VOL. 15, NO. 10, MAY 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ASSESSING THE EFFECTS OF STREET TREES ON ASPHALT CONCRETEPAVEMENT PERFORMANCE

Rana Imam
Department of Civil Engineering, The University of Jordan, Jordan
E-Mail: r.imam@ju.edu.jo

ABSTRACT

This research aims at determining whether a correlation exists between trees planted alongside highways and distresses in asphalt concrete (AC) pavements. The root system of the trees could cause significant distress to the pavement depending on the tree's location, tree species, and the spreading of the root system. In this research two models for calculation of the correlation between the root systems and distresses were used: a statistical model and a geospatial model using the ArcGIS software. Twelve types of trees were identified in the study area which comprised of ten urban arterials around the capital, Amman. The Present Serviceability Index (PSI) was adopted as the evaluation criterion and rating measurement of the pavement section, and was calculated based on observations and measurements of the slope variance, rutting, and cracking and patching. From the field survey during the research, it was found that more than 90% of the distresses associated with the trees were longitudinal and transverse cracking. According to the results of the modelling, it was found that only four of these tree types had a correlation value higher than 50% with distresses. The results of the analysis allow proposing guidelines for tree farming along highways in Jordan based on the scientific and research findings.

Keywords: urban farmed trees; asphalt concrete pavements; PSI; pavement distresses; planting guidelines.

1. INTRODUCTION

Maintenance and rehabilitation of highway pavements for the required serviceability is a routine problem and an enormous effort faced by highway engineers and authorities due to a number of distresses that occur in asphalt concrete pavements. The distresses could be caused by a various of reasons, such: as weather conditions, traffic levels, type and quality of materials, underlying soils and geological formations, adequacy of compaction, or other external factors. This research analyzed the impact of the trees' roots on the pavement as one of these factors.

Generally, trees are planted on the road sides and in the median for a number of reasons: they provide the "green belt" that serves the purpose of noise and air pollution abatement, stabilizing the soils and providing the positive aesthetic impact. The benefits of street tree populations in total often exceed their management (McPherson and Muchnick, 2005). However, the root system of trees could cause significant distresses to the pavement layers depending on their location in relation to the highway alignment, type of trees, and spreading pattern of the root system. This study will explore this phenomenon to identify the tree species associated with pavement distresses.

2. LITERATURE REVIEW

Roads are an important asset for any nation. However, it has to be preserved carefully because if not protected and maintained, it deteriorates fast (Reddy *et al*, 2005). Pavement cracks are important information for evaluating the road condition and conducting the necessary road maintenance as each type of crack holds its own weight in pavement maintenance evaluation (Li *et al.,* 2011).

Urban forests improve air and water quality (Heckel, 2004), moderate extreme temperatures (Long-Sheng *et al.*, 1993), reduce energy consumption (McPherson, 1994), increase real estate values (Anton, 2005), provide wildlife habitat (Dunster, 1998), and provide intangible benefits including aesthetic and recreational amenities. The social benefits of trees include reducing stress, encouraging walking and exercise thus improving health, reducing crime and the fear of crime (Kuo and Sullivan, 2001). Street tree populations thus provide many benefits that in total often exceed their management costs (Maco and McPherson, 2002). Yet street trees are often perceived as liabilities due to litter drop, root damage to sidewalks, and visibility and security problems created by blocking signs and lighting (Lohr *et al.*, 2004).

The root systems of different tree species have varying architecture and though some species have a deep tap root which penetrates vertically into the soil, root systems are typically shallow and wide-spreading. It is generally accepted that most roots grow in the upper 30cm of soil, and that they spread well beyond the crown (Gilman, 1990).The soil environment in which trees grow can influence root growth and distribution. Tree roots grow underneath sidewalk pavement when there is oxygen, water and space for them to grow. Roots are very small when they start growing under pavement but then increase in diameter as the tree grows resulting in lifting or cracking of the pavement (Smiley, 2008). As roots expand rapidly, they deform the soil above them, placing tensile stress on the upper surface of overlying pavements (Nicoll and Coutts, 1997). While pavements are strong in compression they are weak in tension, so underlying root growth leads to eventual pavement failure. These conflicts negatively impact both pavements and trees, often necessitating the repair or replacement of both. It is

ARPN Journal of Engineering and Applied Sciences

important to recognize that not all pavement damage is due to underlying roots; engineering faults and underlying soil type can result in cracking, too. (Sydnor *et al*., 2000). Standard pavements are designed to be impermeable for structural purposes, but if they crack, they expose underlying soil to atmospheric conditions such as precipitation and relatively high oxygen concentration (Morgenroth, 2011). D'Amato *et al*. (2002) found that significantly greater root growth was found beneath existing cracks, and suggested that increased soil aeration beneath the crack resulted in greater root growth. In what could be considered a positive feedback loop, root growth causes pavement failure and pavement failure promotes root growth.

3. METHODOLOGY AND RESEARCH APPROACH

The main goal of this study is to determine whether and what type of correlation exists between the root systems of the trees and the Pavement Serviceability Index (PSI). To achieve this goal, the scope of work encompassed a field survey of the trees (type, characteristics, and location), and the distresses (type and location relative to the trees). This was followed by calculating the PSI in order to assess the correlation between the trees type and the PSI by two methods: statistically and geospatially using GIS (Geographic Information System).

3.1 Data Collection

The hypothesis described above defined the requirements for data collection. Ten urban streets were chosen as the most representative in terms of the presence of a large amount and variety of trees in order to increase the sample size and being geographically spread around the city. Based on these criteria the eight selected streets are: Al-Baounieh Street., Al-Hijaz Street, Al-Istiqlal Street, Al-Shaab Street, Al-Urdon Street, Khalil Saket Street, Madina Munawarra Street, Riyadah College Street, Yajouz Street, and Zahran Street.

The data collection comprised of: tree coordinates; tree distance from the curb and/or median; tree circumference; tree height; tree type; distress coordinates; distress type; size of distress (rut depth/length of crack/area of patching); and a photographic survey of trees and distresses. The circumference was measured using a measuring tape at the breast height for further calculations of the tree diameter, which is essential to the modelling of the root systems. Tree height is an important indicator that allows determining the approximate age of the tree and the approximate range of the root system spreading as mentioned in the literature. Tree height was estimated using goniometry; which is the distance walked away from the base of the trunk until the tree's top is seen from an angle of 45°. Finally, the main purpose of the photographic survey of the trees is the identification of the tree type using The Sibley Guide to Trees (Sibley, 2009). Twelve types of trees were identified in the study area, as presented in Table-1.

Table-1. Identified trees in the study area.

Number	Scientific Name	Common Name
1	Acer tataricum	Tatarian Maple
2	Chamaecyparis formosensis	False Cypress
3	Eucalyptus sideroxylon	Eucalyptus Tree
4	Ficus microcarpa	Indian Laurel Tree
5	Fraxinus excelsior	Common Ash Tree
6	Koelreuteria paniculata	Golden Rain Tree
7	Pinus eldarica	Afghan Pine
8	Pineus pinea	Italian Stone Pine
9	Robinia pseudoacacia	False Acacia
10	Styphnolobium japonicum	Pagoda Tree
11	Thuja occidentalis	Arborvitae
12	Washingtonian filifera	California Fan Palm

3.2 PSI Calculation

The Present Serviceability Index (PSI) is a value based on pavement smoothness, rutting, and patching. Pavement serviceability pertains to the ability of a pavement to provide an adequate level of service to the user. PSI ranges from 0 to 5, based on physical distresses, service or ride quality the pavement provides to the user (vehicle or passenger) and rehabilitation needs. In general; a 4-5 PSI value indicates a pavement in a very good condition, while (0-1) PSI value pavement in a very poor condition. A PSI value of 2.5 is considered the boundary between good and poor condition rating when evaluating a pavement's performance (O'Flaherty, 2002). The PSI for Flexible Pavements is calculated as shown in Equation 1.

$$\mathrm{PSI} = 5.03 - 1.91\log(1+\mathrm{SV}) - 0.01\sqrt{\mathrm{C}+\mathrm{P}} - 1.38(\mathrm{RD})^2 \quad (1)$$

ARPN Journal of Engineering and Applied Sciences

where:

PSI = Present Serviceability Index
SV = Slope variance over section
RD = Mean rut depth (in)
C = Cracking (ft /1000 ft^2)
P = Patching (ft^2/1000ft^2)

Asphalt concrete pavements are flexible pavements which reflect the deformation of the subgrade and the subsequent layers to the surface. Flexible pavements transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure. A conventional flexible pavement is a layered system with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low. Starting from the top, the flexible pavement consists of: seal coat, surface course, tack coat, binder course, prime coat, base course, subbase course, compacted subgrade, and natural sub-grade (Huang, 2004).

Slope Variance (SV) is an important parameter for the calculations of PSI. Therefore, it is essential to measure the slopes of the selected streets. The street areas chosen for the assessment were divided into separate sections and levelling was used for measuring of the slopes in the sections. SV in general is the second spatial derivative of height. Equation 2 is used for calculating the SV (Huang, 2004).

$$SV = \frac{\sum_{i=1}^{n}(S_i - \bar{S})^2}{n-1} \quad (2)$$

where:

S_i = i^{th} slope
$\bar{S}$ = average of all slopes, and
n = number of data points.

The types of distresses common in Asphalt Concrete (AC) or flexible pavements are (Huang, 2004): alligator cracking (fatigue), block cracking (temperature cyclic strains), longitudinal and transverse cracking (not load associated), shrinkage and thermal cracking, ravelling (loss of asphalt binder due to hardening), and bleeding (high asphalt content or low air void content). The surveyed streets in this study were divided into sections, for which cracking and patching were surveyed and measured. Cracking is expressed as linear feet and patching as square feet, both per 1000 ft^2 of pavement area. The Mean Rut Depth was measured by a gage to determine the differential elevation between the wheel path and a line connecting two points each (0.6 m) away from the centre of the wheel path in the transverse direction. Rut depth measurements were obtained in both wheel paths and averaged to give the mean rut depth RD. The SV was calculated using Equation 2. The PSI was calculated using Equation 1, and the results for all the street sections are presented in Table-2.

VOL. 15, NO. 10, MAY 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Table-2. PSI calculation.

Section #	Crack Length (m)	Patch Area (m^2)	Length of the Section (m)	Area of the Section (m^2)	RD (in)	SV	PSI
Al-Baounieh Street							
1	4.67	24	37	370	0.59	0.52	4.12
2	7.6	0	26	195	0.32	0.66	4.41
3	3.4	0	45	337.5	0.16	1.04	4.38
4	10.6	60	54	540	0.22	0.26	4.66
5	35.2	59.5	36	270	0.21	0.3	4.57
6	2.8	44	60	450	0.30	0.49	4.48
Al-Istiqlal Street							
1	26	22	40	400	0.15	4.36	4.36
2	3.85	0	34	340	0.32	4.45	4.45
3	2.16	0	25	250	0.28	4.58	4.58
4	4.6	36	37	370	0.13	4.48	4.48
5	12.4	64	31	310	0.16	4.59	4.59
6	8.15	0	31	310	0.43	4.23	4.23
7	5.5	0	58	580	0.29	4.46	4.46
Al-Hijaz Street							
1	25	79	30	300	0.22	0.47	4.45
2	13.5	28.2	35	350	0.24	1.3	4.16
3	10.75	0	55	550	0.19	0.45	4.63
Madina Munawarra Street							
1	7.3	17	42	420	0.15	1.36	4.22
2	7.9	56	36	360	0.25	1.63	4.01
3	10.8	0	30	300	0.22	1.58	4.12
4	4.4	0	35	350	0.21	0.93	4.39
Al-Urdon Street							
1	5.5	0	40	200	0.22	1.25	4.25
2	5.4	0	30	150	0.18	0.95	4.38
3	5.8	9	22	110	0.32	2.62	3.71
4	3.4	4	28	140	0.17	1.63	4.12
5	2.9	9.5	20	100	0.14	2.27	3.91
6	10.5	7.8	32	160	0.26	1.41	4.11
7	10.3	0	34	170	0.24	1.25	4.21
8	14	0	45	225	0.25	2.12	3.93
9	2.5	0	44	220	0.19	1.53	4.18
10	3.5	10.5	35	175	0.33	0.95	4.24
Al- Shaab Street							
1	20.2	0	50	400	0.21	0.48	4.58
2	4.1	0	44	352	0.35	0.63	4.43
3	10	3.7	80	640	0.22	0.65	4.51

Section #	Crack Length (m)	Patch Area (m^2)	Length of the Section (m)	Area of the Section (m^2)	RD (in)	SV	PSI
4	23	14	37	296	0.16	0.25	4.70
5	2.2	0	36	288	0.17	0.86	4.45
6	36	13	78	624	0.18	0.29	4.69
7	44	0	85	382.5	0.15	0.67	4.47
8	8.2	0	64	288	0.17	1.39	4.22
9	12.2	6.6	67	301.5	0.24	1.39	4.15
Queen Rania Street							
1	40	0	29	145	0.24	2	3.88
2	5.4	14	29	145	0.21	0.96	4.3
3	24	3.6	25	125	0.16	0.96	4.29
4	10	13.65	30	150	0.24	1.71	4.03
5	2.4	1	30	150	0.22	2.22	3.95
6	5	0	33	165	0.15	2.88	3.82
7	6.5	0	35	175	0.17	0.69	4.50
8	10.2	0	28	140	0.19	2.08	3.97
9	6.4	8	27	135	0.25	1	4.27
10	3.3	4.5	25	125	0.28	0.5	4.51
11	20	3	25	125	0.19	1.42	4.12
Sports College Street							
1	12	0	25	200	0.18	8.05	3.09
2	20	14	25	200	0.25	11.17	2.75
3	15	23	25	200	0.22	15.07	2.53

3.3 Assessment of Root Systems

The published literature identifies three main types of root systems depending on their basic three-dimensional form as follows (Stokes and Mattheck, 1996):

a) A 'heart system', the most common type of root system, where multiple branches and horizontal and vertical laterals develop from the base of the tree. Examples include: Birch, Beech, Larch, Lime, Common Ash, Acacia and Norway Maple.
b) 'Plate systems' consist of horizontal lateral roots spreading out from the base of the tree stem just below the soil surface, from which small roots branches spread down vertically. Examples of this type include Eucalyptus and Pine trees.
c) 'Tap root system' where a strong main root descends vertically from the underside of the trunk. Examples of this root system include: Arborvitae, English Oak, and Silver fir.

3.4 Methods of Root Spreading Estimation

In order to estimate the root systems of the trees in the study area, the most applicable approach is to estimate the tree height and the tree diameter. For the horizontal spreading of the roots, two approaches were described in previous reviewed studies:

a) Estimating the radius of the root system according to the tree height (Pregitzer, 2002):
   - For deciduous trees - the ratio between the roots radius and the tree height is 1.5:1. For the purposes of the present study, the assumption has been made that the root system spreads horizontally in circular mode equally in all directions. The trees that this applies to are: Common Ash, Eucalyptus, False Acacia, Golden Rain Tree, Indian Laurel, Pagoda Tree, and Tatarian Maple.
   - For the fir trees, the ratio is 1.2:1. The trees in this category are: False Cypress and Italian Stone Pine.
   - For the palm trees, the studies indicate that there is no correlation between the tree height and the horizontal spreading of roots. It is better estimated based on the radius of the canopy, ratio is 1:1.

b) Another approach described in literature is the estimation of the radius of the root system based on the diameter of the tree trunk (West *et a*l., 1999). For young trees [less than approximately 8 in (20 cm) in diameter], the ratio of root radius to trunk diameter in the documented studies was about 38 to 1. For elder trees, the ratio is 6:1, since all the species of trees in the study are considered tolerant to the climatic conditions; otherwise, the ratio is 18:1 for sensitive species.

As for the vertical spread of the root system, the soil in Amman belongs to the compacted clayey soils; therefore, most of the root system would be in the top 60 - 70 cm from the surface.

3.5 Correlation between the Root Systems and PSI

The study took into consideration the spreading of the root systems at present for all the trees, and after 25 years for the trees that are planted relatively recently and quite young. The value of 25 years was chosen as it is the pavement service life before decommissioning or refurbishing is required. Two methods were used for modelling of the correlation between the root systems and the PSI: a mathematical model and a geospatial model.

The most commonly used techniques for investigating the relationship between two quantitative variables are correlation and linear regression. Correlation quantifies the strength of the linear relationship between a pair of variables, whereas regression expresses the relationship in the form of an equation. Table-3 shows the main factors that are expected to affect pavement cracks and the correlation between every pair of factors using the SPSS software.

Table-3. Correlation between the root systems and distresses.

Variable 1	Variable 2	Correlation
Horizontal roots	Distance of tree to pavement	0.71
Distance of tree to pavement	Length of the cracks	0.87
Distance of tree to pavement	Horizontal roots after 30 years	0.80
Horizontal roots after 30 years	Length of the cracks	0.43

Table-3 shows the strongest correlation is between the position of the tree and the severity of pavement distresses (length of cracks). The total sample size for the present research was 274 trees in a total of 10 streets. Furthermore, the correlation was calculated between the individual type of trees and the pavement distresses and the main findings are shown in Table-4.

Table-4. Correlation between the root systems and distresses at present.

Type of Tree	Percentage of Cracks Associated with the Tree
False Cedar	80% at least
Italian Stone Pine	More than 70%
California Fan Palm	More than 50%
False Cypress	More than 50%
Golden Rain Tree	35%
Eucalyptus Tree	30%
Pagoda Tree	10%
Common Ash Tree	Potentially in future, at present all trees are not fully matured
Afghan Pine Tree	Not conclusive
Tatarian Maple	Not conclusive
False Acacia	Not conclusive
Indian Laurel	Not conclusive

Although the roots of some types of trees have a rather strong impact on the pavements in terms of potentially generating the large number of distresses, thus increasing the cost of the regular pavement maintenance, correlation between the trees and PSI is not significant for 90% of the study area. Only for one street, Sports College, the significant level of correlation exists. The correlation between every type of trees and PSI in the study area is presented in Figure-1.

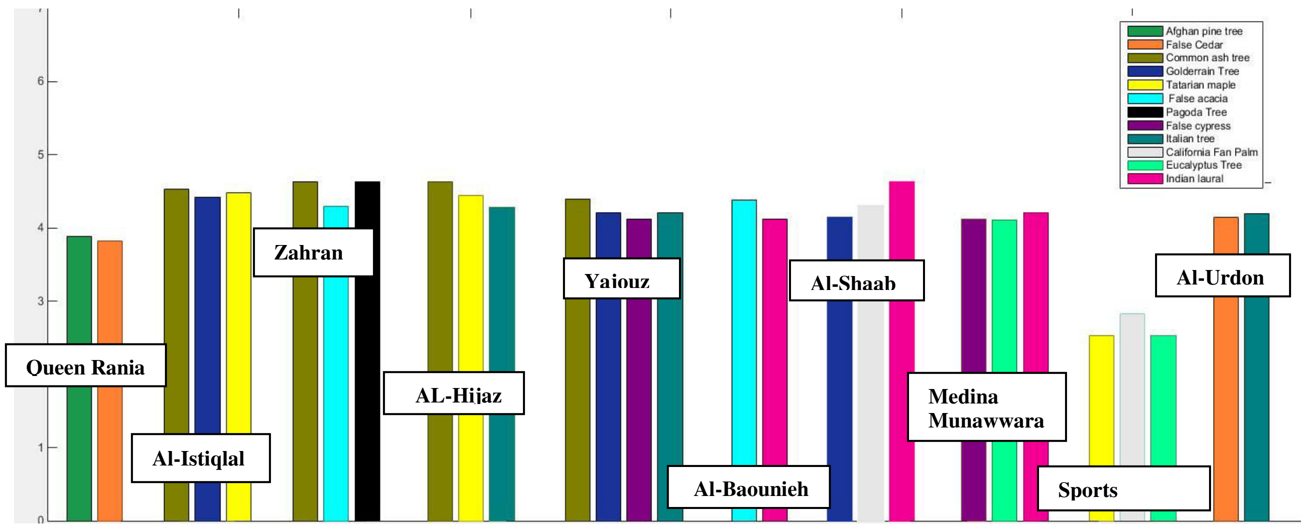

Figure-1. Correlation between the tree types and PSI.

3.6 Geospatial Model

In order to visualize the spatial relationship between the roots and the distresses, the ArcGIS software was used. GIS is a contextual tool for mapping and spatial reasoning that can be used to explore data and share location-based insights. The identified trees and distresses were mapped, using the World Geodetic System (WGS84) as its reference coordinate system. Upon calculation of the approximate radius of the root systems the polygons with the same radius as a root system were drawn around the trees that had distresses in close proximity to them. Using the coordinates collected during the field study, the maps for each street of the study area were prepared. For example, Figure-2 represents the GIS map of Al-Hijaz Street.

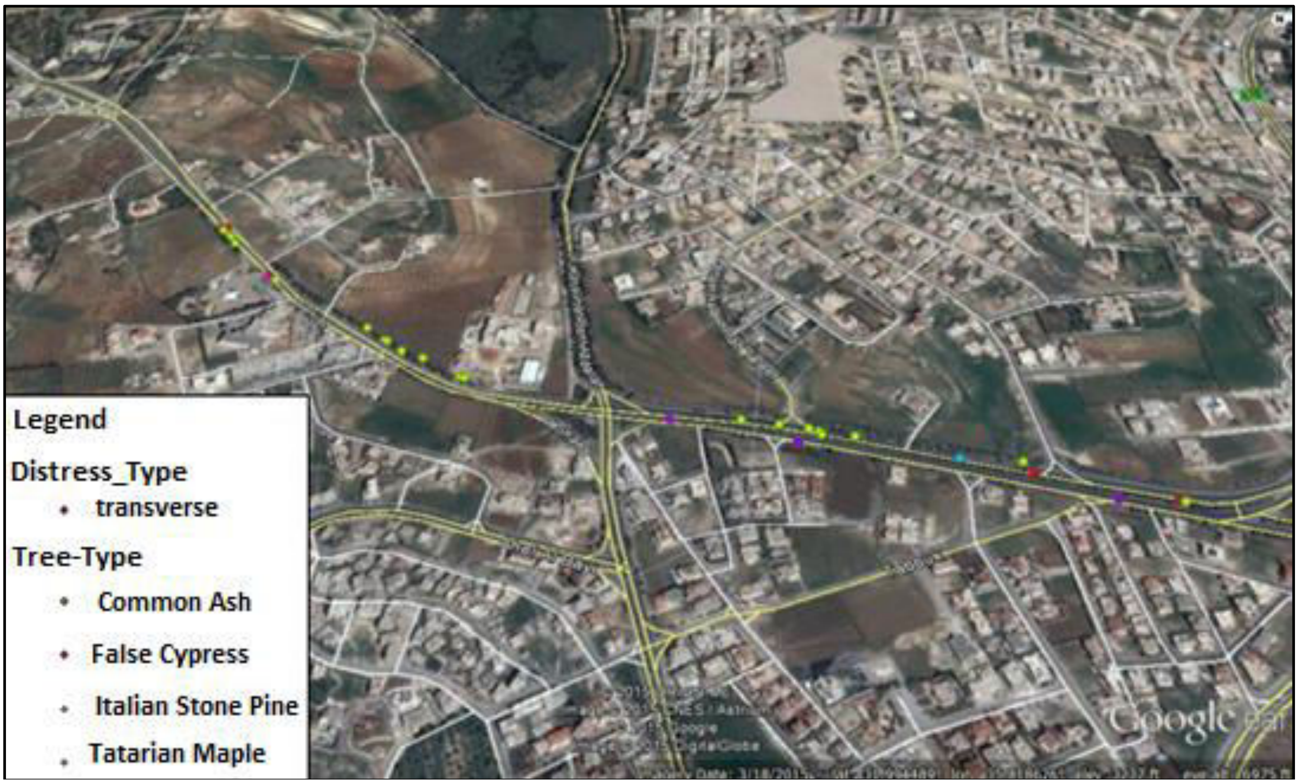

Figure-2. Al-Hijaz street.

4. RESULTS AND DISCUSSIONS

Due to the inability to physically investigate the root systems and in order to minimize the number of variables in the calculations, a number of assumptions were made in the study. To start with, the horizontal spreading of the tree roots was assumed to be in a circular mode equally in all directions. Also, the pavement service life is assumed to be 25 years before decommissioning or refurbishing is required.

The majority (almost 95%) of the identified pavement distresses were longitudinal and transverse cracks. These types of cracks are not usually load associated, which are caused by the shrinkage of asphalt surface due to low temperatures or to asphalt hardening. In this case, it is resulted from reflective cracks caused by the roots beneath the asphalt surface. In thin pavements, cracking starts at the bottom of the bituminous layer where the tensile stress is the highest and then it spreads to the surface as one or more longitudinal cracks. In thick pavements, the cracks usually commence from the top because of high localized tensile stresses from tire-pavement interaction. Transverse cracks are usually formed as a result of thermal movement. It may also occur because of shrinkage of the bituminous surface due to low temperatures or asphalt binder hardening.

Table-5. Correlation of the root systems and distresses by the two modelling methods.

Type of Tree	Percentage of Distresses Associated with Trees		% Difference
	SPSS Modelling	Geospatial Modelling	
California Fan Palm	50%	53.76%	3.76%
False Cedar	80%	78.40%	1.60%
Eucalyptus Tree	30%	31.10%	1.10%
Golden Rain Tree	35%	32.42%	2.58%
False Cypress	50%	46.13%	3.87%
Pagoda Tree	10%	7.03%	2.97%
Italian Stone Pine	70%	74.86%	4.86%

For the present study, the level of confidence was assumed to be 95% and the sample distribution was considered random. The margin of error was calculated as 0.02. For the sample size of 274 trees the acceptable percentage of error is 5.48%. As seen from Table-5, the results obtained by the two methods are similar to each other and are within the margin of error range of 5.48%.

5. CONCLUSIONS AND RECOMMENDATIONS

The study established that there is a very strong correlation between the root systems of trees of certain types and the distresses in the AC pavements if the trees are planted in close proximity to the pavement, or the distance between the trees and the pavement is decreased due to the road expansion. The trees that were found to be associated with the distresses are:

- California Fan Palm is associated with the cracks independently of age: on Queen Rania Street the elder trees were associated with more than 50% of cracks, while in the area of Al-Istiqlal Street, the younger palm trees (max. 2.3m height) are associated with 100 % of cracks.
- False Cedar is found on Queen Rania Street and Al-Urdon streets, where the percentages of distresses is 85% meaning False Cedar tree is strongly associated with distresses in pavements.
- False Cypress causes distress in 47% percentage of cracks on Yajouz and Madina Munawwara streets.
- Eucalyptus Tree is associated with distresses in Sports College and Madina Munawwara streets at about 30%.
- Tatarian Maple, False Acacia, Afghan Pine and Indian Laurel trees are found in very small amounts in the study area, their sample size is considered too small to provide conclusive results.
- Common Ash trees in all the study area are relatively young; consequently their root systems was relatively small at present. However, based on the calculations for future root spreading, they potentially might have an impact on road pavement upon reaching mature size. Similar findings are for the Golden Rain tree type.
- The results of Pagoda Tree effects on the pavement are similar to the results for False Cypress Tree.
- Italian Stone Pine Tree is strongly associated with the pavement distresses - approximately 50% in all locations it was found in.

Planners should consider that the more compacted underlying materials are, the greater is the likelihood that tree roots will spread close to the surface, thereby damaging the pavement layers. It follows that trees to be planted along streets in the future require more space and less compacted soil to reduce the risk of damage. Considering that the proportion of trees causing damage was relatively small, the corresponding sample size per species is also rather small. This makes a statistical analysis rather challenging. Therefore, the author recommends enlarging the study area and focusing on a specific group of trees to increase the sample size and obtain more conclusive results. Such studies should also assess tree trunk and root flare developments to provide a better understanding of root growth and development, particularly under pavements as well as the interaction of the roots and trunk flare with pavements.

REFERENCES

Anton P.A. 2005. The Economic Value of Open Space: Implications for Land Use Decisions. Wilder Research.

D'Amato N.E., Sydnor T.D., Knee, M., Hunt R. and Bishop B. 2002.Which Comes First, the Root or the Crack? Journal of Arboriculture. 28(6):277-289.

Dunster J.A. 1998. The Role of Arborists in Providing Wildlife Habitat and Landscape Linkages throughout the Urban Forest. Journal of Arboriculture. 24(3): 160-167.

Gilman E.F. 1990. Tree Root Growth and Development. I. Form, Spread, Depth and Periodicity. Journal of Environmental Horticulture. 8(4): 215-220.

Heckel P.F. 2004. Using Trees to Mitigate Pollution. In: Air and Waste Management Association's Annual Meeting and Exhibition. pp. 4019-4031.

Huang Y. H. 2004. Pavement Analysis and Design. 2nd Edition, Prentice Hall, New Jersey, USA.

Kuo F.E. and Sullivan W.C. 2001. Environment and Crime in the Inner City - Does vegetation Reduce Crime? Environment and Behaviour. 33(3): 343-367.

Li Q., Zou Q. and Liu X. 2011. Pavement Crack Classification via Spatial Distribution Features. EURASIP Journal on Advances in Signal Processing. 649675(2011), DOI:10.1155/2011/649675.

Lohr V.I., Pearson-Mims C.H., Tarnai J. and Dillman D.A. 2004. How Urban Residents Rate and Rank Benefits and Problems Associated with Trees in Cities. Journal of Arboriculture. 30(1): 28-37.

Long-Sheng M., Yong G. and Wen-Quan S. 1993. Influences of Street Tree Systems on Summer Micro-Climate and Noise Attenuation in Nanjing City, China. Arboricultural Journal. 17(3): 239-251.

Maco S.E. and E.G. McPherson. 2002. Assessing Canopy Cover over Streets and Sidewalks in Street Tree Populations. Journal of Arboriculture. 28(6): 270-276.

McPherson E.G. 1994. Using Urban Forests for Energy Efficiency and Carbon Storage. Journal of Forestry. 92(10): 36-41.

McPherson E.G. and Muchnick J. 2005. Effects Of Street Tree Shade On Asphalt Concrete Pavement Performance. Journal of Arboriculture. 31(6): 303-310.

Nicoll B.C. and Coutts M.P. 1997. Direct Damage by Urban Tree Roots: Paving the Way for Less Damaging Street Trees. In: Arboricultural Practice, Present and Future. Edited by J. Claridge. Department of the Environment, Transport and the Regions, UK. pp. 77-84.

O'Flaher, C. A.2000. Highways: The Location, Design, Construction & Maintenance of Road Pavements. 4th Edition, Butterworth Heinemenn, Oxford, UK.

Pregitze K. 2000. Fine Roots of Trees - A New Perspective. New Phytologist.154(2): 267-273.

Reddy B.B., Sharma R. S. and Veeraragavan A. 2005. Development of Flexible Pavement Preservation Framework for an Integrated Asset Management. Journal of Indian Roads Congress. 66(1): 383-418.

Sibley D. 2009. The Sibley Guide to Trees, Knopf Publishing Group, New York.

Smiley E.T. 2008. Comparison of Methods to Reduce Sidewalk Damage from Tree Roots. Arboriculture & Urban Forestry. 34(3): 179-183.

Stokes A. and Mattheck C. 1996. Variation of Wood Strength in Tree Roots. Journal of Experimental Botany. 47(5): 693-699.

Sydnor T.D., Gamstetter D., Nichols J., Bishop B., Favorite J., Blazer C. and Turpin L. 2000. Trees are Not the Root of Sidewalk Problems. Journal of Arboriculture. 26(1): 20-29.

West G. B., Brown J.H. and Enquist B.J. 1999. A General Model for the Structure and Allometry of Plant Vascular Systems. Nature. 400, pp. 664-667.