Roof Proactive Maintenance Policies

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ABSTRACT

The study proposes an approach to assist facility managers in establishing a proactive roof maintenance plan. Two methodologies, Historical Maintenance Data Analysis (HMDA), and Roof Service Life Prediction (RSLP) are used in this research. HMDA hypothesizes that a mathematical model can predict the chance of potential roof leak causes. The RSLP is based on the assumption that the first-time leak has a linear relationship with the estimated service life (ESL) of the roof.

This research demonstrates that roof maintenance records can be used to identify factors that are likely causes of roof leaks in a mathematical model. Roof leaks are not totally random events and can be predicted. Three parameters (Age, Workmanship, and Roof Repair) have a significant impact on the roof leak's odds. The 'Factor Method' performed in the RSLP confirms the existence of linear relationships between the ESL and the first-time leak. The extents of correlation are found to be low to medium.

The ESL provides a reasonable estimation of a roof maintenance-free period. When ESL information is used in conjunction with knowledge obtained from HMDA, the new synthesis of knowledge will enable the facility maintenance professional to develop and schedule a proactive roof maintenance plan.

Keywords : Roof Maintenance Management, Proactive Maintenance, Factor Method, Logistic Regression Analysis

บทคัดย่อ

งานวิจัยชิ้นนี้ทำขึ้นเพื่อเสนอแนวทางให้ผู้บริหารอาคาร หรือที่ทราบกันดีภายใต้ชื่อ Facility Manager (FM) ใช้ในการวางแผนดูแลรักษาหลังคาของอาคารในเชิงรุกโดยใช้การศึกษาสองวิธี วิธีแรกคือการวิเคราะห์ข้อมูลที่เกี่ยวข้องทั้งจากเอกสารอ้างอิงต่างๆ, เอกสารการซ่อมบำรุง (หลังคาจริง), และการสัมภาษณ์ผู้บริหารอาคารที่มีอายุงานมากกว่า 10 ปี เพื่อระบุสาเหตุหลักของหลังคารั่ว และวิธีที่สองโดยการใช้แนวความคิดของ การคาดคะเนอายุของวัสดุ หรือส่วนประกอบของอาคาร (Service Life Prediction) โดยใช้ข้อมูลของหลังคาจริง และใช้การวิเคราะห์ทางสถิติเพื่อช่วยในการหาคำตอบในทั้งสองวิธี ในวิธีการแรกนั้น ผู้ศึกษาได้ตั้งสมมติฐานว่า การใช้วิธีการจำลองทางคณิตศาสตร์อาจจะสามารถช่วยในการทำนายถึงสาเหตุหลักที่ก่อให้เกิดปัญหาหลังคารั่ว สำหรับวิธีศึกษาวิธีที่สองนั้นยืนอยู่บนข้อสมมติฐานที่ว่า การเกิดหลังคารั่วครั้งแรกนั้น มีความสัมพันธ์เป็นเชิงเส้นตรงกับอายุการใช้งานของหลังคา ยกตัวอย่างเช่น หลังคาที่มีการคาดคะเนอายุการใช้งานนานกว่า การเกิดการรั่วครั้งแรกก็จะเกิดช้ากว่าหลังคาที่มีการคาดคะเนอายุการใช้งานน้อยกว่า

งานวิจัยชิ้นนี้ได้แสดงให้เห็นว่า ข้อมูลของการซ่อมบำรุงหลังคานั้นสามารถที่จะนำมาใช้เพื่อระบุถึงสาเหตุของปัญหาหลังคารั่วได้โดยการใช้การจำลองทางด้านคณิตศาสตร์ และยังได้พิสูจน์อีกว่า การรั่วของหลังคามิใช่เหตุบังเอิญ ในทางตรงกันข้าม เราสามารถที่จะทำนายการเกิดของหลังคารั่วได้โดยดูจากปัจจัยหลักๆสามประการ คือ 1 อายุของหลังคา 2 คุณภาพฝีมือของผู้ติดตั้ง และ 3 ความถี่ของการซ่อมบำรุงหลังคา ซึ่งปัจจัยทั้งสามตัวนี้มีผลอย่างมากต่อการเกิดหลังคารั่ว วิธีการศึกษาที่เรียกว่า “Factor Method” ซึ่งถูกใช้ในการศึกษาในส่วนที่สองนั้น ได้ยืนยันความสัมพันธ์เชิงเส้นตรงระหว่างการคาดคะเนอายุการใช้งานของหลังคา และการเกิดหลังคารั่วครั้งแรก จากการศึกษาพบว่า ความสัมพันธ์ของการคาดคะเนอายุการใช้งานกับการเกิดหลังคารั่วครั้งแรกนั้นมีค่าต่ำถึงปานกลาง

การคาดคะเนอายุการใช้งานของหลังคาช่วยทำให้ผู้ดูแลอาคารค่อนข้างมั่นใจได้ว่าหลังคาที่มีการคาดคะเนอายุการใช้งานยาวกว่าจะไม่ประสบปัญหาการรั่วซึมในช่วงอายุเริ่มต้นของหลังคานั้นจะยังไม่ประสบกับปัญหาการรั่วซึม ดังนั้นจึงอาจจะยังไม่ต้องได้รับการดูแลรักษาอย่างเข้มงวดนัก เมื่อนำข้อมูลการคาดคะเนอายุนี้มารวมกับข้อมูลที่ได้จากการศึกษาข้อมูลประวัติการซ่อมบำรุงของหลังคาแล้ว ผู้ดูแลอาคารก็สามารถที่จะจัดทำตารางช่วงเวลาของการดูแลรักษาหลังคาเพื่อป้องกันการรั่วของหลังคาได้ตรงกับความจำเป็นโดยไม่ต้องรอให้หลังคารั่วเสียก่อน ซึ่งเมื่อรอถึงจุดนั้นการซ่อมบำรุงอาจจะเป็นไปได้ยาก และเกิดความเสียหายมากกว่าที่มองเห็น

คำสำคัญ : การจัดการการบำรุงรักษาหลังคา, ปัจจัยการรั่วของหลังคา

1 MOISTURE PROBLEMS IN BUILDINGS

Moisture problems in building envelopes are common and universal. They affect all building types and geographical regions (Nevalainen, Partanen et al. 1998; Rao 2005). Moisture accumulation causing bio-contamination in buildings has been associated with numerous mold-induced personal health problems (Oliver 1997; Rivin 2001; Haverinen, Vahteristo et al. 2003). Litigation related to water damages is also on the rise; a triple digit increase of lawsuits in commercial buildings has been observed (Rivin 2001; Smith 2002; Silicato 2003). Uncontrolled moisture causes visual, as well as physical damage, to buildings. Damages caused by moisture include component disfiguration, dimensional changes, rotting, decay, mold, and corrosion. The unexpected deterioration can result in a shorter functional service life of building parts leading to a premature failure of the structure (CRDBER-1; IFMA 2003).

2 THE RESEARCH PROBLEM AND SCOPE

The research problem originates from facility managers' major concerns regarding sick building syndrome and other impacts from moisture-related problems. Recent studies have reported principal factors and conditions contributing to building mold growth (Rivin 2001; Rodriguez 2002). One conclusion, similar to the U.S. Environmental Protection Agency (EPA), is that indoor mold growth can be controlled by managing moisture that enters facilities (Ricketts 1999; Rivin 2001; U.S.E.P. Agency 2003). Compared to other portions of building envelopes, roofs are much less durable, less energy-efficient, and more trouble-prone (Miller and Desjarlais; Wilson 1984). Roof problems, especially roof leaks, not only disrupt building operations, but can also contribute to the occurrence of severe internal Indoor Air Quality (IAQ) problems and sick building syndrome (Oliver 1997; Rivin 2001; Haverinen, Vahteristo et al. 2003).

The scope of this study is therefore limited to roof leak problems especially in the low-slope, single-ply roofing system used in the continental U.S., with the exception of Alaska, Hawaii, and California. Water penetration through roofs, especially from rain and snow, is the focus of this study. This research employs an empirical technique using in-use data to try to explain the potential for roof leaks caused by human involvement.

3 ROOF MAINTENANCE AND ROOF LEAKS

One of the well-accepted causes of roof leaks is the lack of roof maintenance (Lounis, Vanier et al. 1998a). The out-of-sight, out-of-mind nature of a roof's location, misjudgment regarding roof warrantees, and a lack of relevant roof maintenance information are among the reasons contributing to a reactive roof maintenance plan. The associated costs of repair due to roof problems can be a substantial. According to the General Office Audit of Canada, the conservative estimate for roof repair is 30 to 35 percent of all annual repair expenditures (Lounis, Vanier et al. 1998a).

Building roofs, similar to other building components, regularly experience insufficient funding and lack of crucial maintenance information. For some organizations, roof maintenance plans are proprietary, reactive, or too generic in nature. Many plans and schedules formulated for maintenance often fail due to the complexity and unpredictability of the environment (Cohen and Cohen 1983). Due to this, roofing-related decisions are typically made with incomplete information, and, therefore, approximately 85% of roofs are replaced unnecessarily (IFMA 2003). With ownership costs on the rise, building owners now realize that, only when effective tools are in place, the cost for maintenance will be reduced and service will be less disruptive (Arditi and Nawakorawit 1999a; Shohet, Puterman et al. 2002).

4 RESEARCH METHODOLOGY

The goal of the study is to provide facility managers with critical information to proactively and effectively manage their roofs using two research methodologies. The first approach, Historical Maintenance Data Analysis (HMDA), comprehensively collects the potential root causes of roof leaks, investigates, and pinpoints the significant leak contributor using roof maintenance records. The one-on-one expert interview is performed to explore and understand roofs and how human involvement with roofs can lead to potential problems. A literature review is conducted simultaneously to gather initial information and to supplement knowledge gathered from the expert interviews. Following this approach, a mathematical model has been developed to identify relationships of leak causes and leak incidences and to predict the risk of roof leaks within the first three years of roof lives.

The second approach, Roof Service Life Prediction (RSLP), investigates the applicability of the 'Factor Method', proposed by the International Organization for Standard (ISO) in roof maintenance management. The use of RSLP for leak prediction hypothesizes that the first-time leak has a linear relationship with the estimated service life of the roof. The second goal of this research seeks to investigate the claim that service life prediction can improve the maintenance program's reliability and effectiveness (Shohet and Paciuk 2006). A detail of 'Factor Method' methodology can be found in the ISO 15686-8.2 'Buildings and constructed assets-Service life planning-Part8: Reference service life and service-life estimation' document. To estimate the service life of components, the following formula is used (ISO 2000; ISO 2006).

$$ESLC = RSLC \times FC\ A \times FC\ B \times FC\ C \times FC\ D \times FC\ E \times FC\ F \times FC\ G \quad (1.1)$$

Note: ESLC is Estimated Service Life of a component, RSLC is Reference Service Life of a component, FC is Factor Class

5 INTERVIEW RESULTS: POTENTIAL CAUSES OF ROOF LEAKS

All information gathered from interviews is classified into groups based on the similarity of the origin of causes. There are a total of 27 possible causes of roof leaks that can be classified into five different groups: problem from 1) Maintenance Stage, 2) Design Stage, 3) Installation Stage, 4) Environment, and 5) Others. In general, most of the roof experts have similar opinions regarding the causes of roof leaks. About 50% of the issues listed are mentioned by more than half of the roof experts as either contributing or not contributing to leaks. Three issues are agreed by all experts as potential causes of roof leaks. They are: 1) physical damages caused by humans working on roofs; 2) material and system compatibility; and 3) inherent weak-points in the system.

The raw data also reveal that approximately 40% of issues mentioned in the interviews originated during the pre-construction (design) phase. Twenty-six percent and 15 percent involve human involvement during installation and maintenance, respectively. The remaining 19 percent are almost equally split between environmentally-induced problems and other issues. Some variables, however, showed inconsistent opinions among experts. For example, some experts disagreed that the availability of walk pads on roofs helps prevent damage (punctures) to roof membranes caused by foot traffic. The experts simply stated that the walk pads are typically not used by crews.

From the preliminary investigation, it is clear that not all identified variables can be quantified and obtained for analysis. Only variables that are identified as potential sources of roof leaks with availability of data are therefore included in the analysis as presented in Table 1.

Table 1 A list of variables identified as potential sources of roof leaks with availability of data

Variables	
1. Crew names	9. Relative humidity
2. Frequency of on roof foot traffic	10. Roof age
3. Numbers of equipment on roofs	11. Roof problems reported
4. Geographical locations (Weather patterns)	12. Roof prototype
5. Installation seasons	13. Solar radiation
6. Local settings	14. Temperature and Deviation
7. Membrane types	15. Wind (Maximum and average)
8. Precipitation (Rain and snow)	16. Frequency of roof maintenance

6 DATA COLLECTION

Data are obtained from one retail chain that owns multiple warehouse-type retail stores across the United States. These stores generally have similar structures, components, and configurations. The company also purchased products and agreed to use installation crews from a sole manufacturer.

7 HMDA MODEL DEVELOPMENT

7.1 Model Development

The logistic regression analysis is adopted as a tool due to the binary nature of the study dependent variable. Eight different starting models are created based on 1) assumptions regarding influence predictors; 2) variable selection strategies; 3) levels of entry and removal (Alpha Level - α); and 4) numbers of cases used and variable selection strategies to overcome the unbalanced ratio problem between predictors and observed cases. The preliminary models are then tested for the best performance (best fit to the data) and used in the final model development.

The k-folder cross validation is chosen to test the model robustness (Anonymous 2004; Gutierrez-Osuna 2006) while the second dataset obtained from a different source is used in the external validation process. The result of the internal validation shows that the average estimated generalization errors are relatively similar to the misclassified numbers in the full model in all cases. The test results confirm that the developed model is a good fit for the data. The model accuracy prediction rate (external validation) for the second dataset is 82%, compared to the prediction rate in the original data set (92%). This evidence shows that the model developed is accurate enough to predict the leak incidence in the second dataset (Field 2005).

7.2 Final Model Results

The final model has the power to correctly predict roof leaks or no leaks at a rate of 92.1%. The R-square also confirm that the model accounts for approximately 60-86% of the variance in roof leaks (roughly one-fifth of what causes roof leaks is still unknown). Therefore, the probability of roof leaks can be predicted using the following equation:

$$\text{Probability (leaks)} = \frac{1}{1 + e^{-(3.65 + 3.36(AG) + 7.12\,(WE) - 2.39\,(RR))}} \quad (1.2)$$

Table 2 shows that Roof Age (AG), Workmanship Quality (WE), and average Roof Repair (RR) make a significant contribution to the prediction of roof. The correlation analysis in Table 3 also confirms the significant relationship of these variables to roof leaks (small and medium relationship with $p < 0.001, 0.01$).

Table 2 Variables in the Final Model

	B	S.E.	Wald	df	Sig.	Exp(B)
AG	3.36	.52	42.02	1	.000	28.64
WE	7.12	1.12	40.85	1	.000	1240.67
RR	-2.39	.47	26.18	1	.000	.09
Constant	3.65	.61	36.21	1	.000	38.37

Note:

B = is the regression coefficient of the corresponding variable X (probability of Y occurring given known values of X)

S.E. = is the standard error around the coefficient for the constant

Wald = is Wald statistic that tells us whether the b-coefficient for that predictor is significantly different from zero (if it is then we can assume that the predictor is making a significant contribution to the prediction of the outcome)

df = is degrees of freedom for the Wald chi-square test. There is only one degree of freedom because there is only one predictor in the model, namely the constant.

Sig = is Significant of the Wald chi-square test

Exp (B) = is an indicator of the change in odds resulting from a unit change in the predictor

Table 3 Correlations between each Variable and Leaks

		AG	WE	RR	Leaks
Leaks	Pearson Correlation	.517(**)	.470(**)	.165(**)	1
	Sig. (2-tailed)	.000	.000	.003	
	N	311	311	311	311

** Correlation is significant at the 0.01 level (2-tailed)

7.3 Variable Interpretation: Variable Relations with Roof Leaks

In the model (Table 2), AG and WE have a positive relationship with leak problems. An increase in one unit of these variables increases the odds of roof leaks. In this case, the increasing powers are equal to the variables' odds ratios. The average Roof Repair (RR), on the other hand, has a negative relationship with roof leaks. An increase of the average frequency of roof repair decreases the odds of leaks.

The odds of roof leaks increase by a multiplicative factor of 28 and more than 100, as the age and average per month of roof recalls within the first year increases by one unit respectively. In another words, each additional month or number roof recall increases the odds of leaks about 28 folds or tremendously, controlling for other variables in the model. The 95% confidence interval reveals that the odds of roof leaks lie somewhere between 10 to 79 for the age variable and 139 to more than 1000 times for the workmanship. The relationship of age and roof leaks in this sample is true for the entire population of this particular retail store, when all other factors are equal.

The odds ratios of roof repair indicates that if the average roof repair per month increases by one, the odds of leak incidences will decrease. Put in another way, with all other factors held equal, an increase of an average of one roof repair per month decreases the odds of roof leaks by 91%. The decreased odds are between 77-96%, which is relatively narrow. The relationship of roof repairs and roof leaks found in this sample is true for the entire population of this particular retail stores.

8 ESTIMATED SERVICE LIFE AND FIRST-TIME LEAK RELATIONSHIP ANALYSES

The same raw data used in HMDA are reorganized and entered into Equation (1.1) to estimate the service of each roof case. In this process, the ESL is calculated using different combinations of value coding, observed cases, and means to derive factor classes based on 'Factor Method' principles. Due to limited space, a more detail of how each factor is identified and how raw data are genereated can be read in “Roof maintenance record analysis toward proactive maintenance policies”, the dissertation by the main author. The first-time leak is extracted from maintenance records, while the reference service life of a roof (RSL) is assumed to be equal in all cases (same roof types). Fifty-six analysis trials are performed to investigate the relationship between estimated service life (ESL) of roof assemblies and the age of the first-time leak. The ESL and first-time roof leaks data are then inputted into the SPSS 13 under Pearson correlation analysis.

8.1 Relationship between Estimated Service Life and First-Time Leak Results

The 56 analysis trials prove that there are some significant correlations between the ESL of roofs assemblies using ‘Factor Method’ and first-time roof leaks. The strengths of significant correlations vary from low-to-medium (1.44 – 3.39) with significant < .05 or .001. Nevertheless, to be able to detect the significant, a certain set of conditions need to be satisfied. The following table presents the sample of correlation results in the second approach.

Table 4 Correlation between Estimated Service Life and First-Time Leak Results

Trials	Pearson	
	correlation coefficiency	significant
Trial 1	0.050	0.160
Trail 2	0.460	0.414
Trial 3	0.071	0.214
Trial 46	.296**	0.000
Trial 47	.355*	0.012
Trial 48	.334**	0.000

9 DISCUSSION

This research demonstrates that roof maintenance records can be used to predict and identify major factors that are likely causes of roof leaks in a mathematical model. Also, roof leaks are not totally random events and can be predicted with parameters identified in this study. The results from HMDA clearly show that three parameters (Age-AG, Workmanship-WE, and Roof Repair-RR) have a significant impact on the odds of roof leaks within the first three years of a roof life. A unit change of WE and AG increases the odds of a roof leak. On the other hand, changes in RR decrease the odds of a roof leak.

The one unit positive change of the average of roof call-backs, represented as workmanship quality, within the first year has a tremendous negative ramification on the odds of roof leaks, when all other variables are held constant. This finding confirms the results from expert interviews that the majority of early roof failures are caused due to poor workmanship.

Roof age is another important factor directly affecting leak probabilities. An increase of one additional month increases the odds of roof leaks (probability of leaks divide by probability of no leaks) by 28 times with other factors are held constant, regardless of geographical locations or local environments. The finding confirms the drastic impact that age has on roof's performance, and the need for different maintenance regimes based on age.

The increase of roof repair, on the other hand, reduces the odds of roof leaks by 91%. The reverse impact is explained by the fact that when roof repairs are requested, the roofers are not only correcting the problems, but they also generally perform a quasi-maintenance tasks that can potentially prevent future leak incidences. The finding underlies the importance of performing roof maintenance.

Out of the three most important variables (WE, AG, and RR), only two (WE and RR) can potentially be controlled by facility managers. Lack of involvement of a roofing specialist or effective quality control during roof installation, are the most likely causes for the workmanship-related issues that substantially increase the chances of roof problems. A more-rigorous quality control procedure from facility managers needs to be put in place, in order to reduce the number of roof call-backs in the first year, and more research is needed in this area. The other human involvement is during building occupancy and maintenance. The frequency of roof repairs that can be perceived as a quasi-roof periodic maintenance, prolongs roof life by not only restoring roofs back to water tightness conditions, but also by reducing the occurrence of future roof problems that can eventually lead to leaks. An increase in roof repair frequencies (maintenance) reduces the odds of roof leaks. The notion is similar to the practice suggested by the roofing industry that roofs should be inspected at least bi-annually.

There are no surprise findings from the HMDA; however, the study findings confirm the experience-based knowledge of roof industry experts regarding root causes of roof leaks. It also sharpens understanding about the degree of significance of these three variables.

The 'Factor Method' performed in the RSLP confirms the existence of a relationship between the estimated service life (ESL) and the first-time leak. This finding proves that ESL and first-time leaks are linearly related. In this study, the correlations discovered in this proof-of-concept sample between the two parameters are positive and significant-to-highly-significant. The extent of correlation is found to be medium-to-low with a relatively normal distribution of cases. The finding also illustrates a relatively simple and useful 'Factor Method' technique in estimating the service life of roofs that can be applied to the roof maintenance decision-making process.

10 CONCLUSIONS

This research proposes the move towards proactive maintenance that is applicable to new warehouse-type retail store roofs. The HDMA study has identified critical information, specifically the variables that most impact roof lifespan, which can be used in roof maintenance planning. The findings provide facility managers a rationale to establish a proactive roof maintenance strategy. By paying more attention toward the root causes of roof failures during roof's inception to operation, the likelihood of making mistakes that lead to leaks can be minimized.

Second, a 'Factor Method' is used to estimate the service life of roofs and a potential timeframe of a first-leak occurrence. This information provides owners with a holistic view of a required roof maintenance methodology from a building occupant's perspective.

By combining new knowledge gained from these two studies, a proactive roof maintenance management regime can be created. The estimated service life of a roof provides a reasonable estimation of a maintenance-free period. When ESL information is used in conjunction with knowledge obtained from HMDA, the new synthesis of knowledge will expand the facility maintenance professional's ability to develop and schedule a proactive roof maintenance plan. Through carefully monitoring the numbers of roof recalls in the first year, roof repairs, and the age of roofs, the initial maintenance plan, typically a bi-annual inspection, can be suitably modified to reflect actual environmental conditions and usage. A customized, on-going intervention strategy based on WE, AG and RR can develop a realistic roof leak prevention plan.

The findings from the study are valuable in providing crucial information for facility managers in establishing a proactive roof maintenance plan. In addition, the simplicity of the 'Factor Method' procedure in estimating roof life is expected to bring about the needed change in roof maintenance regimes.

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