A Knowledge Management Platform for Infrastructure Performance Modeling

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A final report submitted to the Infrastructure Technology Institute for SAFETEA-LU funded projects designated A225.

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1) Background and Objectives:

Performance models are used to process condition data in order to assess current needs, and to forecast (the effect of interventions/investments on) future condition, and in turn (on) the remaining service-life or time-to-failure distribution of infrastructure facilities and their components. Performance models are mathematical expressions that relate condition data to a set of explanatory variables such as design characteristics, traffic loading, environmental factors, and history of maintenance activities. The motivation for our work is that in the last 40 years, and particularly in the last 10-15 years with developments in statistics and in computer availability, storage capacity and power, numerous techniques have been employed to estimate these models under different structural assumptions, using countless data types and sources, and to address and support a plethora of managerial decisions, i.e., design, construction, maintenance and rehabilitation. Unfortunately, these efforts have been disconnected and as a result there is a lack of standards/criteria for the development, utilization, evaluation and selection of performance models.

Thus, the objective of the study is to build an online platform/repository/test-bed to facilitate the exchange of data and information related to performance models as a step to correct this significant problem. Specifically, the platform would contribute to the science and practice of performance modeling by:

1. Serving as a central, reliable source of relevant data and information; and by
2. Providing on-line access to a test-bed that would allow analysts evaluate the capabilities of their own models.

The platform advances infrastructure performance modeling because analysts are able to build and benefit from existing knowledge (as opposed to starting from scratch). Moreover, analysts would be able to assess and compare their assumptions and models, i.e., the nature of their contributions, against well-established, state-of-the-art benchmarks.

Finally, the proposed platform further establishes the Infrastructure Technology Institute at Northwestern University as a leader in providing knowledge management services to the engineering community.

Scope of Work:

We developed a web-based platform that can be accessed through the URL http://www.modelingpavements.iti.northwestern.edu. The platform's current capabilities and features include:

1. A detailed description of the experimental design used and data obtained during the AASHO Road Test.
2. Provides a short description of various state-of-the-art performance models from the literature (structural assumptions, statistical technique used to estimate, data

subset used for estimation, etc.). These models are preloaded on to the site to provide benchmarks for analysis.

3. The platform allows analysts to (formulate and estimate models on their own and) input performance models on to the online platform.
    a. In addition to providing a set of parameter estimates, analysts will specify information such as what subsets of the data were used in estimating their model.
4. Empirical comparison:
    a. Analytical tool to compare the predictive capabilities of the model based on common set of data. The measures include overall error and time-dependent error for a specific facility, a subgroup of facilities, or all data set.
    b. The platform produces various plots and tables that provide statistics and measures that can be used to evaluate and compare statistical pavement performance models.
5. Analysts can choose to submit their models (along with a brief explanation) so that they can be added to the benchmarking database.

Our choice of the considering data from the AASHO Road Test, and models where the dependent variable corresponds to the Present Serviceability Index is justified because:

1. This data set is of high quality, and still widely used in the development of state-of-the-art performance models (in spite of its age).
2. Furthermore, pavement design standards in the United States (and elsewhere) are largely based on data collected during this study. The ASHTO Design Equation, in particular, predicts the PSI as a function of accumulated traffic loading.

2) Context of the Research

As stated, the context of the research is related to the large number of techniques that have been used to develop infrastructure performance models. The capabilities and features of the ensuing models, e.g., properties of the parameter estimates, have been analyzed and evaluated qualitatively in the academic literature (cf. McNeil et al. (1992), Hudson et al. (1997), Gendreau and Soriano (1998), and Frangopol et al. (2004)). Unfortunately, this information has not made its way to analysts in engineering practice. Moreover, no standards/criteria to evaluate or select between models are available.

As a step to address this problem, we recently developed a quantitative framework to compare the predictive capabilities of performance models (Chu and Durango-Cohen, 2007). We used the framework to conduct an empirical comparison of nine representative performance models that were estimated using functional performance data collected during the AASHO Road Test. The motivation for our work is to make the framework available to the public so that analysts can use it in the future development, evaluation and selection of infrastructure performance models.

<u>An Example:</u>

Consider the **AASHO** model presented in Equation (1). This model predicts a flexible pavement's serviceability in *PSI's* as a function of traffic applications, *W*. PSI_0 represents the *PSI* of a new pavement, PSI_1 represents the *PSI* of a failed pavement. The parameters, β and ρ, respectively, represent the deterioration rate and the traffic applications to failure. The original estimates of these parameters are presented in Equations (2) and (3).

$$PSI(W) = PSI_0 - (PSI_0 - PSI_1)\left(\frac{W}{\rho}\right)^{\beta} \tag{1}$$

$$\beta = 0.4 + \frac{0.081(L_1 + L_2)^{3.23}}{(SN+1)^{5.19} L_2^{\ 3.23}} \tag{2}$$

$$\rho = \frac{10^{5.93}(SN+1)^{9.36} L_2^{\ 4.33}}{(L_1 + L_2)^{4.79}} \tag{3}$$

Recognizing that some of the pavements in the experiment outlasted the experiment, meaning that only the lower bound on part of the ρ's are observed, Small and Winston (1988) obtain an updated estimate by using Tobit (or censored) regression. The updated estimate is presented in Equation (4). We label Equation (1) with the updated estimate **ASHO(T)**.

$$\rho = \frac{10^{5.24}(SN+1)^{7.761} L_2^{\ 3.238}}{(L_1 + L_2)^{3.652}} \tag{4}$$

Prozzi and Madanat (2000) present a stochastic duration model where time-to-failures are probabilistic, and are asumed to follow a Weibull distribution. This distribution is often used in structural reliability theory. The model also accounts for the censoring discussed above. The new estimate is presented in Equation (5). We label Equation (1) with the updated estimate **AASHO(D)**.

$$E[\rho] = \frac{10^{5.28}(SN+1)^{6.68} L_2^{\ 2.62}}{(L_1 + L_2)^{3.03}} \tag{5}$$

The motivation for our work is to develop standards/criteria that can aid analysts in choosing between the three estimates (in different situations).

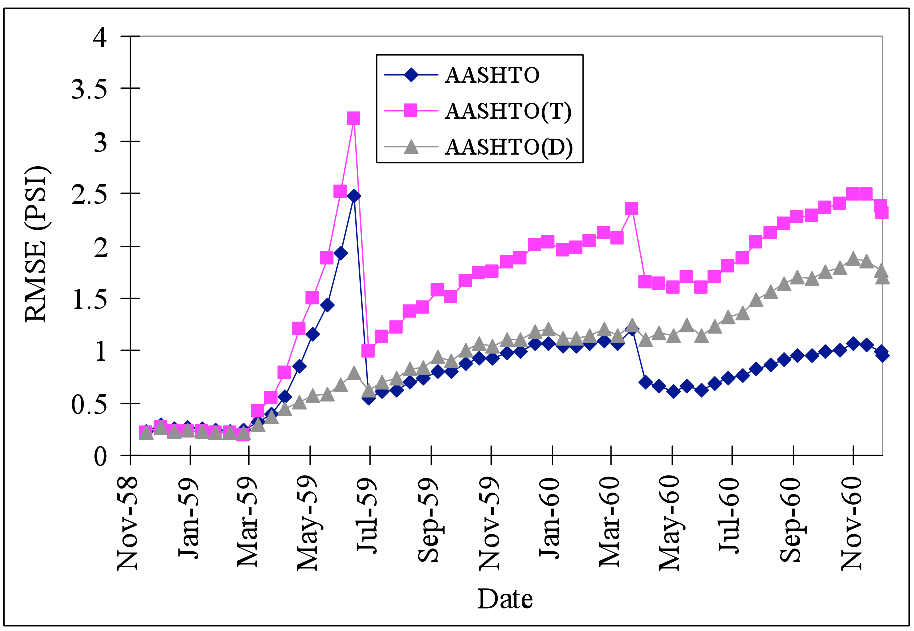
For example, in Chu and Durango-Cohen (2007) we compare the (in-sample) predictive capabilities of each of the three models **AASHO, AASHO(T), and AASHO(D)**. Examples of the results are presented below:

Model	RMSE (PSI)
AASHTO	0.916
AASHTO(D)	1.113
AASHTO(T)	1.755

Note: RMSE=root mean square error.

The above table shows the Root Mean Square Error in prediction (measured in PSIs) that is obtained by comparing the predictive capabilities of the above models. The predictions are carried out rigorously for a common subset of the data used for estimation.

Figures such as the one below could also be provided where we compare the trend in RMSE over time. As a result, the predictive capability and prediction error at different stages of facility life can be understood. For example, the reason of the peaks of RMSE in AASHTO and its updates is that pavement sections failed and were taken out of the comparison. The lesson is that these models generate large errors when facilities are close to failure than other models. In other words, they show that deterioration is more erratic right before failure. This type of graph can also show seasonal patterns, etc.



Interestingly and rather surprisingly, we observe that while the updated estimates seem more appealing, the ensuing models have inferior predictive capabilities. For example, this may mean that the assumption of deterministic deterioration for pavements in the AASHO Road is reasonable. It also may mean that ignoring censoring does not adversely affect the predictive capabilities. These and other interesting questions/issues cannot be identified without conducting a quantitative comparison of the models' predictive capabilities.

A more rigorous discussion that includes six additional models is presented in Chu and Durango-Cohen (2007).

3) Concluding Remarks

The project consisted of developing a web-based knowledge management platform for infrastructure performance modeling. While early indications are that the site has sparked interest among academic users from around the world, the next step will be to increase the exposure of the website within the infrastructure research and practice communities.

Finally, I would like to acknowledge the contributions of Northwestern students:

Chih-Yuan (James) Chu, PhD Civ Env 2007;
James Spadaro, BS EECS 2009;
Emily Rosenbloom Kushto, PhD Candidate Civ Env (who was the student funded by the project during the summer of 2008). Emily was responsible for editing the website.

References:

1. Chu, C. and Durango-Cohen, P. (2007), "An empirical comparison of statistical pavement performance models.", *In Press ASCE Journal of Infrastructure Systems.*
2. Frangopol, D., Bruhwiler, E. Faber, M. and Adey, B. (2004). *Life-cycle performance of deteriorating structures: Assessment, design and management.* American Society of Civil Engineers, Reston, VA.
3. Gendreau, M. and Soriano, P. (1998), "Airport pavement management systems: An appraisal of existing methodologies.", *Transportation Research Part A,* 32(3), 197-214.
4. Hudson, W., Haas, R. and Uddin, W. (1997), *Infrastructure management: Integrating, design, construction, maintenance, rehabilitation, and renovation.* McGrw-Hill Companies, Inc., New York, NY.
5. McNeil, S., Markow, M., Neumann, L., Ordway, J., and Uzarski, D. (1992), "Emerging issues in transportation facilities management.", *ASCE Journal of Transportation Engineering,* 118(4), 477-495.
6. Prozzi, J. and Madanat, S. (2000), "Analysis of experimental pavemet failure data using stochastic duration models.", *Transportation Research Record*, 1699, 87-94.
7. Small, K. and Winston, C. (1988). "Optimal highway durability.", *The American EconomicReview,* 78(3), 560-569.