PAVEMENT REMAINING SERVICE INTERVAL: A LOGICAL REPLACEMENT TO THE REMAINING SERVICE LIFE CONCEPT

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Paper Statistics
Submission date: August 29, 2014
Total Words =4,418 words + 2 figures + 2 tables =5,418

This paper is being submitted for consideration for possible presentation at and publication in the proceedings of the 9th International Conference on Managing Pavement Assets (ICMPA9) in Washington, D.C., May 18-21, 2015.
ABSTRACT
The process of providing and managing a pavement network requires a plethora of decisions to be made. At the heart of those decisions is the prediction of future construction events, but many issues exist with the current remaining service life (RSL) terminology that confuse, confound, and complicate proper interpretation, interagency data exchange, and use. The major source of ambiguity with RSL is the use of the term “life” to represent different points in the construction time-line. There could be up to four different types of future construction events on which a RSL definition could be based, depending on the condition of the pavement, and it is impossible for a single number called RSL to properly describe all of these future construction events. The recommended path to consistency involves adopting terminology of time remaining until a defined construction treatment is required—RSL is replaced by “Remaining Service Interval” or “RSI.” This terminology has the ability to unify the outcome of different approaches for determining needs by focusing on when and what treatments are needed, and the service interruption created. This paper explains the RSI concept and outlines the validation efforts using State Highway Agencies and the Pavement Health Track analysis tool at the national level. It also details how RSI can contribute to the requirements of the Moving Ahead for Progress in the 21st Century (MAP-21) legislation.

INTRODUCTION
A goal of pavement management systems (PMSs) is to make the best use of agency resources while providing an optimum level of service to the users. Accomplishing this requires monitoring the condition of the pavement network and forecasting future pavement performance in order to effectively plan future pavement construction events. Predicting the time until a construction treatment should be applied is critical to pavement management planning. Knowing or estimating the future condition of pavement sections is the rational basis of informed pavement infrastructure planning decisions.

The term remaining service is typically defined as the period over which a pavement section adequately performs its desired function or performs to a desired level of service, and remaining service life (RSL) is simply the time from the present to when a pavement reaches an unacceptable condition requiring construction intervention. However, while the prediction of time until a construction treatment should be applied is a critical component at all levels of pavement management decisions, many issues exist in the current RSL terminology that confuse, confound, and complicate proper interpretation, interagency data exchange, and use.

One common RSL definition is the time until the next rehabilitation or reconstruction event, but these are two different events in terms of the condition of the pavement at the time of construction as well as the associated construction costs. Attempting to interpret combined RSL estimates from mixed rehabilitation and reconstruction "units" provides little information to decision makers. Also, the timing of the next rehabilitation or reconstruction will depend on what future lower-level treatments than rehabilitation or reconstructions are applied.

Another common RSL definition is the time until a condition index threshold limit is reached. This approach shares the same issues as rehabilitation and reconstruction RSL units, but also introduces other service and safety condition indices, which further complicate the RSL meaning. Setting threshold limits for pavement conditions that are not based on human subjective ratings, such as cracking, can be complicated to justify. Interpretation of a single RSL number gets more complicated when it is based upon multiple condition states. Also, since there
are many construction treatments that can be classified as pavement preservation, this approach adds maintenance type activities to RSL units.

Yet another approach to RSL is based upon agency management rules on the time between applications of corrective pavement construction treatments; e.g., an agency may establish a policy that every eight years a resurfacing, rehabilitation, or reconstruction treatment is applied to each construction segment unit on their network. The RSL becomes the difference in time between the policy construction frequency and how long it has been since the last treatment was applied. However, this does not provide for optimal distribution under a limited funds constraint scenario.

An unintentional consequence of using current RSL terminology is that it tends to promote "worst-first" approaches to correcting pavement deficiencies. By expressing pavement condition in terms of RSL, layperson and elected officials expect that pavements in the worst condition get treated first, which tend to cost the most. Optimum allocation of annual pavement resurfacing, rehabilitation and reconstruction budgets will be a mixture of pavements with differing remaining lives and not based solely on a worst first approach.

From a communication standpoint, while the engineer who computed a RSL value has full knowledge of what that life end point means, the current RSL terminology leads to possible misinterpretation by recipient of the information. When RSL information is communicated, the intricate details of the endpoint is not obvious and the recipient may make his or her own interpretation of what that end point means. Compounding the issue, there are multiple definitions and interpretations for RSL which further aggravate the potential for misinterpretation. Even within pavement engineers and managers, it may mean one thing to those in preservation and another to those in design or budgeting.

REFORMULATING RSL CONCEPT
This paper provides an alternative definition of and process for determining pavement RSL that promotes consistency in the use of the terminology. Both the definition and process were developed under a Federal Highway Administration (FHWA) project that culminated in the publication of the following two reports:

- Reformulated Pavement Remaining Service Life (RSL) Framework
- Pavement Remaining Service Interval (RSI) Implementation Guidelines

The major source of uncertainty in the current RSL definitions is the use of the term “life” to represent different points in the construction history. When communicated, the meaning of “life” is also lost and it is interpreted differently by different stakeholders. In the pavement design context, "life" is used to represent the time until the “as-designed” pavement structure reaches an unacceptable condition. In the pavement management context, the "as-constructed" properties become more important in pavement life expectations than the assumed inputs into the original design process. Moreover, as a “repairable system”, the life of a pavement is not defined by correctable component (layer) failures.

The proposed solution to the problem is to remove the word "life" from the lexicon since it is the basis for confusion. Instead of using remaining service life, the recommended path to consistency involves adopting terminology of time remaining until a defined construction treatment is required – "Remaining Service Interval" or “RSI” replaces RSL. This terminology has the ability to unify the outcome of different approaches to determining needs by focusing on when and what treatments are needed, and the service interruption created.
Adoption of a definition related to construction treatments also opens up the vocabulary to treatments related to other factors besides pavement condition. For example, if a construction cycle is defined in terms of time until the next construction event requiring lane closures, then capacity improvements, shoulder widening, utility construction, and realignment construction activities can be included in the construction event, which provides for broadening the application of the definition in the future.

While the RSI framework is in place, as the old adage goes, the proof is in the pudding. Recognizing this, FHWA has undertaken a follow-up project to validate and demonstrate the RSI concept. Towards this end, PMS, both procedures and data, from the Maryland State Highway Administration (MDSHA) and Washington State Department of Transportation (WSDOT) are being used as well as the FHWA Pavement Health Track (PHT) analysis tool and Highway Performance Monitoring System (HPMS) 2010+ data.

Over the remainder of this paper, details about the RSI concept and implementation framework are presented, followed by the outcomes from RSI validation and demonstration efforts to date as well as the initial conclusions and recommendations. The paper also details how the RSI concept is directly in-line with the Moving Ahead for Progress in the 21st Century (MAP-21) (3) legislation and how it can help agencies implement MAP-21, thus shifting from a “worst-first” to a lowest life-cycle cost (LLCC) approach.

RSI CONCEPT AND FRAMEWORK
Most pavement construction activity planning is based on an annual or biennium fiscal time cycle used by the agency. The planning steps are cyclical and depend on the time cycle appropriate to the type of pavement asset. The process starts with input data that are fed into the performance prediction models to produce predictions of future change in the construction trigger models. The outputs from the predictions are then used to select the most appropriate construction or treatment strategy. The feedback cycle starts with documentation of the actual condition observed over time as well as the actual construction activities performed. During the operational phase, monitoring of pavement condition provides updated inputs for the next planning cycle and also to refine the performance prediction models.

Within the context of the planning process, the fundamental elements required to replace the existing RSL terminology with the new RSI terminology include a "controlled" vocabulary to define pavement construction events, a common basis for "when" the future construction event is needed, "how" future needs are determined (different levels of business decisions), and "where" defines the location and extent of the needed treatment. The objective of the vocabulary is to uniquely define the "what" in the type of predicted future construction event need. The vocabulary requires identification of three attributes – time when a treatment is needed, type of construction treatment, and reason for the construction treatment. Time is being specified since it is the basis for budgeting decision making and it is also meant to replace prediction models based upon traffic applications.

The following are examples of construction event definitions for improvements commonly included in agency PMSs:

- Crack sealing: application of sealants in surface cracks.
- Thick overlays: application of a material layer of intended uniform thickness greater than 50 mm (2 in.) that increases thickness of bound pavement layers by more than 25 percent.
- Concrete pavement restoration: application of full or partial depth joint repairs, slab replacement, dowel bar retrofit, or other restoration treatment not covered in another definition.
• Reconstruction: removal and replacement of all bound layers of an existing pavement.
  Similarly, the following are examples of the reason(s) for a future construction event:
• Roughness exceeds limiting International Roughness Index (IRI) value.
• Construction event that can reduce life cycle cost (LCC)
• Rut depth correction requires construction event.

Moving beyond terminology, implementation of the RSI concept requires consideration of generic agency and RSI implementation issues. The generic agency issues address the establishment of an agency’s RSI protocol, the identification of a RSI coordinator and the dissemination of the RSI concept within the agency. These issues only need to be addressed once, with periodic monitoring and revision to ensure they are still appropriate; however, they are vital to the success of an agency’s RSI program. The RSI implementation issues, on the other hand, focus on the step-by-step approach necessary for establishing the RSI concept within the agency. The suggested six implementation steps are detailed next.

1. Setting Construction Triggers
These are measurable or other aspects of a pavement’s condition that can be used to indicate the need for application of a construction event. Some of the considerations in the selection of triggers include historical practice, related agency practice, extent of pavement network, data collection budget, and family of pavements managed by an agency. Triggers that may be considered by an agency include:
• Level of service: mostly based on human ratings of pavement serviceability and measurement of roughness.
• Surface distress: standards exist, but they are not typically required for construction decisions. Reducing number of distresses to a small number of core distresses can reduce field data collection costs.
• Structural capacity: based on certain distress types and/or deflection testing. Common distresses include fatigue cracking on asphalt concrete (AC) pavements, corner cracks on jointed portland cement concrete (PCC) pavements, faulting on jointed PCC pavements, and punch-outs on continuously reinforced concrete pavements (CRCP). Deflection measurements can be used as diagnostic tool to look below pavement surface to get indication of subsurface damage.
• Safety aspects: mostly related to friction and hydroplane potential. Friction is typically characterized using a skid number parameter. Hydroplane potential is related to the ponding of water on the pavement surface.
• Agency time-based rules: time since last construction treatment, including maximum time between construction events.

2. Setting Threshold Limits
These are used to indicate when a condition has been reached that requires a construction event. Methods that can be used to establish limits include:
• Subjective: based on ratings from panel(s) of judges (layperson and/or experts). The basic process is to create rating scale to be used by judges, and then use statistical methods to interpret ratings and establish limits.
• Engineering: based on pavement performance mechanistic concepts or pavement-vehicle interaction factors.
• Empirical: based on observations of events, such as analysis of friction data and associated accident rates. This approach does not require thorough understanding of mechanism
being modeled, but considerations outside of inference space of original observations can limit applicability of models to future events.

- Economic analysis: based on an economic analysis of construction time-series costs over a long-term period, which depends on knowing or estimating how long alternative construction treatments will last based upon the predicted condition of the pavement at the time of the treatment, and the cost of the construction treatment.
- Combinations: combinations of two or more of the approaches previously described.

3. Selecting or Developing Performance Prediction Curves
These are used to predict the time when pavement conditions will reach a level of service construction trigger threshold and to predict post treatment performance as a function of pre-treatment condition in determining optimum construction treatment type and timing that minimizes life cycle costs. Current state-of-the-practice is to base the curves on analysis of pavement performance observations, which requires long-term data. When past performance data are not available, the creation of curves based on best available information can be used as a surrogate. A summary of the performance prediction curve options follows:

- Models based on design equations: curves used for pavement design can be different than those used for management. Nonetheless, they can be used for pavement management.
- Empirical models: curves based upon observations of events, including survivor curves, numerical regression models, Bayesian statistical updates, and neural network models. Measure of variability should be contained in these models to accumulate future risk probabilities.
- Agency time-based rules: the simplest curve is a time-based rule for future construction events, which does not require data collection investments, but does not provide basis for optimization of agency resources.

4. Identifying Collection of Inputs
Collection of pavement condition data should be based on the construction triggers, which form the basis for decisions on construction needs. While this appears straightforward, the challenge is integrating, adapting, and adopting advancements in pavement condition measurement to legacy management systems. The following list provides potential typical inputs to the RSI process:

- Pavement roughness
- Pavement distress
- Pavement structural response
- Traffic loads
- Climate
In addition, it is also important to give serious consideration to the following data-related issues:

- Missing data
- Measurement variability
- Sampling intervals and frequency

5. Establishing Strategy Selection Process
Selecting the most appropriate pavement construction strategy has many facets and considerations. The current challenge is to create a rational basis to move from “worst first” to a
"lowest construction cycle cost," since the application of construction events at the right time can extend the time until more costly treatments are required.

At the network-level, the objective of strategy selection is to characterize the current condition of pavements that require consideration of appropriate sequence of construction events. Since data tends to be more aggregated and less detailed, the more generic models used to predict performance can have greater variability. Likewise, strategy selection may be broken down into broad-based categories using a standard set of cost assumptions based on the treatment type.

At the project-level, objective of strategy selection is to provide decisions on what construction events are needed for each project identified from network-level needs analysis. The most significant difference between network- and project-level strategy selection is that project-level decisions are based upon human interpretations of available data and information as opposed to reliance on automated computer algorithms.

Recommended practices at both levels is to use life cycle costs (LCC) concepts to optimize selection of construction project and forecast future sequence of construction needs. LCC concepts are based upon consideration of multiple streams of future construction activities driven by prediction of future change in pavement states. At the project-level, LCC analysis can be supplemented with cost engineering considerations specific to each project site.

6. Performing Periodic Assessments and Updates
Modern quality management systems rely on a continual cycle of assessments and updates based on the assessments results:

- Assessments: formal assessments should be performed at periodic intervals to identify improvement opportunities. Tactics can range from internal agency review panels to external peer review experts. The former typically provide recommendations based on the current system, while the latter typically provide lessons learned from experience gained from use of other management methods.

- Updates: updates to models and processes used in the PMS process are needed to adapt to technology changes, such as new materials and construction techniques.

RSI CONTRIBUTIONS TO MAP-21
The MAP-21 defines asset management as a “strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on both engineering and economic analysis based upon quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at minimum practicable cost.” With the passing of the (MAP-21), there is a greater emphasis on asset management and performance and risk-based transportation management. This leads more towards long-term performance and sustainability.

The RSI concept is framed upon the same principles – that of identifying an optimized sequence of construction actions through engineering and economic analyses that minimizes the life cycle cost (LCC) while providing above acceptable level of service to the users. The RSI concept quantifies future needs and liabilities with a view towards minimizing LCC and can help agencies as they move away from “worst-first” to lowest life cycle cost (LLCC) approach to managing their pavements and effectively communicate this to agency executives and stakeholders. As agencies begin to address the requirements of MAP-21 by implementing
performance and risk based asset management plans, setting targets and measuring performance, RSI can contribute to the goals through conscientious application of the same principles and processes.

VALIDATION OF RSI CONCEPT
There are three on-going efforts to validate the RSI concept. The first two relate to on-going efforts at the MDSHA and WSDOT. The third one relates to FHWA PHT analysis tool utilizing HPMS 2010+ data.

The validation efforts at MDSHA and WSDOT will be based on comparison of the outputs from the State DOTs PMS system to the computations performed using the RSI algorithm. Computations using the RSI algorithm will follow the agency practices as closely as possible. For example, MDSHA uses its PMS to select treatments for road segments based on yearly budget analysis, which can be carried out for a 6 year period. This method results in segments selected based on current conditions and budget. Utilizing the RSI algorithm and MDSHA data, a multi-year benefit/cost optimization will be performed that will not only consider current condition, but also condition deterioration over the analysis period of 30 years in order to determine the optimum combination of construction events for the LLCC. For example, Figure 1 shows four possible combinations of construction events and schedules that will be considered in the LLCC optimization. The LCC of the four combinations will be compared to determine the LLCC. In addition the methodology will also quantify the increase in LCC of not implementing optimum construction needs under constrained budget scenario.

![Figure 1: Partial set of construction event combinations and schedule of activities.](image)

An illustration of a possible combination of construction events and schedule over the analysis period is depicted in Figure 2. Table 1 presents a typical RSI module output summarizing the years till the specific construction event for each project in the network, in which project shown in Figure 2 is presented as project number 1. It is noted that the RSI values are valid only when construction events are implemented as scheduled. When a schedule construction event is delayed or not implemented, the RSI should be re-computed incorporating...
this change. The cost of scheduled construction events for each project can be used to estimate annual budget requirement for each type construction treatment at network as illustrated in Table 2. In order to perform these calculations for MDSHA, the following information was obtained:

- Pavement performance models and construction triggers
- Threshold values used to define acceptable minimum level of service
- Decision trees
- Treatment benefits (i.e., if place a preservation treatment when IRI is 120 inch/mile (1.97 m/km), what is resulting IRI) and corresponding performance models.
- Any rules applied within PMS (i.e., must apply certain amount of friction treatments)
- Treatment cost information

A software program is being developed in order to conduct this analysis. For WSDOT, similar methodology will be followed as with MDSHA but within its PMS system for the extended analysis period.

The national level validation of the RSI algorithm is utilizing the PHT analysis tool with HPMS 2010+ data. The PHT analysis tool as originally developed estimates the RSL of pavement sections using the simplified Mechanistic Empirical Pavement Design Guide (MEPDG) based performance prediction models. The RSL is given as the least number of years until each various pavement distress reaches the specified threshold triggers. In order to validate the RSI concept, a plug-in is being developed for the PHT analysis tool implementing the RSI algorithm. This plug-in will follow the same algorithm as used with the State agencies but will be performed using HPMS 2010+ data at the national level.

FIGURE 2 Illustration of pavement RSI concept.
Although the validation efforts are still underway currently, each will have been completed by the time of 9th ICMPA and the outcomes will be presented.

### TABLE 1 A Typical RSI Summary of Each Project in the Network for the Analysis Period

<table>
<thead>
<tr>
<th>Project</th>
<th>RSI, year (Preservation)</th>
<th>RSI, year (Rehabilitation)</th>
<th>RSI, year (Reconstruction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3, 12, 18, 25</td>
<td>9</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>8, 24</td>
<td>5, 20</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>5, 7, 29</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>X</td>
<td>11, 13</td>
<td>26</td>
<td>6</td>
</tr>
</tbody>
</table>

### TABLE 2 A Typical Network Cost Estimation Summary for Each Construction Event and Year in the Analysis Period

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost, USD (Preservation)</th>
<th>Cost, USD (Rehabilitation)</th>
<th>Cost, USD (Reconstruction)</th>
<th>Total Cost, USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,240,000</td>
<td>24,355,000</td>
<td>5,546,000</td>
<td>31,141,000</td>
</tr>
<tr>
<td>2</td>
<td>2,650,000</td>
<td>12,122,000</td>
<td>12,980,000</td>
<td>27,752,000</td>
</tr>
<tr>
<td>3</td>
<td>590,000</td>
<td>8,456,000</td>
<td>20,456,000</td>
<td>29,502,000</td>
</tr>
<tr>
<td>X</td>
<td>3,234,000</td>
<td>12,466,000</td>
<td>4,234,000</td>
<td>19,934,000</td>
</tr>
</tbody>
</table>

### SUMMARY AND CONCLUSIONS

The “remaining service life” or “RSL” concept has been around for decades and is well entrenched in the pavement community. It is used at all levels of the pavement management decision process to plan for future field construction events. However, there is not a single, clear and widely accepted definition of RSL. Moreover, there is a great deal of ambiguity associated with the definition, especially with the use of the term “life” to represent different points in a pavement’s construction history. In addition, when communicated, the meaning of “life” is lost and it is interpreted differently by different stakeholders.

To overcome the RSL shortcomings, an alternate terminology has been introduced that removes the word "life" from the lexicon since it is the basis for confusion. Instead of “life,” the new terminology introduces the concept of time remaining until a defined construction event is required – "Remaining Service Interval" or “RSI.” Overcoming the RSL terminology, however, will not take place over-night.

While providing a logical alternative, the outcomes from the RSI process can be used, presented and communicated in the same fashion agencies have been doing for years using RSL. The RSI concept does not provide an alternative to assessing the health of the network or making decisions about where to spend the available funds. It simply provides a clear terminology and a logical process to move away from erroneous statements such as "this pavement has only 5 remaining years of life" and towards a consistent construction event-based terminology and understanding, types of construction events and the timing of those events. An added benefit of adopting the RSI terminology is that it provides a readily available way to communicate impacts of alternate budget scenarios. In addition, the RSI concept is directly in-line with MAP-21 and can help agencies implementing MAP-21 as they move away from a “worst-first” to LLCC approach.

The RSI concept is being validated using PMS data from MDSHA and WSDOT as well as at the national level utilizing the PHT analysis tool and HPMS 2010+ data. The validation...
efforts will be completed prior to 9th ICMPA conference, enabling presentation of the validation results.

REFERENCES

