

Remaining Service Life of Concrete Pavements

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Abstract

A proactive approach to protecting or maximizing the investment of concrete pavements requires periodic assessment of the pavement condition to determine deficiencies and predict deterioration patterns. Pavement management strategies must be employed at an optimal time in order to attain the most cost effective maintenance and rehabilitation solutions for the structure. Determining the remaining pavement service life is critical for making better decisions about preservation treatments, rehabilitation, or reconstruction. This paper discusses three key approaches developed for determining concrete pavement remaining service life (RSL) and presents case studies demonstrating the use of each method. The three methods include an empirical based procedure, a new approach based on survival curves, and a comprehensive mechanistic based procedure using the new National Cooperative Highway Research Program (NCHRP) Project 1-37A analysis methodology.

Introduction

Concrete pavements are a vital component of the transportation system and represent a substantial investment. Due to their typical long term life, highway agencies tend to ignore preservation treatments (e.g., restoration) and even the application of rehabilitation treatments until the concrete pavement is in a condition that is well past any possibility of economic opportunity. Determining the remaining service life (RSL) of pavements will facilitate making pavement management decisions in order to use resources efficiently. Although the expected service life of a pavement is a criterion in the design phase, subsequent management decisions must take actual pavement site conditions into consideration to accurately predict and extend the service life, including traffic, climate, material properties, and construction quality. As-built conditions often vary and result in a major change in the rate of pavement deterioration.

A proactive approach to protecting or maximizing investment in concrete pavements involves periodic assessment of the condition to determine deficiencies and predict deterioration patterns. Pavement rehabilitation strategies need to be employed at an optimal time in order to attain the most cost effective and economic solutions. As discussed in the work by Corvi and Bullard (1970), these needs are not new to the pavement community. Since at least 1970, numerous methods have been

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proposed, researched, and used to predict the RSL of pavements; however, there does not appear to be an overall definitive method that is used on network or project levels.

Part of the problem stems from variations in the way service life can be defined as shown in the work by CTC *et al.* (2004). Typically, service life is expected to be a measure in terms of years from the initial construction until the pavement will require major expenditures for restoration, overlays, or other rehabilitation. Service life may also be expressed through performance indicators or condition indices and, as will be demonstrated, traffic loadings. Early in the analysis process and as part of the discussions on service life, the key criterion that needs to be defined is the point of failure. It may be expressed in terms of function (e.g., low friction), key distresses indicating major problems ahead, excessive maintenance needs, or structural deficiency (e.g., fatigue damage) and may take into consideration load-related (traffic volume) or material distress-related factors. Other issues include (a) the purpose for needing the information as far as determining the time until preservative-type rehabilitation is needed rather than complete loss of service; (b) the requirements being met by results in terms of time or rating; and (c) the decision on the key characteristics that should be evaluated.

Knowing the pavement RSL may impact choices made for preservation or restoration treatments, rehabilitation alternatives, and reconstruction to ensure the efficient use of resources. This is a driving force behind the continuing effort to assess the RSL. Several projects throughout the country are exploring the issue to some degree. The projects cover a range of methods in both data collection and data analysis. Current data, technologies, and practices should be considered in determining the most usable form of pavement evaluation. A combination of these items, as well as taking a look at methods developed in other industries, may yield even better results.

In order to use current technology, data acquisition should provide information that can be used and manipulated through data analysis. In some cases the data is collected using rather subjective methods, such as visual inspection of the pavement structure. The analysis is then performed on historical data using relatively complex calculations or models to derive an estimated prediction. For a short-term solution, data on pavement condition contained in existing pavement management databases can be utilized.

Summary of Data Collection Technology

Relationships can be derived between various pavement characteristics to create conversion factors or indices for analysis. However, re-examining the types of data that are collected may reveal that other basic characteristics should be evaluated either in place of or in addition to the standard data that is currently gathered. In one approach the Federal Highway Administration (FHWA) is working to improve the collection of highway performance data for the Highway Performance Monitoring System (HPMS) database. This project is focusing on identifying the types of data inputs required to estimate pavement RSL along with the issues and concerns that States may face in providing those various data items as part of the HPMS submittal.

It appears that the most commonly used method of assessing the pavement condition is by visual inspection or windshield survey. This provides subjective data

and requires a significant investment of time and resources. In order to gain insight into the underlying factors, agencies often resort to destructive sampling and testing methods. Among other requirements is the need to properly train personnel and maintain equipment to ensure that the sampling and testing are done correctly. In efforts to reduce these expenditures, there is increasing demand to use nondestructive testing and evaluation methods when possible. Recent technological advances have lead to the development of more non-destructive pavement condition assessment tools such as deflectometers, which consider load-related rather than material distress-related factors.

There are projects underway that attempt to make pavement evaluation more objective and automated through the use of highway measurement vehicles equipped with technology such as computers, cameras, sensors, lasers, gauges, profiling devices, gyroscopes, and other data collection instruments. Research is also being conducted on using geophysical methods including seismic vibrations and ground-penetrating radar to provide objective, network-level pavement condition evaluation and to detect early stage deterioration. These tools provide an opportunity to gather data more efficiently as well as to improve the data in terms of quality, consistency, quantity, and frequency (e.g., annually rather than biennially).

There are other innovative methods being considered which look beyond current technology. For instance, the National Consortium on Remote Sensing in Transportation and the National Aeronautics and Space Administration (NASA), along with other entities, are investigating the roles of remote sensing and geospatial technology in pavement evaluation.

Summary of Data Analysis Methods

Data analysis includes utilizing relationships between pavement site conditions and performance. Algorithms, models, and indices that vary from simple to very complex can be used to estimate the RSL. The following is a brief summary of some promising approaches for prediction of remaining life.

HPMS Study. FHWA has a study underway entitled “Modification of FHWA Highway Performance Data Collection System and Pavement Performance Models”. One of the project objectives is determining approaches for estimating pavement RSL. Initial recommendations present three potential approaches: (a) use of deflection-based non-destructive/destructive testing, (b) use of pavement visual distress, and (c) use of smoothness/serviceability predictions (Battelle, draft white paper, 2004). The project includes bringing several States together into a committee to discuss these and other approaches as an exchange of experiences. It is anticipated that this committee will provide guidance and input for the second phase of the project.

Empirical Approach Based on Serviceability for HPMS Database. An approach was developed specifically for the HPMS database by Lee *et al.* (1993) that projects the remaining number of years that any given section of rigid (or flexible or composite) pavement will survive through knowledge of its current serviceability index level, the annual traffic equivalent single axle loads (ESALs), and its pavement

structure (i.e. slab thickness). This approach is empirically-based, requires very few inputs, and is incremental (e.g., year by year) in nature to be used for large networks of pavements for programming purposes.

Remaining Service Life Based On Survival Curves. A number of agencies have developed survival curves for various “families” of pavement types using their pavement management database as described in the work by Von Quintus *et al.* (2003). These curves provide the agencies with factual data on the service lives and amounts of truck traffic that their pavements have carried. The survival curves form the basis for predicting the RSL of pavements. For a given family of pavement, such as a specific jointed reinforced concrete, the survival curves for aging and truck traffic allows the estimation of the probability of rehabilitation being applied due to aging problems and due to overloading damage into the future of any given pavement section. This approach requires survival curves for aging and traffic loadings but requires very few inputs to apply and is also useful on the network level.

NCHRP 1-37A Mechanistic-Empirical Pavement Design Guide (M-E PDG). The work by Applied Research Associates (2004) describes the new M-E PDG developed under the National Cooperative Highway Research Program (NCHRP) Project 1-37A. The M-E PDG provides comprehensive structural analysis tools to predict deterioration based on design features, material properties, climatic conditions, and traffic inputs. This procedure provides one of the most promising approaches to prediction of RSL in terms of key types of deterioration: slab cracking, joint faulting, and smoothness. It requires a large number of inputs to produce estimates of future deterioration but is by far the most accurate of the approaches to RSL prediction. This approach can be used on the project level and may be simplified for use on the network level.

Other Approaches. Considering the impact pavement RSL may have on the decision process in a state department of transportation (DOT), many DOTs are evaluating approaches used to predict RSL. A method to estimate the RSL of continuously reinforced concrete pavements (CRCP) led to the development of a software program, called PAVLIF, by Dossey *et al.* (1996). This program has since been incorporated as a part of a CRCP analysis program used by the Texas DOT. Data from Mississippi DOT was used in a comparison of methods to calculate RSL in the work by Vepa *et al.* (1996). Another example is a project entitled “Pavement Forecasting Models”. The researchers are using data from Ohio DOT to derive the pavement condition rating (PCR). Once complete, the resulting models will be embedded into the state’s existing pavement database to be used in future analysis.

Opportunities to improve the approaches used to determine the RSL of concrete pavements may also be pursued by learning about the advances made in other fields as well as other countries. For example, the U.S. Navy has a project that is developing a “next-generation service life prediction model” for concrete waterfront structures called SUMMA™ as described by the authors Heffron and Buslov (2004). A company in the Netherlands has outlined a procedure for standard pavement evaluation of airfields. The procedure described by Stet and Diele (2004)

includes using falling weight deflectometer (FWD), performance models, statistical techniques, and pavement classification number. Austroads (2003) describes a commissioned study on the current practices of estimating RSL of pavements and bridges in Australia and New Zealand. The report's main findings and conclusions suggest issues that are similar to those identified in the U. S. demonstrating the potential and need for a continued exchange of information.

Remaining Service Life Case Studies

Three case studies are presented to illustrate three of the approaches to estimating RSL. A jointed plain concrete pavement (JPCP) section with random joint spacing on a 4-lane divided Interstate in Utah is used to demonstrate the simple empirical approach and the comprehensive mechanistic-based approach from NCHRP 1-37A. Actual measured pavement data was obtained from the Long Term Pavement Performance (LTPP) database for section 49-3011. The pavement was constructed in 1986 and performance data is available into 2002. Historical data indicated a 16-percent compound growth in traffic and the initial International Roughness Index (IRI) was estimated to be 1.15 m/km (73 in/mile). Another case study utilizes the survival curves obtained from the Illinois DOT for continuously reinforced concrete pavement (CRCP).

Empirical Approach for HPMS & Similar Databases. Models were developed using information from several databases on different pavements in the Illinois network and modified to account for different functional groups and climate zones based on information from the HPMS databases. The results were deemed reasonable for a large portion of analyzed cases in the work by Lee *et al.* (1993). The following equation predicts the present serviceability rating (PSR) based on knowledge of the pavement type and structure (i.e. slab thickness), the current year pavement condition, and the current annual ESALs:

$$PSR = PSR_I - AF * [a * STR^b * (AGE + \Delta YEAR)^c * (CESAL + \Delta ESAL)^d]$$

where	PSR _I	=	initial value of PSR at construction (3.65 was used in analysis)
	AF	=	adjustment factor to account for the effects of climate zone and functional group
	STR	=	existing pavement structure: THICK, slab thickness for PCC pavements (in inches)
	AGE	=	age of pavement since construction (in years)
	$\Delta YEAR$	=	increment in age over analysis period
	CESAL	=	cumulative 18-kip ESAL applied to the pavement (heaviest traffic lane) (in millions)
	$\Delta ESAL$	=	increment in ESAL over analysis period
	a, b, c, d	=	regression coefficients

The adjustment factor for an interstate road in "climate zone 7: dry; freeze" and the regression coefficients for a JPCP were provided in tables within the report by Lee *et al.* (1993) and are summarized in Table 1.

Table 1. Adjustment factor and regression coefficients used for JPCP PSR curve.

AF	$\log_{10} a$	B	C	D
0.79	0.5104	-1.7701	1.0713	0.2493

This equation can be rearranged to operate in a year by year incremental manner. The section's PSR curve (see Figure 1) follows the general pattern of JPCP with a convex shape demonstrating late rapid loss of PSR. The results show a rapidly deteriorating section of JPCP given the rapid decent of the PSR curve after 10 years. This information could be used to program a major rehabilitation as soon as possible to avoid the roughness that develops after about 9 to 10 years ($PSR < 3.0$).

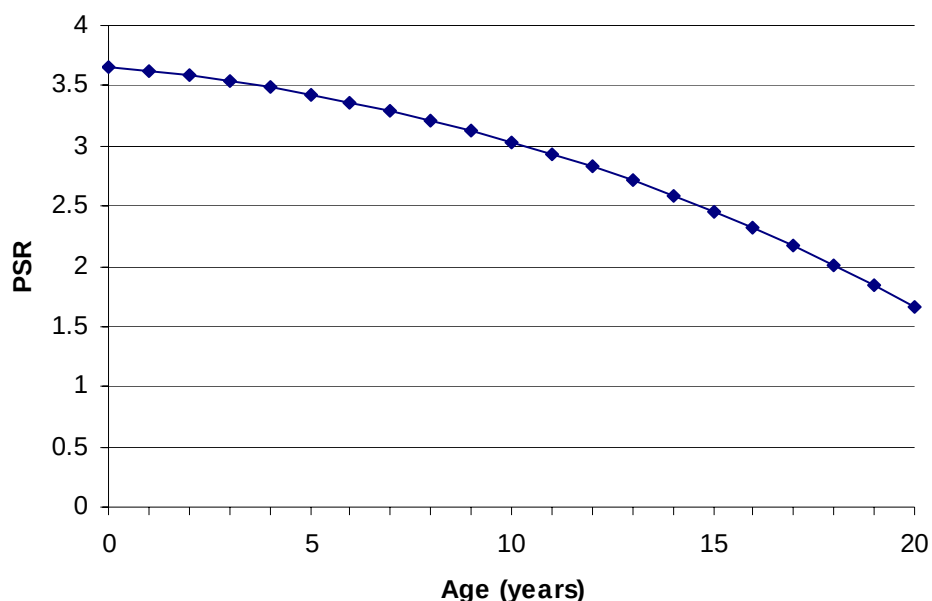


Figure 1. Predicted PSR deterioration by age for JPCP section 49-3011, Utah.

Remaining Service Life Based On Survival Curves. A number of agencies have developed survival curves for various “families” of pavement types using their pavement management database. These curves provide the agencies with factual data on the service lives and amounts of truck traffic that their pavements have carried. Illinois has been developing and using survival curves for nearly 20 years for all of the major types of pavements constructed on their freeway system. The most recent curves for 229-mm (9-in) thick CRCP from the work by Gharaibeh and Darter (2002) are shown in Figure 2 for aging and Figure 3 for traffic loadings. The curves are based on a large number of sections and miles of highways in Illinois.

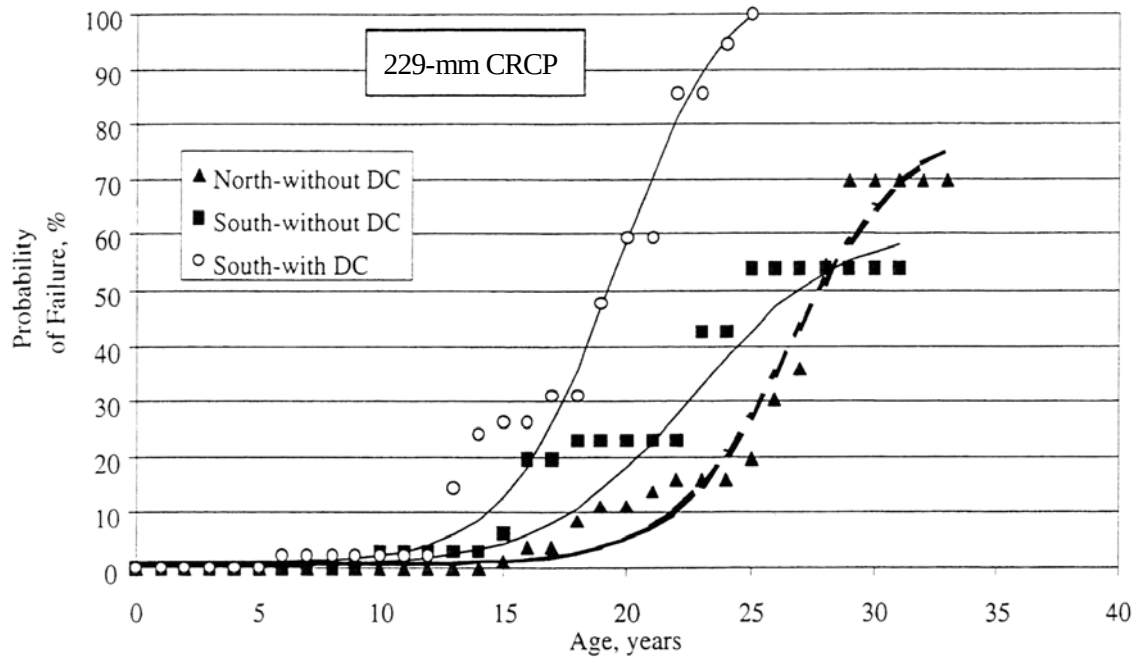


Figure 2. Aging survival curve for a 229-mm (9-in) CRCP in Illinois.
(Gharaibeh and Darter, 2002)

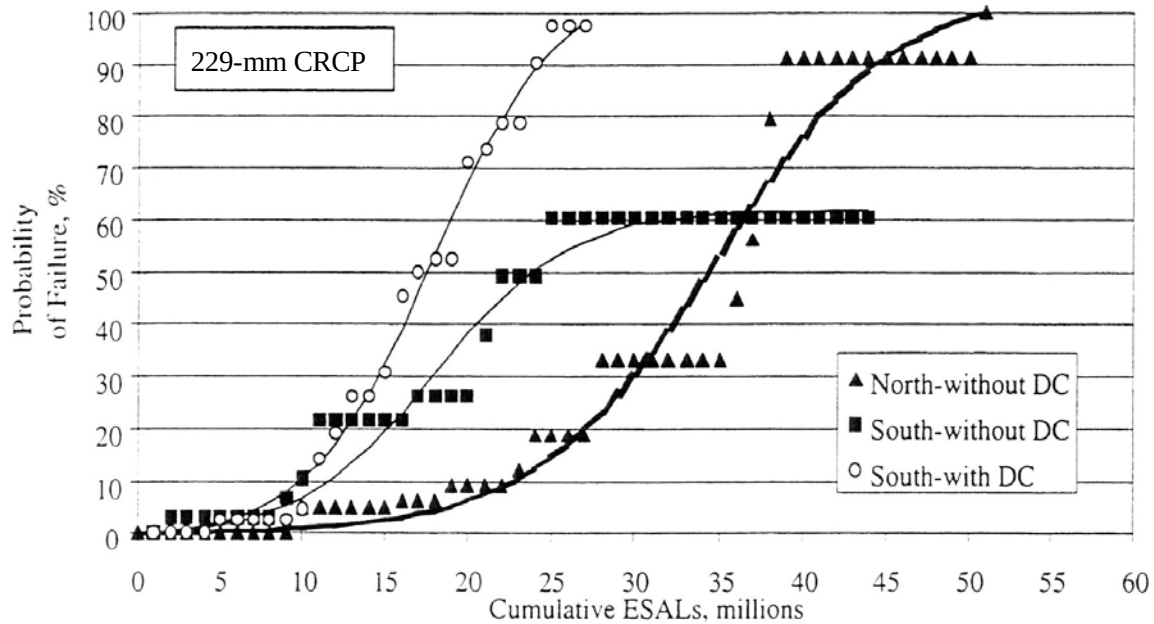


Figure 3. Traffic loading survival curve for a 229-mm (9-in) CRCP in Illinois.
(Gharaibeh and Darter, 2002)

These survival curves (actually plotted as percent failure meaning they were rehabilitated) can be used to estimate RSL considering both “aging” of the pavements (e.g., materials durability problems, subgrade movements, construction problems)

and “traffic” loadings. For example, consider a section of 229-mm (9-in) CRCP located in the southern area of Illinois that is 15 years old, has carried approximately 10 million ESALs, and exhibits “D” cracking. The probabilities of survival (which is $100 - \text{probability of failure}$) for such a pavement are as follows based on Figures 2 and 3:

- 100-2 = 88 percent based on 15-years of aging
100-10 = 90 percent based on 10 million ESALs carried

Thus, this pavement, at the present time, has a low probability of failure (in these survival curves, failure is specifically defined as when an overlay is required). The RSL can be estimated by determining the time and traffic at which this pavement would have less than 50 percent probability of survival. Table 2 lists the probabilities determined from Figures 2 and 3.

Table 2. Probability of failure based on survival curves for a 229-mm (9-in) CRCP in Illinois.

Pavement Age (years)	Probability of Survival Due to “Aging”	Probability of Survival Due to “Traffic”
15 (current)	88	90
18	60	75
21	30	60
24	2	36
27	0	20
30	0	4

The absolute maximum RSL of this “D” cracked pavement would be an additional 9 years (to age 24 when the probability of survival is 2 percent). However, it is likely to have only 4 to 6 years when the probability of survival ranges from 50 to 30 percent. Given this information, a cost-effective rehabilitation strategy could be planned and carried out.

Further confirmation of this approach is achieved when driving along any given Illinois freeway pavement and making an independent assessment of its RSL based on its visual condition. When this RSL estimate is compared to the probabilities of failure due to aging and traffic loadings, there is generally good agreement. For example, a section of 229-mm (9-in) CRCP was recently observed to exhibit numerous structural punchouts and obviously in need of major rehabilitation. Examination of the appropriate survival curves for this section indicated that while aging showed an 80 percent probability of survival, the traffic that this pavement had carried indicated a 10 percent probability of survival. In other words, the pavement had been overloaded and was rapidly failing due to inadequate structure.

This approach allows the pavement manager to program work several years into the future when the probability of survival becomes less than 50 to say 25 percent.

Mechanistic-Empirical Concepts. The most complex approach of data collection and analysis is the M-E based PDG, with additional data on traffic, climate, and structural layer properties, to analyze the Utah pavement section. Although data were available over 16 years of service life, it was assumed for illustration that data was available for only the first 5 years. Thus, at this time the following conditions existed:

- Slab cracking, 3 percent.
- Joint faulting, 0.8-mm (0.03-in.)
- IRI, 1.58 m/km (100 in/mi)

These values indicate a pavement that is performing reasonably well and there is no particular cause for concern. However, when the M-E PDG software is utilized and future deterioration predicted, the obtained results are illustrated in Figures 4, 5, and 6 (Darter and Titus-Glover, Utah DOT unpublished report, 2004).

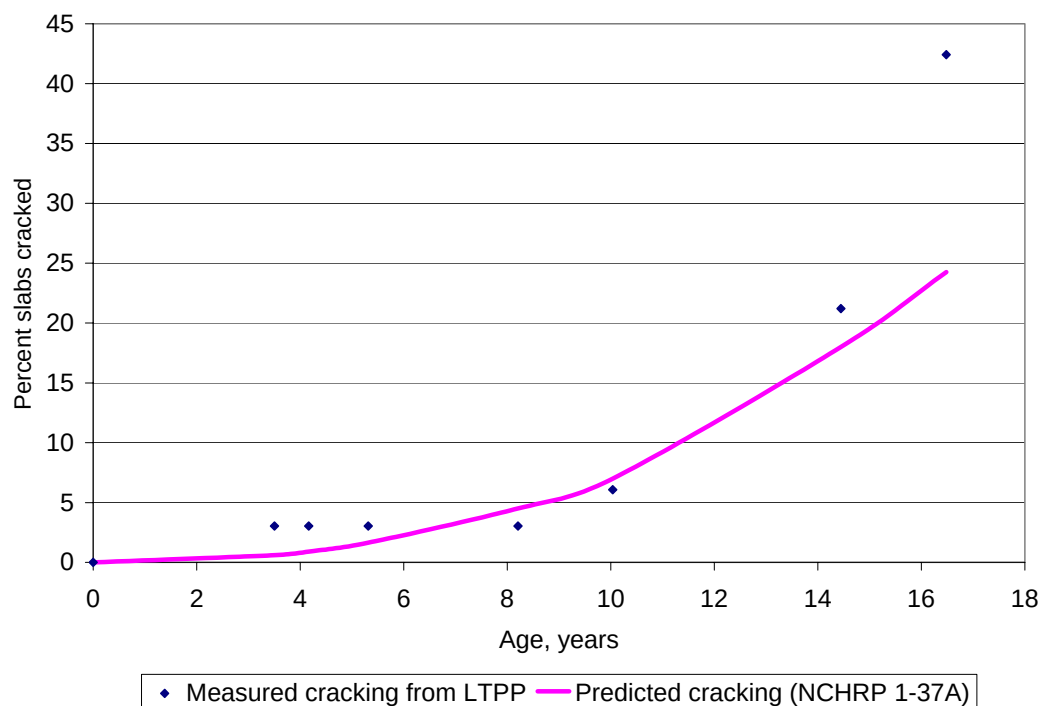


Figure 4. Measured and predicted transverse slab cracking. (Darter and Titus-Glover, Utah DOT unpublished report, 2004)

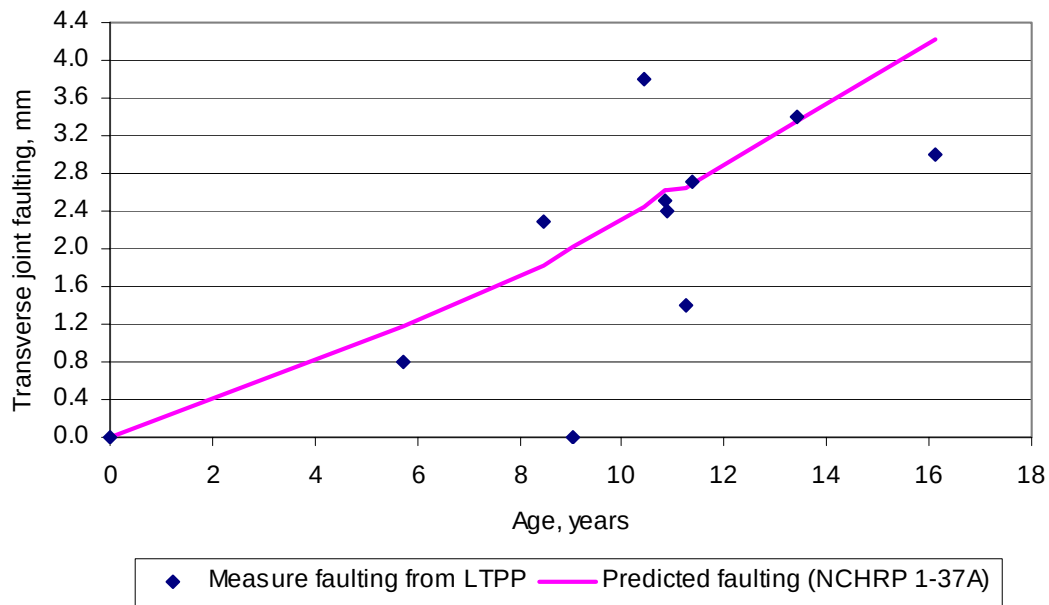


Figure 5. Measured and predicted transverse joint faulting. (Darter and Titus-Glover, Utah DOT unpublished report, 2004)

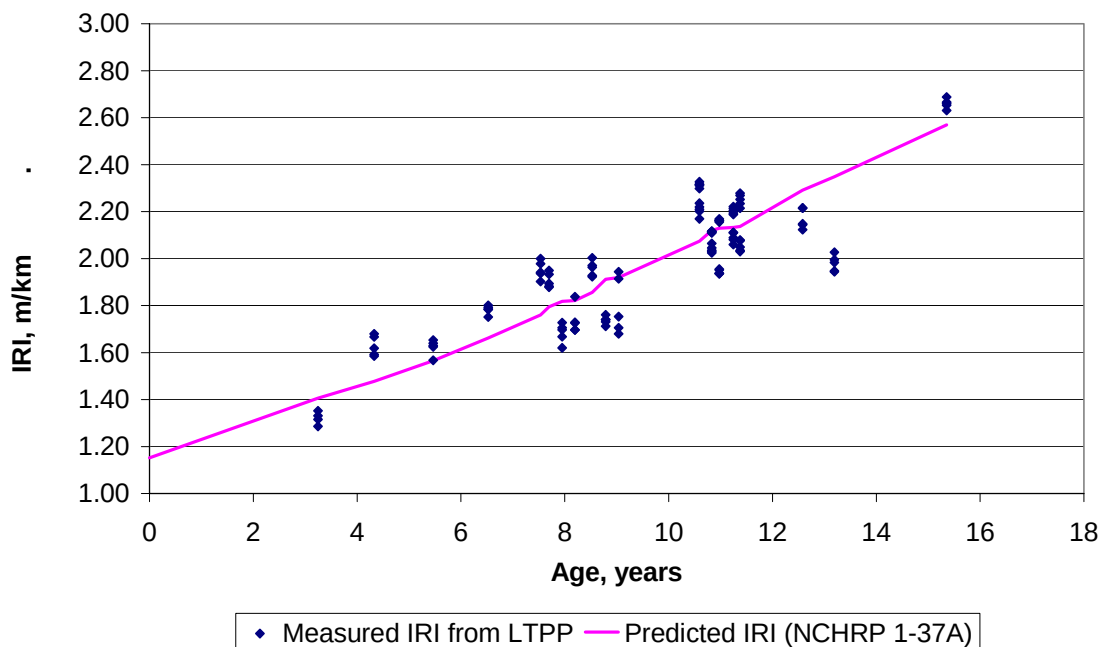


Figure 6. Measured and predicted IRI. (Darter and Titus-Glover, Utah DOT unpublished report, 2004)

As summarized in Table 3, the 5-year and “future” predictions are in general agreement except that cracking really increases after 12 years beyond the predictions. However, if a pavement manager could have known that this rapid rate of cracking and joint faulting was going to occur, a preservation treatment could have been

applied between 5 and 10 years to avert the rapid deterioration that occurred after this time period (e.g., dowel bar retrofit at joints, structural overlay).

Table 3. Measured and predicted values for JPCP section 49-3011, Utah.

Pavement Age (years)	Slab Cracking (percent)	Joint Faulting (mm)	IRI (m/km)
5 (Current)	3 Measured 2 Predicted	0.8 Measured 1.0 Predicted	1.58 Measured 1.42 Predicted
8	4 Measured 5 Predicted	2.3 Measured 1.8 Predicted	1.82 Measured 1.70 Predicted
12	12 Measured 12 Predicted	2.8 Measured 2.8 Predicted	2.13 Measured 1.97 Predicted
16	43 Measured 23 Predicted	3.0 Measured 4.1 Predicted	2.68 Measured 2.37 Predicted

Conclusions

The RSL of a concrete pavement structure can be estimated using several approaches. Each of the three approaches presented has advantages and disadvantages. Each approach has different levels of accuracy in predicting RSL, as summarized in Table 4.

Table 4. Summary of RSL approaches presented.

Approach to RSL Prediction	Data & Required Models	Output Provided	Accuracy of RSL Prediction
Empirical models of pavement performance	Age, annual truck traffic (in ESALs), pavement structure	Future years & ESALs to reach terminal condition	Reasonable for short term, but not for long term.
Survival curves	Survival curve for pavement type & design, age, cumulative ESALs	Probability of reaching terminal condition in years & ESALs	Probability of reaching terminal condition good due to agency developed survival curves.
Mechanistic- based incremental damage (NCHRP 1-37A)	Cumulative mechanistic-based damage models. Many inputs for design, traffic, structure, materials for project level application	Future years to reach terminal slab cracking, joint faulting, & IRI	Most accuracy possible in predicting RSL due to detailed input and comprehensive models used in prediction.

For pavement management purposes, either the empirical modeling approach or the survival curve approach is believed to provide acceptable accuracy at the

network level. The NCHRP 1-37A mechanistic-based approach is believed to be very good for a project level prediction of RSL. These procedures for predicting RSL are believed to be useful as tools for the pavement management engineer to program more cost-effective preservation and rehabilitation treatments for concrete pavements.

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