Factors associated with root failure in the June 2013 Minneapolis storm

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February 11, 2014

Background and Goals:

The June 2013 storm in Minneapolis offered an opportunity to study factors that were associated with root failure. The questions of interest were:

- Is replacement work associated with increased root failure?
- Does this association depend on the tree species, boulevard width, tree size, or soil quality?

Because all of this data is observed from a single storm, care should be used in extrapolating results to future storms; it is perhaps best to think of this study as a case study for this particular storm rather than a conclusive report on the causes of root failure.

Study Design and Data Collection
Researchers visited every block where two or more trees experienced root failure, and recorded measurements on every tree on those blocks, as well as some measurements for each block.

Data collected at the tree level

- Root failure (yes or no)
- Block (BSS)
- Tree genus and species
- Diameter at Breast Height (DBH); this was estimated from stump size when needed
- Boulevard width (feet); only for trees with root failure
- Length of replaced sidewalk (feet)
- Length of replaced curb (feet)
- Utility repaving (yes/no)
- Street replacement (yes/no)

Data collected at the block level:

- Penetrometer readings at 6 and 12 feet
- Percent organic matter
- Percent sand, silt, and clay

The data set contained 3076 trees on 122 blocks. The primary response was root failure; this occured in 367 of the 3076. Trees were grouped into five categories by Genus, using the four largest genuses, and then grouping the remaining trees in an "other category". There were 1365 Tilia, 940 Fraxinus, 289 Acer, 229 Ulnus, and 253 Other. DBH values were centered around the mean for each category separately. For analysis purposes, the boulevard width was log-transformed, as the distribution was skewed to the right. Boulevard width was calculated for each BSS using the average of the values for which it was collected. For street work, a combined variable denoting any replacement work was calculated; it denoted when the length of replaced sidewalk > 0, length of replaced curb > 0, any utility repaving, or any street replacement was done. Of the 3021, 945 had sidewalk, 2 had curb, 54 had utility repaving, and 14 had street replacement; a combined 979 had any replacement work done. Because of the relatively small numbers of curb, utility, and street replacement, these variables were not considered separately; only the combined variable was used. For penetrometer 12, an additional binary variable was included to indicate if the reading was able to be made at all; as this missing value was informative and meant that it was very hard soil.

Analysis:
To investigate which variables were associated with root failure, generalized logistic mixed modeling was used, with root failure as the response and BSS as a random effect. Several models were fit to explore the various predictors, and the most parsimonious model was chosen to explore further. First, the primary predictors, replacement work, boulevard width, DBH, and Genus group, were considered, along with all two-way interactions. Non-significant terms were excluded, and the resulting model compared using AIC with the full model. Secondary predictors of penetrometer reading (at both 6 and 12), and percent organic matter, sand, silt, and clay, were then added to this model, along with interactions with genus group and replacement work done. Each variable was considered separately; only the two penetrometer reading terms were significant. Since they gave similar model fits and are known to be correlated, the penetrometer reading at 6 was chosen for inclusion as then the additional binary variable was unneeded. The final model included replacement work and Genus group, as well as boulevard width, DBH, the penetrometer reading at 6, and their interactions with replacement work.

Results:
The major finding is that having replacement work done increased the odds of root failure by 2.24 times (95% CI: 1.77, 2.83; $p<0.0001$). For illustration, when no replacement work was done, the average Tilia had a 10.6% chance of root failure; this increased to 21.0% when replacement work was done.

The genus of the tree was also significant ($p<0.0001$), even after adjusting for the average DBH of each group. Compared with Tilia, which was considered the baseline genus, Fraxinus had a decrease in odds of root failure of 0.94 times (95% CI: 0.73, 1.21); Acer of 0.47 (95% CI: 0.29, 0.77), Ulmus of 0.39 (95% CI: 0.22, 0.69) and other of 0.22 (95% CI: 0.11, 0.46). For illustration, Fraxinus had a 10.0% chance of root failure when no replacement work was done, compared with a 20.0% chance when it was done; for Acer these were 5.3% and 11.1% respectively, for Ulmus, 4.4% and 9.4%, and for other, 2.6% and 5.6%.

Boulevard width was found to have a significant interaction with replacement work ($p=0.011$). When work was done, an increase in boulevard width of 1.42 times (one standard deviation) reduced the odds of root failure by 0.64 (95% CI: 0.49, 0.84; $p=0.001$). For illustration, two otherwise average Tilia on streets with widths of 3.94 and 7.99 (one sd up and one down from the geometric mean) have a 29.4% and 14.6% chance of failure, respectively, when work is done. However, when no replacement work done, boulevard width was not significant ($p=0.50$).

DBH was also found to have a significant interaction with replacement work ($p=0.008$). In this case, when no replacement work done, an increase in DBH of 6.77 (one sd) increases the odds of root failure by 1.27 times (95% CI: 1.08, 1.51; $p=0.005$). So two otherwise average Tilia with DBH of 8.2 and 21.7 (one sd up and one down from mean) has 8.5% and 13.2% chance when no work was done. When replacement work was done, DBH was not significant ($p=0.29$).

Penetrometer at 6 units deep also had a significant interaction with replacement work ($p=0.019$). When no replacement work done, an increase in penetrometer reading increases the odds of root failure by 1.10 (95% CI: 0.95, 1.28, $p=0.20$), but when replacement work is done, the odds decrease by 0.84 (95% CI: 0.71, 1.00, $p=0.045$). So two otherwise average Tilia with penetrometer readings of 204 and 516 (one sd up and one down from the mean) have a 9.7% and 11.6% chance of failure when no work was done, but a 24.1% and 18.3% chance of failure when work was done.