account. In this case there are no uncertainties in the design, which means that the uncertainty is purely statistical. An analyses only of the cases where financial data was known made the populations too small to apply a proper statistical analyses, especially the data on personal damage, where often the mean is formed by one observation. The frequency of all cases of personal damage increases the number of cases with personal damage, although it remains small compared to tangible damage.

4.2 Conclusions

This study contributes to the investigations that are based on quantitative figures by collecting data from municipalities and professional stakeholders in this field. Personal damage of tree failure was hardly reported. Besides the initially reported cases, some damage figures came up after repeating questions. This raises questions about to what extent this data is reliable and its completeness. The results of this research on personal damage is therefore not compared to other risks. Concerning tangible damage 1:18,899 persons experiences tree failure. Per square kilometer 1:336 persons experiences tree failure per year. A lightning strike, which occurs 1 to 2 times a year / km^2, with on average 490 inhabitants per km^2 for The Netherlands, is quite comparable to the risk of experiencing tree failure.

4.2.1 Personal damage

The first sub-objective concerns personal damage. The raised question was: what is the frequency of tree-related fatal and non-fatal injuries and the related costs. Figure 1 shows the two different directions of gathering information: first the frequency expressed in the annual number of cases and second the effect expressed in the financial damage of Euro per case. In practice it turned out to be reasonable to make the distinction between claimed compensation and paid compensation. All different sources of information as presented in table 5 could provide some information on the frequency of personal damage. When we regard all the different sources of information as representative for the Netherlands as a whole, the total annual number of cases of personal damage differs between 10 and 15 cases a year. From personal communication with several employees of municipalities and from newspaper articles, it is known that this number is rather low. The cases reported were all made public in the newspapers. On the effect however only some information was revealed from municipalities. The information concerned financial information on 7 cases over an average reported period of on average 11 years per municipality. Resulting in an average for claimed compensation of € 1,017 with a minimum of € 112 and a maximum of € 3,000, and resulting in an average for paid compensation of € 934 with a minimum of € 112 and a maximum of € 3,000. However the limited availability of information on the effect makes that questions can be raised about the use of this information for general purposes.

4.2.2 Tangible damage

The second sub-objective concerns tangible damage. The raised question was: what is the frequency and costs of tree-related damage on immovable and movable assets due to tree failure? The different sources as displayed in table 5 could all provide some kind of information on the frequency or the effect of tangible damage due to tree failure. On average the annual number of cases of tree failure for each municipality is 8. The average claimed compensation equals € 1,336 per case and the average paid compensation is € 1,328 per case. Each year there are 1 to 2 lawsuits concerning damage due to tree failure concerning an average damage of € 8,940 per case with an minimum of € 130 and an maximum of € 61,270. Annually there are on average 5 cases of tree failure on highways with a claimed compensation for damage of € 2,300. Road authorities did not pay any compensation, because of restrictions of liability for governmental organizations under administrative law.

4.3 Further research

4.3.1 Continuing this study

The period of thesis writing does not limit the collection of data, but it does limit the processing of these data in this thesis. Beyond the time constraints of this thesis, data on this topic is still and will be collected and used for further research and publications in this field. To get a better picture on what's going on in this field in the Netherlands, also additional sources could be consulted. It is also possible to extend the data collection to occupational tangible and injury damage.

Municipalities: Most important is to approach more municipalities to obtain a representative sample from all municipalities in The Netherlands. Since only 21 municipalities responded with information and not all municipalities in The Netherlands apply tree risk assessment procedures, it is a justified question how representative the current figures are for The Netherlands. A subgroup analyses of municipalities which do not perform a regular tree risk assessment could give more insight in the frequency an effect of damage due to tree failure.
Insurance companies: Initially there was the plan to incorporate insurance companies as well, we received several confirmations that insurance companies do have data on this topic. However the process of delivering and sharing data is so slow that it was not possible to engage data from insurance companies in this thesis. Concerns of commercial nature might play a role too. Insurance companies are a relevant source for several reasons. Most municipalities and road authorities are insured for damage in general due to liability reasons. For this reason municipalities and road authorities are also insured for damage and (lethal) injuries caused by tree failure. Insurance companies can provide data on costs and claims due to tree failure, where the nature and description of charges might give insight whether and in how far it is related to (fatal) injuries. Almost all municipalities are insured in one insurance company named Centraal Beheer. From municipalities and road authorities we obtained the names of insurance companies in case they differ from Centraal Beheer. Meanwhile the umbrella organization of insurance companies was approached to see up to what extent data of the sector is registered that can provide information on damages or injuries due to tree failure. This information refers to the whole Netherlands.
Road authorities: Several road authorities did not provide information (yet) which do have information on tree failure. In The Netherlands roads are owned by different governmental organizations (Provincial Councils, district water boards) and sometimes even private organizations (housing organizations, individuals). The Provincial Councils do have a registration on claims, including cases of tree failure. The difficulty for the other organizations is often that they can hardly provide data collected by themselves due to the outsourcing of activities. Since the amount of different governmental organizations in The Netherlands is relatively small (12 Provincial Councils, 25 district water boards), this source of information is easy to approach within a limited time. The obtained information refers again to the Netherlands as a whole.
Expert elicitation and Board of Arbitration: In the Netherlands the law[4] describes to consult an expert on technical information. Tree failure is in practice often grouped under expert elicitation. These experts could provide additional information on frequency and effect in lawsuits. The same goes for the Board of Arbitration, which is separated from the Dutch Civil Courts and characterized by its own jurisdiction and jurisprudence. Checking the jurisprudence from the Board of Arbitration might again deliver supplementary information.

4.3.2 Interrelations of this study with other fields

The 21 municipalities that respond to this research all applied a form of tree risk management. However there seem to be municipalities that do not execute any form of tree risk management at all. By incorporating these municipalities, we would be able to make comparisons between the

[4] Article 194 et seq Code of Judicial Procedures

damage that regularly occurs despite the assessment of tree risks and the damage that occurs without any assessment of tree risks. Additionally, it can be determined if indeed trends in the frequency of tree failure over time occur and what factors underlie these developments. This will be a set of social, biological and mechanical influences on trees and the frequency of tree failure.

The survey for this study could be broadened by a request for more information on the age of trees and which (sub)species of trees were involved in cases of tree failure. The thus derived frequency could be a concern for policy makers in the choice of trees species for road plantings and for growers and plant breeders for selecting (sub)species that are less prone to tree failure or varieties which are susceptible for improvement (genetic engineering, breeding). For municipalities this information could create a fundament for future cases of tree failure, which can be expected. This information also could of course be combined with other information on the development and damage which occurs because of tree roots. Other possibilities arise from linking the current database with climatological databases from the Royal Netherlands Meteorological Institute. Besides arboriculturists and tree technicians, municipalities benefit from this information as well. Storms and other extreme climatological conditions restrict the liability of municipalities and thus the obligation to pay compensation for damage caused by tree failure. The link with storms and other extreme climatological conditions could also indicate the quality of tree assessment together with other factors, which is executed by arboriculturists and tree technicians and to the extent municipalities take their responsibility with regard to the safety of inhabitants.

Appendix I

Likelihood rating		Safety and health classifications per author				
Level	**Description**	**Schlechter, 1995**	**Defense, 2000**	**European Commission**	**Reniers, 2005**	**Marhavilas, 2008**
	Super catastrophic	Several fatalities on personnel, damage of > 500 million rand, widespread property damage. One or more fatalities on town residents. Severe national pressure to cease business				Massive deaths damage and production loss > € 1,000,000
I	Catastrophic	One fatality on personnel, damage between 100 million and 500 million rand, considerable property damage. A chance of 1:10 of a fatality on town residents. Severe local and national press to reaction	Could result in death, permanent total disability, loss exceeding $1M, or irreversible severe environmental damage that violates law or regulation.	Injury or consequence that after basic treatment (first aid, normally not by a doctor) does not substantially hamper functioning or cause excessive pain; usually the consequences are completely reversible.	An on-site or an off-site death. Damage and production loss greater than € 750,000	Multiple deaths damage and production loss > € 100,000
II	Critical	A chance of 1:10 of fatal injury on personnel, damage between 10 million and 100 million rand, limited property damage. Hospitalization of town residents. Local press to react	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding $200K but less than $1M, or reversible environmental damage causing a violation of law or regulation.	Injury or consequence for which a visit to A&E may be necessary, but in general, hospitalisation is not required. Functioning may be affected for a limited period, not more than about 6 months, and recovery is more or less complete.	Multiple injuries. Damage and production loss between € 75,000 and € 750,000	Death or multiple injuries damage and production loss between € 10,000 and € 100,000
	Hazardous	Disabling injury for personnel, damage between 1 million and 10 million rand, minor property damage. Complaints of town residents. Minor local reaction.				Time loss or permanent injury damage and production loss between € 1000 and € 10,000
III	Marginal	Non disabling injury for personnel, damage between 100,000 rand and 1 million rand, very minor property damage. No effect on town residents. Little local reaction.	Could result in injury or occupational illness resulting in one or more lost work days(s), loss exceeding $10K but less than $200K, or mitigatible environmental damage without violation of law or regulation	Injury or consequence that normally requires hospitalisation and will affect functioning for more than 6 months or lead to a permanent loss of function.	A single injury. Damage and production loss between € 7,500 and € 75,000	Single injury damage and production loss between € 100 and € 1000

			where restoration activities can be accomplished.			
IV	Negligible	No injuries for personnel, damage < 100,000 rand, no property damage. No effect on town residents. No societal risks or reactions.	Could result in injury or illness not resulting in a lost work day, loss exceeding $2K but less than $10K, or minimal environmental damage not violating law or regulation.	Injury or consequence that is or could be fatal, including brain death; consequences that affect reproduction or offspring; severe loss of limbs and/or function, leading to more than approximately 10 % of disability.	No injuries Damage and production loss less than € 7,500	Slight or no injury damage and production loss < € 100
Sector		Chemical process industries	Department of Defense US	Governance	Chemical industry	Aluminium extrusion industry
Journal		International Journal of Pressure Vessels & Piping	Publication of the Department of Defense US	Directive 2001/95/EC	Journal of Loss Prevention in the Process Industries	Journal of Loss Prevention in the Process Industries

Probability rating		**Safety and health classifications per author**				
Level	**Description**	**Schlechter, 1995**	**Defense, 2000**	**European Commission**	**Reniers, 2005**	**Marhavilas, 2008**
A	Frequent	Could happen as much as 10 times per year, the acceptable frequency is 10 events per year	Likely to occur often in the life of an item, with a probability of occurrence greater than 10^{-1} in that life.	Probability of damage > 50%	Occurs more than once per year	1 event during a time period of Dt< 10^{3} h
B	Probable	Could happen as much as once per year, the acceptable frequency is 1 event per year	Will occur several times in the life of an item, with a probability of occurrence less than 10^{-1} but greater than 10^{-2} in that life.	Probability of damage > 1/10	Occurs between 1 and 10 years	1 event during a time period of 10^{3}<Dt<10^{4} h
C	Occasional	Could happen in 10 years, the acceptable frequency is 1 event per 10 years	Likely to occur some time in the life of an item, with a probability of occurrence less than 10^{-2} but greater than 10^{-3} in that life.	Probability of damage > 1/100	Occurs between 10 and 100 years	1 event during a time period of 10^{4}<Dt<10^{5} h
D	Remote	Could happen once in a lifetime, the acceptable frequency is 1 event per 100 years	Unlikely but possible to occur in the life of an item, with a probability of occurrence less than 10^{-3} but greater than 10^{-6} in that life.	Probability of damage > 1/1,000	Occurs between 100 and 10,000 years	1 event during a time period of 10^{5}<Dt<10^{6} h

E	Improbable	Not happening during lifetime, the acceptable frequency is 1 event per 1,000 years	So unlikely, it can be assumed occurrence may not be experienced, with a probability of occurrence less than 10^{-6} in that life.	Probability of damage > 1/10,000	Occurs less often than once per 10,000 years	1 event during a time period of 10^6<Dt<10^7 h
F	Impossible	Expected never to happen, the acceptable frequency is 1 event per 10,000 years		Probability of damage > 1/100,000	Physically impossible to occur	1 event during a time period of Dt>10^7 h
				Probability of damage > 1/1,000,000		
				Probability of damage < 1/1,000,000		
Sector		Chemical process industries	Department of Defense US	Governance	Chemical industry	Aluminium extrusion industry
Journal		International Journal of Pressure Vessels & Piping	Publication of the Department of Defense US	Directive 2001/95/EC	Journal of Loss Prevention in the Process Industries	Journal of Loss Prevention in the Process Industries

Appendix II

Datum	Plaats	Totaal aantal bomen	Frequentie controle boomveiligheid	Wat is er gebeurd?	Wat is er beschadigd?	Schade	Betaald?	Is er sprake van (dodelijk) letsel? (welke)	Boomsoort

Appendix III

Qualitative articles	Country	Subject of article				
		Tree management	Tree risk assessment methods	Liability	Risk analyses	Education
(Norris, 2005a)	Australia	Reviews maintenance and assessment approaches and its sense from different fields (biological, societal, environmental, engineering, asset management)				
(Manning et al., 2002)	Canada		Describes the determination process of dangerous trees			Considers tree risk assessment training
(Adams, 2007)	Great Britain	Concludes tree risk management as being disproportionally risk averse given the amount of tree related deaths.			Advocates for Fault Tree Analysis and expresses disappointments about Cost-Benefit analysis.	
(Ball, 2007)					Discusses the use of risk based approaches.	
(Eden, 2007)			Advocates for standardizing of Tree Inspection Techniques	Depicts the importance of tree inspection based on jurisprudence		Portrays the different levels of training.
(Ellison, 2007)			Introduces Quantified Tree Risk Assessment (QTRA) a method to determine and quantify acceptable risks			
(Fay, 2007)			Examines tree risks in the UK and the role of QTRA	Explains the influence of judiciary on tree risk assessment	Puts the acceptance of tree related risks into perspective using ALARP-principle and the level of Tolerability of Risk	
(Lonsdale, 2007)		Emphasizes the necessity of a proper tree risk management system to assess fatality.	Pleads for approach on Frequency times Costs to calculate the expected value of loss.			
(Britt and Johnston, 2008)		Proves insight in policies and practices of local urban		Questions whether public concerns on damage and		

		tree management		injuries make trees an asset or liability.		
(Boddy, 2009)		Considers the different British Standards in the UK related to trees				
(Brown and Fisher, 2009)		Provides an overview of advantages and some disadvantages of Trees outside the Woods				
(Forbes-Laird, 2009)				Displays a framework for English jurisprudence on liability due to tree failure		
(Bennett, 2010)				Deliberates on public safety and liability expressed in standards for safety inspections.		
(NTSG, 2011)		The risks from trees and relevant legal cases lead to a reasonable tree risk management in the UK.				
(Barrell, 2012)		Proposes a decision-making framework to meet the responsibility of owners		Evaluates how English courts seem to view harm from the structural failure of trees		
(Hong Kong Government 2012)	Hong Kong		Sets guidelines for tree risk assessment and maintenance			
(Wagner, 1963)	United States	Probably the first article which names the possible hazardous effects of trees, promotes tree safety inspections and measures				
(Paine, 1971)		Evaluates accident hazard control decisions on forest recreation sites.				
(Anderson and Eaton, 1986)		Minimizes liability through three procedures: tree inspection, documentation of inspection, and adoption of other urban forestry practices.		General principles of law courts use, determine who is liable when tree defects result in personal injury or property damage.		

(Costello and Berry, 1991)			Reports urban tree failures of occurrences and species, where personal injuries and property damage may arise.			
(Edberg and Berry, 1999)		Analyses different influences that lead to tree failure based on the database of California Tree Failure Report Program				
(Pokorny et al., 2003)			Informs how to detect, prevent and correct for hazardous effects from trees.			A manual on urban tree risk management for community leaders, administrators, city foresters, parks and public works staff and private tree care practitioners
(Mortimer and Kane, 2004)		This paper closes by addressing various practical means to minimize the risks.		This paper evaluates the U.S. legal context for hazardous trees and the impacts on tree owners.		

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