Best Practices for Long-Lasting Low-Volume Pavements

Stephen T. Muench, PE, M.ASCE[1], Joe P. Mahoney, M.ASCE[2]; Weston Wataru, PE, M.ASCE[3]; Lois Chong, PE[4]; and John Romanowski, M.ASCE[5]

Abstract

A majority of U.S. and international roads are low-volume. Pavements on these roads, which are often owned or managed by local agencies with limited resources, represent a large transportation infrastructure asset and could benefit from lower life-cycle costs and better performance. The concept of long-lasting or "perpetual" pavements, often applied to high-volume pavements, is likely to produce similar benefits for low-volume pavements. Careful consideration of current long-lasting pavement research and existing practice can produce a straightforward set of best practices for use by local agency practitioners in designing, constructing, preserving, financing and marketing long-lasting low-volume pavements. These best practices are (1) a maximum traffic loading, (2) a minimum subgrade support, (3) a minimum pavement structure, (4) construction quality, (5) financing, and (6) and marketing. A case study involving the City and County of Honolulu illustrates how these best practices can be put into use in developing and implementing a long-lasting low-volume pavement strategy.

Suggested CE Database subject headings: Pavement design, pavement management, pavements, policies, best management practice, life cycle cost

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[1] Assistant Professor, Civil and Environmental Engineering, University of Washington, Mailbox 352700, Seattle, WA 98195, phone: 206.616.1259, fax: 206.543.1543, e-mail: stmuench@u.washington.edu

[2] Professor, Civil and Environmental Engineering, University of Washington, Mailbox 352700, Seattle, WA 98195, phone: 206.685.1760, fax: 206.543.1543, e-mail: jmahoney@u.washington.edu

[3] Chief, Permitting and Inspection, Department of Planning & Permitting, City and County of Honolulu, 650 S King St., DPP, Honolulu, HI 96813-3078, phone: 808.527.6303, fax: 808.527.6743, e-mail: wwataru@honolulu.gov

[4] Department of Design and Construction, City and County of Honolulu, 650 S King St., Fl 15, Honolulu, HI 96813-3078, phone: 808.527.6981, fax: 808.527.6103, e-mail: lchong1@honolulu.gov

[5] Vice President, Jas. W. Glover, Ltd., P.O. Box 579, Honolulu, HI 96809, phone: 808.591.8977, fax: 808.591.9174, e-mail: johnr@gloverltd.com

Introduction

Low-volume roads comprise the majority of U.S. and international roadway centerline miles. They are estimated to comprise 86 percent of the developing world's road network (Behrens, 1999) and almost 70 percent of the U.S. road network centerline miles (Muench et al., 2004). Pavements associated with these low-volume roads, termed "low-volume pavements" should, like any other pavement, perform adequately and be cost-effective. While much effort has been put forth developing design, construction and rehabilitation guidelines for long-lasting high-volume pavements, the idea of long-lasting low-volume pavements can also be of great value. However, given the prevalence of low-volume pavements and the significant financial constraints of agencies charged with their care, the benefits of sound research, ideas and best practices for long-lasting low-volume pavements could be substantial and even greater than those associated with high-volume pavements.

This paper proposes a set of best practices associated with long-lasting low-volume pavements in the U.S. These proposed best practices are meant for the practitioner and as such, provide specific quantitative guidance to assist in the development of a long-lasting low-volume pavement strategy. As an example of best practice use, this paper then presents a case study of the City and County of Honolulu's efforts to implement a long-lasting low-volume pavement strategy based largely on these best practices.

Background

This section presents key definitions and concepts related to long-lasting low-volume pavements.

Low-Volume Pavement

Low-volume pavements are defined as those high-type surface pavements (urban or rural) subjected to one million 80kN (18,000 lb) equivalent single axle loads (ESALs) or less over 40 years. This definition is consistent with the American Association of State Highway and Transportation Officials (AASHTO) (AASHTO, 1993) and Muench et al. (2004). This paper specifically addresses low volume pavements surfaced with hot mix asphalt (HMA), although many best practices would be equally applicable to other surface types.

Disposable Pavements

Historically, low-volume pavements have been designed for short life spans (10 to 20 years) and lighter traffic, while design and construction methods have often been less rigorous than those for high-volume pavements. These items combine to create a "disposable" pavement since the likely result will require one or more reconstructions (or disposals) during a typical 40- or 50-year analysis period. A sampling of local agency standards for pavements in Washington State (Table 1) indicates that some specify disposable low-volume pavements.

The structural designs listed in Table 1 for the City of Spokane, City of Seattle, King County, Klickitat County and Chelan County are unlikely to last long because at least one of the following is true:

- The surface course is thin enough to allow significant at-depth fatigue cracking.
- The HMA portion of the pavement is too thin to allow potentially damaged surface material to be removed by milling. This is a concern where curb lines and bridge clearances must be maintained.
- The overall structural support is too little to prevent subgrade rutting.
- Subgrade strength or stiffness is not adequately specified. This lack of specification could allow a marginal pavement structure to be built on a weak subgrade resulting in early failure.

Encouragingly, the designs listed for the City of Redmond, City of Vancouver and the Washington Asphalt Pavement Association (WAPA) are likely to be long-lasting pavements.

Principles of Long-Lasting Pavements

In general, a long-lasting pavement is designed to make at-depth distress unlikely. Therefore, when distresses do occur, they will initiate at the surface and propagate downward. This pattern of distress can then be corrected by periodic surface maintenance and renewal before it affects the bulk of the pavement structure. In this way, life-cycle costs are minimized because the bulk of the pavement structure remains relatively undamaged and can be left in place for substantially long periods of time.

Long-Lasting Low-Volume Pavements

A long-lasting low-volume pavement is one designed, constructed, maintained and rehabilitated such that it will last longer than 40 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement. This definition purposefully mimics the Asphalt Pavement Alliance's definition of a Perpetual Pavement (APA, 2002).

Existence of Long-Lasting Low-Volume Pavements

Long-lasting low-volume pavements do exist and have been verified through substantial and accurate records. An investigation in Washington State (Muench et al., 2004) identified the existence of a substantial number of long-lasting low-volume pavements owned by the Washington State Department of Transportation (WSDOT). The investigation used the Washington State Pavement Management System (WSPMS) to examine over 15,300 km (9,500 miles) of pavement in an effort to identify long-lasting low-volume pavements. This investigation found:

- Low-volume pavements comprise about 7 percent of all WSDOT centerline miles. This is to be expected since WSDOT generally owns the higher volume routes within the State.
- Nearly all low-volume pavements are surfaced with hot mix asphalt (HMA) or bituminous surface treatments (BST).
- Low-volume pavement locations are spread throughout the state.
- About 64 percent are 35 years or older and have not undergone any major rehabilitation, which meets the Asphalt Pavement Alliance's Perpetual Pavement award criterion for age (APA, 2005).
- HMA pavements were constructed relatively thin but receive regular non-structural overlays that, over time, improved the pavement structure.

By chance or by design, WSDOT's long-lasting low-volume pavement strategy has been to initially construct a rather thin pavement but then monitor it closely and provide timely maintenance and rehabilitation in the form of HMA overlays or surface treatments. In sum, even for pavements of marginal structure, a consistent long-term preservation strategy can result in long-lasting low-volume pavements.

Benefits of Long-Lasting Low-Volume Pavements

Generally, long-lasting pavements are considered beneficial because they (APA, no date):

- Offer the lowest life-cycle cost
- Minimize traffic delays because long reconstruction projects are not needed

- Save money through recycling milled pavement surface
- Conserve nonrenewable natural resources and landfill space through recycling

With the possible exception of minimizing traffic delay, these advantages apply to long-lasting low-volume pavements as well.

Best Practices for Long-Lasting Low-Volume Pavements

In order to assist practitioners in realizing long-lasting low-volume pavement benefits, it would seem prudent to develop a set of best practices for the design, construction, preservation, financing and marketing of long-lasting low-volume pavements.

Traffic Loading

Future traffic loading must meet the definition of a low-volume pavement: no more than 1 million ESALs over 40 years. While long-lasting high-volume pavements are generally designed to perform adequately regardless of ESAL loading, long-lasting low-volume pavements will not. Typical HMA thicknesses required to produce acceptable long-lasting pavement strains of about 70 microstrain tension on the bottom of the HMA layer and about 200 microstrain compression on the top of the subgrade (limiting strain values from Monismith and Long, 1999) are on the order of 200 to 250 mm (8 to 10 inches), which is likely beyond the range of initial construction affordability for many local agencies. Thinner pavements are thus necessarily constrained by loading.

While it may be difficult to accurately predict traffic loading on a low-volume pavement, a general classification is usually possible and adequate. Most low-volume pavements endure far less than 1 million ESALs over 40 years as heavy loads are generally limited to farm equipment, regular garbage truck routes and the occasional moving van or delivery truck. If no other regular heavy vehicles contribute substantially to loading, then the assumption of no more than 1 million ESALs over 40 years is reasonable and likely. Overweight farm equipment or regular heavy vehicles such as buses or tractor-trailer trucks would likely invalidate the assumption of no more than 1 million ESALs over 40 years.

Recommendation

- Loading of no more than 1 million ESALs over 40 years.

- No regularly overweight vehicles. If some overweight vehicles are expected, a brief layered elastic analysis should be conducted to determine if the anticipated number of overweight vehicles can be accommodated over 40 years without failure.
- No current or planned regular bus (FHWA class 4 vehicles) routes.
- No current or planned regular tractor-trailer truck (FHWA class 8 through 13 vehicles) routes.

Subgrade Strength and Stiffness

Subgrade support is essential to long-term pavement performance (Hveem, 1948; AASHTO, 1993), which implies that it is important to properly and thoroughly specify subgrade conditions upon which long-lasting low-volume pavements are built. This section first references some of the more popular subgrade characterization tests and then examines two possible subgrade characterization directions for long-lasting low-volume pavements: (1) specifying pavement structural design based on existing subgrade support, (2) using minimum support criteria with a standard pavement design.

Subgrade Characterization Tests

There are a number of tests that can be used to characterize subgrade support. Agencies such as the Central Federal Lands (2005) and AASHTO (1993) have developed recommendations on practices for sampling and testing subgrades.

Structural Design Based on Existing Subgrade Support

For low-volume pavements within the U.S. it is most common to specify a particular pavement structure based on a existing subgrade support. This support is usually characterized by one of several common measures including California Bearing Ratio (CBR), Resistance Value (R-value) and resilient modulus (M_R). These measures can be quantified by field or laboratory tests (usually limited in number) or based on a general soil classification. Often times, subgrade support is summarized using general categories as illustrated in Tables 2 and 3.

While specifying a particular pavement structure based on existing subgrade support can be successful, it tends to imply that poor subgrade conditions can be overcome with added pavement structure alone, which may not result in a feasible design. An alternative approach is to specify a minimum subgrade support on which a standard pavement section can be built and then investigate options for achieving that minimum subgrade support.

Minimum Support Criteria with a Standard Pavement Design

Some international agencies have developed design catalogs and procedures that are based, in part, on a fixed subgrade strength. This implies that the actual subgrade strength must be known or approximated in order to determine what must be done to achieve the minimum assumed strength level.

In South Africa, the National Roads Agency through their design standards (National Roads Agency, 1996; South Africa/US Pavement Technology Workshop, 2000) uses a minimum CBR criterion of 15 percent for development of their catalog designs. That minimum is attained through the use of granular or lightly cemented subbase layers placed over the subgrade. Thus the combination of the existing subgrade and the addition of subbase material form the foundation for the pavement structural layers. Table 4 shows the subbase options listed in the South African design procedure (often referred to as capping layers).

In the United Kingdom, the subgrade, the capping layers, and the subbase are considered to be the "foundation" for the remainder of the pavement structure (Merrill, 2005). This foundation serves two roles: (1) a platform for constructing the remaining pavement layers, and (2) to bring the foundation support up to a minimum standard. This pavement design process incorporates, like South Africa, the concept of capping layers to bring the subgrade up to an equivalent CBR of at least 15 percent. Capping layers are commonly used in the European Union (European Commission, 1999). Out of the 20 countries that reported using capping layers, 10 reported characterizing capping layer strength by the use of the CBR test.

Recommendation

Specify subgrade support using appropriate test results and use a combination of the two approaches: a tabular format (first approach) with a minimum allowed subgrade CBR of 10 percent (second approach). Subgrades with a CBR of less than 10 percent would require geotechnical analysis or remediation (e.g., subbase layers, stabilization, capping layers) to bring CBR up to 10 percent. A CBR of 10 percent is chosen as a conservative value that will, if met, enable the designer to be confident that poor subgrade conditions (generally agreed to be a CBR of 5 or less according to Table 2 and 3) are avoided.

Minimum Pavement Structure

Some minimum pavement structure is needed to (1) prevent at-depth distress, (2) allow for periodic mill-and-overlay projects to maintain adequate surface condition where applicable, (3) prevent frost damage where applicable, and (4) ease constructability.

HMA Thickness to Prevent At-Depth Distress

A number or research efforts have pointed out that in pavements that are sufficiently thick, distresses tend to initiate on the surface and propagate downward. Distresses, then, can be eliminated through periodic surface maintenance and renewal, which is less costly than the total reconstruction or extensive rehabilitation efforts required to eliminate distresses that initiate at the bottom of the pavement. Muench et al. (*2*) point out specific distress research:

Cracking. Numerous studies (e.g., Schmorak and Van Dommelen, 1995; Nunn, 1998; Uhlmeyer et al., 2000; Myers and Roque, 2001) have concluded that a majority of cracking, if not all cracking, in thick pavements (thicker than about 160 mm (6 inches)) initiates at the surface and propagates downward. Cracking that initiates at the bottom of the HMA layer is unlikely if the tensile strain is limited to less than 70 microstrain (Monismith and Long, 1999). Schmorak and van Dommelen's (1995) analysis of pavements thinner than 160 mm (6 inches) that exhibited full-depth cracking suggested these cracks had also initiated at the surface.

Rutting. Surface rutting, which occurs through HMA plastic deformation, is generally confined to the top 100 mm (4 inches) of thick HMA pavements (Nunn, 1998). Subgrade rutting is unlikely if vertical strain at the top of the subgrade is limited to less than about 200 microstrain (Monismith and Long, 1999). Nunn (1998) reported that for the conditions encountered in the United Kingdom's Transport Research Laboratory (TRL) experimental roads, structural or subgrade rutting was relatively insignificant at HMA depths of 180 mm (7 inches) or greater.

HMA Thickness to Allow for Mill-and-Inlay Rehabilitation

Surface renewal that involves milling off a specified thickness of HMA and replacing it with a new HMA layer of the same thickness is gaining popularity because it can restore smoothness, produce recyclable material, and maintain existing pavement elevations. To make this a viable rehabilitation option, a pavement needs to accommodate a minimum mill depth and still be able to support construction traffic on its remaining structure. A rough rule-of-thumb is that a mill depth of at least 38 to 50 mm (1.5 to 2 inches) is typically necessary to remove even minimal defects, while a remaining thickness of at least 50 mm (2 inches) should remain to (1) support construction loads, and (2) minimize the possibility that large full-depth pavement chunks will be inadvertently removed by the milling machine.

Aggregate Base Material Thickness for Constructability

Thin unbound aggregate layers (less than 150 mm (6 inches) thick) are possible, however (1) they do not add much strength to the overall pavement structure, (2) they provide little protection from frost heave (if locally applicable), (3) fines from the underlying subgrade may contaminate a substantial portion of the layer and inhibit drainage, (4) they are difficult to compact, (5) they are frequently subject to quantity overruns and (6) it is difficult to construct and maintain smoothness in thin aggregate layers.

Pavement Structure Thickness for Frost Protection

Some form of frost protection is prudent in areas susceptible to frost action. While many methods can be successful, perhaps the most straightforward one is to limit the depth of frost by designing the pavement structure to be greater than 50 percent of freeze depth. In the absence of other resources, maximum frost depth can be calculated using the Modified Berggren formula in *Modberg* (free software by Cortez et al., no date given).

Recommendation

HMA thickness of no less than 125 mm (5 inches). This represents the low end of top-down cracking research data, is adequate for mill-and-inlay rehabilitation and can be comfortably constructed in two lifts. While the WSDOT investigation (Muench et al., 2004) showed that initially thin pavements could be periodically overlaid to extend pavement life, this option is often not acceptable in areas where curb heights drainage paths, roadside hardware clearances and overpass clearances must be maintained. If these items are of concern an initially thicker design is prudent in order to accommodate mill-and-inlay rehabilitation.
Aggregate base thickness of no less than 150 mm (6 inches). This makes for better constructability.

Adequate pavement structure thickness to provide frost protection. In the absence of other guidance, a pavement structural thickness at least 50 percent of design freeze depth is acceptable. Increasing aggregate base layer thickness is likely the most economical way of achieving increasing pavement structural thickness in order to meet this recommendation.

Quality Construction

Proper construction is necessary for a pavement to function as designed. This implies adequate construction specifications, and minimum quality control practices.

Construction Specifications

Construction specifications must be clear in their communication of an owner agency's expected standards. While not all agencies have developed construction standards, many trade organizations publish quality guide specifications that can be adapted for local use including the National Asphalt Pavement Association, Asphalt Institute, and Asphalt Pavement Associations of Oregon, Colorado, and Indiana. In addition to these guide specifications, state specifications can be used as a starting point, however they will likely have to be modified to accommodate the more limited resources of local agencies.

Quality Control

Quality control programs and quality assurance regimes that are commonly practiced on paving jobs at the State and Federal level should, in a scaled-back form, be practiced on local level. While local agencies often do not have the manpower or facilities to perform quality assurance checks, contractors generally do and arrangements can be made for the contractor to provide the owner agency with quality control test results. As a minimum, arrangements for density testing on each HMA lift should be made. While there are many other possible construction quality measurements (e.g., aggregate gradation, asphalt content, smoothness), acceptable density measurements taken at random locations are probably the best single construction quality measure for low-volume pavements. An unpublished 2001 survey (Mahoney) for the Pacific Coast Conference on Asphalt Specifications (PCCAS) organization showed that for western State DOT agencies (Alaska, Arizona, California, Hawai‘i, Nevada, Oregon, Washington and Western Federal

Lands) minimum acceptable density standards ranged from 91 to 92 percent of maximum theoretical density, with typical average in-place density ranging from 92 to 95 percent.

Recommendation

- Use a construction specification that addresses paving quality.
- If resources are scarce make provisions for the contractor to share quality control test results.
- Specify a minimum average density of 92 to 94 percent of theoretical maximum density. Specifying the local State DOT minimum compaction level may be a straightforward way of doing this.

Pavement Preservation

In addition to normal pavement preservation best practices, long-lasting low-volume pavements present two more significant issues. First, significantly delayed rehabilitation could allow distresses that initiated at the surface to propagate down into the pavement structure to such a depth that a more costly rehabilitation or even a reconstruction would be necessary. This would, understandably, negate the benefits of a long-lasting low-volume pavement.

Second, long-lasting low-volume pavements allow more maintenance and rehabilitation options to be considered than disposable pavements do. The thin HMA surface layer of a disposable pavement is likely to deteriorate from the bottom up through either subgrade rutting or traditional fatigue cracking. Thus, when distress becomes visible at the surface, the entire structure is already compromised and, in general, cannot be saved. Therefore, treatment options that address small surface defects or provide surface protection such as chip, slurry and fog seals would not be effective. In curbed areas, overlays, which can be used to add pavement structure, must be gradually thinned as they approach the curb in order to maintain adequate curb height which can result in inadequate structure near the pavement's edges. As discussed in the "minimum pavement structure" section, mill-and-inlays are also problematic. In contrast, because a long-lasting low-volume pavement is designed to have substantial structure in good condition, seals and mill-and-inlays are viable preservation options.

Recommendation

- Maintain a timely schedule of rehabilitation actions.
- Investigate the feasibility of using surface treatments and other maintenance and rehabilitation practices that are not normally effective on a disposable pavement.

Financing

One of the most difficult aspects of a long-lasting low-volume pavement strategy is long-term financing. Without regular and somewhat predictable financing, maintenance and rehabilitation activities may be significantly delayed allowing pavements to deteriorate past their most cost effective rehabilitation point. WSDOT experience has been that in order to restore pavement condition to a predetermined level, it will cost 2 to 3 times as much if the pavement is allowed to deteriorate for 2 to 3 years beyond the optimum rehabilitation point (Muench et al., 2003).

Table 5 shows WSDOT, Nevada Department of Transportation (NDOT) and City and County of Honolulu funding data from 1994 through a planned 2007. This data suggest that at the state and large city level preservation programs should be funded in the $7,000 to $9,000 per lane-mile (1.6 lane-km) per year range. Although this data applies to all pavements, it provides a useful rule-of-thumb for pavement preservation funding. It is likely that for low-volume pavements only, the required preservation funding level is less.

One mechanism that has helped the equitable distribution of WSDOT funding for both high and low-volume pavements is the Chapter 47.05 of the Revised Code of Washington (RCW):

> **RCW 47.05: Priority Programming for Highway Development**
>
> "…It is the intent of the legislature that investment of state transportation funds to address deficiencies on the state highway system be based on a policy of priority programming having as its basis the rational selection of projects and services according to factual need and an evaluation of life cycle costs and benefits that are systematically scheduled to carry out defined objectives within available revenue. The state must develop analytic tools to use a common methodology to measure benefits and costs for all modes."

The RCW also mandates the most cost effective pavement surfaces, which would tend to support a long-lasting low-volume pavement strategy (RCW 47.05.030). This mechanism has helped minimize political influence in WSDOT's pavement preservation program decision-making process.

Recommendation

No specific funding plan is proposed. However, without reasonably consistent funding, maintenance and rehabilitation actions cannot be consistently scheduled when they would be most cost effective. Therefore, without reasonably consistent funding, any pavement preservation program will contain inefficiencies and, in the long-term, cost more money. Based on Table 5, it seems that sufficient funding for low-volume pavements could be as high as $7,000 to $9,000 per lane-mile (1.6 lane-km) per year but perhaps somewhat less.

Marketing

Marketing should involve a deliberate program designed to educate public officials, politicians, contractors, developers and general public of the costs and benefits of long-lasting low-volume pavements. Many different marketing plans can be successful. This section discusses several general ideas in the form of research and communications that can prove useful in an overall marketing effort.

Key Research for Use in Marketing

These two research items can be used to provide quantifiable data to strengthen arguments for a long-lasting low-volume pavement strategy.

Gather information regarding existing low-volume pavements. Actual evidence tends to be more convincing than general ideas. If possible, this evidence should consist of (1) current pavement structural profiles, (2) time periods between pavement construction and reconstruction, (3) costs of initial construction, maintenance and rehabilitation and reconstruction efforts. Ideally, evidence should consist of historical trends and averages as well as specific detailed cases.

Perform a life-cycle cost analysis (LCCA) of existing and proposed long-lasting low-volume pavements. Long-term costs are often overlooked in considering different pavement strategies. A fair LCCA can be a powerful tool to illustrate long-term costs associated with pavements. LCCAs should be conducted in accordance with the FHWA's *Life-Cycle Cost Analysis in Pavement Design* Interim Technical Bulletin (Walls and Smith, 1998), a widely accepted document. At least two free Web-accessible software programs are specifically designed to perform such an analysis: *RealCost* (from the FHWA) and *LCCA* (from the Asphalt Pavement Alliance).

All LCCA procedures tend to involve rather significant assumptions that can influence outcomes. Based on trial runs using Hawai'i cost data, the most critical input data for low-volume pavements are typically (1) initial construction costs, (2) rehabilitation/reconstruction costs, (3) pavement life between rehabilitation/reconstruction efforts, and (4) discount rate.

Communication Plan

Long-lasting low-volume pavement ideas and investigation results should be effectively communicated to both the pavement professional community and the general public.

Communication to the professional community. The professional and technical community consists of all those in professional positions dealing with pavements including contractors, consultants and agency personnel. If this community is convinced of the benefits associated with a long-lasting low-volume pavement strategy, they can be strong advocates and help disseminate long-lasting low-volume pavement ideas to other professionals and the public at large. Typically, this community can be engaged through local asphalt pavement associations, technical training programs (e.g., Federal Highway Administration Local Technical Assistant Programs) and professional newsletters.

Communication to the general public. Use clear and straightforward language to communicate the present situation, what about it makes it necessary for change, the new strategy and the anticipated costs/benefits. Washington State government recently formalized what they call "plain talk" when Governor Christine Gregoire issued Executive Order 05-03 (Baroga et al., 2005):

> "…requiring state agencies to use "Plain Talk" in letters, announcements, publications, and other documents. Plain Talk means writing with everyday language, presenting information logically, composing short sentences, developing easy-to-read layout and design, and using active voice sentences that clearly show who is responsible for what."

Specific strategies will vary but could include public meetings, project signs emphasizing that "these pavements are specifically designed to be long-lasting", and press releases.

Recommendation

Develop and execute a marketing plan, which, as a minimum, should involve:

- Basic research into low-volume pavement design practices, life expectancies and associated costs. Actual data is more convincing than broad generalities.
- Communication plans for both the pavement professional community and the general public.

Case Study: Honolulu City & County

In order to illustrate how a local agency can use best practices to implement a long-lasting low-volume pavement strategy, this paper presents a case study of the City and County of Honolulu and their 2006 structural design standards update. A key component of this update involved a switch from disposable to long-lasting low-volume pavements. This section's discussion will focus on this low-volume pavement aspect. This case study represents one implementation path for such a strategy; there are likely many others.

Existing Conditions

From 2004 to the present, increased public attention has been focused on pavement condition in Hawai‘i and specifically in the City and County of Honolulu as many roads and streets deteriorated to what the press deemed "bone-rattling" and "hubcap spinning" conditions (*Honolulu Advertiser*, 2004). In February of 2005, the newly elected mayor made road repair a priority declaring a "war on potholes" (Leidemann, 2005).

Unusually wet 2004 conditions were often blamed for poor pavement conditions in the press. Independent of press issues, there was growing sentiment within the City and County that existing new construction structural design standards were inadequate and required updating from the existing 1972 standard. Examination of this standard reveals that HMA layers were only 50 mm (2 inches) thick placed over 150 mm (6 inches) of crushed aggregate and borrow of varying thicknesses depending upon subgrade CBR. While perhaps adequate in 1972, this design was believed to contribute to several key problems:

- **New subdivision pavements in poor condition**. Roads in new subdivisions are typically turned over to the City and County upon substantial completion of the subdivision. These roads, typically paved early in the development process to provide improved construction traffic access, were often turned over to the City and County already in need of substantial rehabilitation or reconstruction because of their thin HMA structure and heavy construction traffic.

- **Existing pavements with few rehabilitation options**. The thin HMA surface layer of many existing pavements precluded a reasonable mill-and-inlay rehabilitation strategy and left overlays as the only viable option. However, on curbed streets, these overlays are typically only placed at the design thickness in the center of the roadway because they must be gradually thinned as they approach the curb in order to maintain adequate curb heights and wheelchair access. Surface treatment options (e.g., chip seal, slurry seal, fog seal) were not considered useful because they are unable to correct the significant structural damage that usually occurred in the thin HMA layer.
- **The exceptionally wet weather experienced in 2004 exacerbated pavement deterioration**. A contributing cause to poor pavement performance may be that excess moisture saturated much of the underlying aggregate and borrow layers and substantially weakened them. Subsequently, the thin HMA layer, which may have been viable when placed over a strong, dry unbound base layer was inadequate when placed over a weakened saturated one.

Other significant contributing factors to perceived poor pavement conditions were: (1) a general lack of consistent and adequate pavement preservation funding over the previous decade (Table 5), (2) a political mindset that at times valued the surface area of new pavement rather than the volume, which may have encouraged thin overlays in order to achieve maximum surface area.

Proposed New Standard

In the summer of 2005, the City and County of Honolulu began developing a proposed new structural design standard, which centered on 4 main ideas:

1. **Separate the standards for low-volume pavements from other pavements**. While low-volume pavements lend themselves to simple design tables, high-volume pavements, due to the complex nature of their loading, generally do not. Therefore, a two-level approach should be used.
2. **Design high-volume pavements using any of several approved design procedures**. Allow consultants to design high-volume pavements using any generally accepted procedure. This allows

designers greater latitude to use their expertise and judgment when designing a high-volume pavement rather than confining them to a formulaic design procedure or a simple table.

3. **Design low-volume pavements to be long-lasting**. Most new pavements are low-volume and do not warrant extensive design effort and expense. A design table approach would simplify the design procedure and reduce its cost.
4. **Retain the simplicity of the 1972 standard**. The 1972 standard's simplicity allowed for broad use by those both familiar and unfamiliar with technical pavement issues.

These central ideas and the new structural design standard were developed by the City and County with the assistance of the Hawai'i Asphalt Paving Industry (HAPI).

Drafting the New Standard

After initial development, a draft copy of the new standard was circulated through City and County departments for internal review and comment. Some nomenclature and specification changes were made. After the resulting revisions, the new standard was sent out for comment to about 150 organizations that conducted local business associated with pavements including contractors, developers, consultants, and the state DOT. From these 150 requests, only one response raised a significant concern: increased construction costs of long-lasting HMA pavements would result in higher home costs. This legitimate concern was addressed using a life-cycle cost argument that showed a likely lower life-cycle cost to the community when long-lasting low-volume pavements were used. The final approved standard (Figure 1) went into effect 1 March 2006.

Marketing the New Standard

Communication of the new standard began as the draft was in progress. It was felt that (1) the general public needed to be aware of efforts to shift to a long-lasting low-volume pavement strategy, and (2) the strategy needed to be presented to the pavement professional community in more detail. Communication efforts continue as of this writing. The following sections describe two key communication events and their effects.

Presentation to the Honolulu City Council Public Works & Economic Development Committee

On 30 November 2005, a 30 minute presentation by a small coalition of HAPI and City and County personnel was used to forward the idea of long-lasting pavements and discuss their potential benefits and some of the best practices associated with them. This presentation helped communicate to both the City Council and the general public (both a newspaper article and an evening news spot resulted from the presentation) the potential benefits of a long-lasting pavement strategy.

Workshop Training

On 20 March 2006 a day-long workshop jointly sponsored by the Hawai‘i Local Technical Assistance Program (LTAP) and HAPI presented the new structural design standard and specifically its long-lasting low-volume pavement strategy as part of a general program on pavement preservation and life-cycle costing. Over 100 people attended the event including City and County, State Department of Transportation and Federal Highways personnel, consultants and contractors. This event helped introduce and reinforce long-lasting low-volume pavement ideas, costs and benefits. A second workshop is scheduled for late 2006.

Case Study Summary

The City and County of Honolulu long-lasting low-volume pavement effort used the best practices presented in this paper albeit incompletely. For instance, the effort does not substantially address quality construction or financing while the minimum CBR is 5 percent, which is lower than the best practice recommended 10 percent minimum. This lack of full best practices use does not imply failure, but rather the idea that multiple approaches to long-lasting low-volume pavement strategies can be successful.

Summary and Conclusions

Low-volume roads comprise the majority of U.S. and international roadway centerline miles. Historically, pavements for these roads have often been built as disposable pavements: ones that are designed for short 10- to 20-year life spans and constructed with lower standards. The concept of long-lasting pavements, popularized through its application to high-volume pavements, can benefit low-volume pavements by (1) reducing life-cycle cost, (2) allowing more rehabilitation options and (3) generally remaining in better condition.

Research done in the areas of high-volume long-lasting pavements as well as existing practices that have produced high-quality pavements can be combined to produce a set of best practices for the design, construction, preservation, financing and marketing of long-lasting low-volume pavements. These best practices are:

- **Maximum traffic loading** of 1 million ESALs over 40 years with no current or anticipated bus or heavy vehicle routes.
- **Subgrade strength and stiffness** adequately specified using approved testing methods. A minimum allowable CBR of 10 percent provides high confidence that the subgrade will not contribute to pavement failure.
- **Minimum pavement structure** of at least 125 mm (5 inches) of HMA and 150 mm (6 inches) of unbound aggregate base material. This provides (1) reasonable assurance that distresses will not initiate at the bottom of the HMA layer, and (2) a constructible base layer on which to place the HMA.
- **Quality construction** consisting of adequate paving specifications and a quality control plan that, as a minimum, includes a density specification of 92 to 94 percent of theoretical maximum density for all HMA layers.
- **Financing** that is reasonably consistent and is at least several thousand dollars per lane-km (lane-mile) of low-volume pavement.
- **Marketing plan** that includes communication plans for both the professional community and general public as well as actual evidence to substantiate claims.

The City and County of Honolulu's case study in implementing a long-lasting low-volume pavement strategy captured dissatisfaction with disposable pavements and one particular implementation plan. While ultimate success can only be measured over time, their adherence to some, but not all, the discussed best practices shows that (1) it is possible to implement a long-lasting low-volume pavement strategy, and (2) acceptance of such a strategy by the professional community can be near unanimous.

References

American Association of State Highway and Transportation Officials (AASHTO). *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

Asphalt Pavement Alliance (APA). *2005 Perpetual Pavement Award Nomination Form*. Asphalt Pavement Alliance, Lexington, KY, 2006. http://www.asphaltalliance.com. Accessed 15 March 2006.

Asphalt Pavement Alliance (APA). *Perpetual Pavement Fact Sheet.* Asphalt Pavement Alliance, no date.

Asphalt Pavement Alliance (APA). *Perpetual Pavements: A Synthesis*, Asphalt Pavement Alliance, Lanham, MD, 2002.

Baroga, R., S. Pedigo-Marshall and K. Boyd. Using Plain English at WSDOT. *Grey Notebook*, volume 17. Washington State Department of Transportation, Olympia, WA, 31 March 2005, p. 65.

Behrens, I.L.C. (1999). Overview of Low-Volume Roads. In *Transportation Research Record 1652* TRB, National Research Council, Washington, D.C., pp. 1-4.

Central Federal Lands. *Pavement Investigation and Report*, Central Federal Lands Highway Division, Federal Highway Administration, Lakewood, CO, 2005.

Cortez, E., S. Moore, D. Pidgeon, M. Kestler and R. Berg. *ModBerg*, version 99.2.0. Software from the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH, no date given. Download at: https://transportation.wes.army.mil.

European Commission. *COST 333: Development of New Bituminous Pavement Design Method*, Final Report, COST 333, Directorate General Transport, European Commission, 1999.

Hawai‘i Asphalt Paving Industry (HAPI). *HAPI Asphalt Pavement Guide*. Hawai‘i Asphalt Paving Industry, Honolulu, HI, 2003. http://www.hawaiiasphalt.com. Accessed 15 March 2006.

Hveem, F.N. *A New Approach for Pavement Design*, Engineering-Record New Reprint, McGraw-Hill Publishing Co., Inc., 1948.

Leidemann, M. Mayor calls for “war” on city potholes. *Honolulu Advertiser*, 25 February 2005.

Merrill D. *Guidance on the Development, Assessment and Maintenance of Long-Fife Flexible Pavements*, Report TRL639, Transport Research Laboratory, Crowthorne, Berkshire, UK, 2005.

Monismith, C.L. and F. Long. *Mix Design and Analysis and Structural Section Design for Interstate Route 710*. Technical Memorandum No. TM-UCB-99-2, prepared for Long Life Pavements Task Force, 1999.

Muench, S.T., G.C. White, J.P. Mahoney, L.M. Pierce and N. Sivaneswaran. Long-Lasting Low-Volume Pavements in Washington State. *Proceedings*, International Symposium on Design and Construction of Long Lasting Asphalt Pavements, Auburn, AL, June 7-9, 2004, pp. 729-773.

Muench, S.T., J.P. Mahoney and L.M. Pierce. WSDOT *Pavement Guide Interactive* (CD-ROM). Washington State Department of Transportation, Olympia, WA, 2003.

Myers, L.A. and Roque, R. Evaluation of Top-Down Cracking in Thick Asphalt Pavements and the Implications for Pavement Design. In *Perpetual Bituminous Pavements, Transportation Research Circular No. 503*. TRB, National Research Council, Washington, D.C., 2001, pp. 79-87.

National Roads Agency. *Technical Recommendations for Highway Structural Design of Flexible Pavement for Interurban and Rural Roads*, TRH4, South African National Roads Agency Ltd, Pretoria, South Africa, 1996.

Nunn, M. *Design of Long-Life Roads for Heavy Traffic*. Australian Asphalt Pavement Association Industry Conference, Surfers Paradise, Queensland, Australia, 1998.

Potholes: Is O‘ahu a Third World country? Editorial in the *Honolulu Advertiser* posted on Wednesday, 7 January 2004.

Schmorak, N. and A. Van Dommelen. Analysis of the Structural Behavior of Asphalt Concrete Pavements in SHRP-NL Test Sections. *Proceedings*, International Conference on the Strategic Highway Research Program and Traffic Safety, Prague, 1995.

South Africa/US Pavement Technology Workshop. Session 2: Structural Pavement Design , Course Notes, University of California, Berkeley, CA, 20-23 March, 2000.

Texas Asphalt Pavement Association. (TxAPA). *Pavement Selection for City Streets*, Technical Article, Texas Asphalt Pavement Association, Buda, TX. http://www.txhotmix.org/public_articles.php?article_id=6&sess_id=bd447d35266b38dc4ddae1e17475056d. Accessed 22 March 2006.

Uhlmeyer, J.S., K. Willoughby, L.M. Pierce, and J.P. Mahoney. Top-Down Cracking in Washington State Asphalt Concrete Wearing Courses. *Transportation Research Record 1730*. Transportation Research Board, National Research Council, Washington, D.C., 2000, pp. 110-116.

Walls, J. and M.R. Smith *Life-Cycle Cost Analysis in Pavement Design.* FHWA report FHWA-SA-98-079, Federal Highway Administration, Washington, D.C., 1998.

Wisconsin Asphalt Pavement Association (WAPA). *2001 Design Guide*, Wisconsin Asphalt Pavement Association, 2001.

Tables

Table 1. A Sampling of Local Residential Road Minimum Structural Design Standards in Washington State[a]

Agency	Surface Course	Base Course	SN[b]	Subgrade[c]
City of Spokane	50 mm (2 in.) HMA	150 mm (6 in.) crushed stone	1.66	Design independent of subgrade strength
City of Seattle	75 mm (3 in.) HMA	150 mm (6 in.) crushed stone	2.10	Design independent of subgrade strength
City of Redmond	75 mm (3 in.) HMA	100 mm (4 in.) asphalt-treated	2.72	Design independent of subgrade strength
King County				
Alternative 1	50 mm (2 in.) HMA	100 mm (4 in.) asphalt-treated	2.28	Design independent of subgrade strength
Alternative 2	50 mm (2 in.) HMA	165 mm (6.5 in.) crushed stone	1.73	
Klickitat County	62.5 mm (2.5 in.) HMA	225 mm (9 in.) crushed stone (this is a minimum depth)	2.27	Existing soil conditions are a factor in determining pavement depth.
Chelan County	75 mm (3 in.) HMA	225 mm (9 in.) crushed stone (this is a minimum depth)	2.49	Soil investigation and design required if subgrade does not meet general standards.
City of Vancouver				
Alternative 1	120 mm (4.8 in.) HMA	55 mm (2.2 in.) asphalt-treated	2.88	AASHTO A1 through A5 soils
Alternative 2	120 mm (4.8 in.) HMA	170 mm (6.6 in.) crushed stone	2.97	
WAPA				
Alternative 1	75 mm (3 in.) HMA	150 mm (6 in.) asphalt-treated	3.12	Subgrade Resilient Modulus ≈ 34 MPa (5,000 psi)
Alternative 2	125 mm (5 in.) HMA	150 mm (6 in.) crushed stone	2.98	

a. Sampling taken from local city and county design standards and the Washington Asphalt Pavement Association (WAPA).
b. Structural number calculated with $a_{HMA} = 0.44$, $a_{crushed\ stone} = 0.13$, $a_{asphalt\text{-}treated\ base} = 0.30$.
c. Subgrade strength or stiffness requirements listed in design. Often, standards will mention that poor subgrade should be accounted for in design but not give any detailed guidance.
d. From the Washington Asphalt Pavement Association's *Asphalt Pavement Guide* design catalog (www.asphaltwa.com).

Table 2. Categories of Subgrade Support from the Hawaiʻi Asphalt Paving Industry (2003)

Category	CBR	R-Value	M_R	Typical Description by Unified Soil Classification
Good	≥ 10	≥ 25	138 MPa (20 ksi)	Gravels, crushed stone and sandy soils. GW, GP, GM, SW, SP, SM soils are often in this category.
Fair	5-9	12-24	69 MPa (10 ksi)	Clayey gravel and clayey sand, fine silt soils. GM, GC, SM, SC soils are often in this category.
Poor	3-5	5-12	34 MPa (5 ksi)	Fine silty sands, clays, silts, organic soils. CL, CH, ML, MH, CM, OL, OH soils are often in this category.

Table 3. Categories of Subgrade Support from the Texas Asphalt Pavement Association (2006)

Class	CBR	Texas Triaxial	Description
Good	≥ 10	3.0-4.0	Retain a substantial amount of load bearing capacity when wet. Sands, sand gravels, materials free of detrimental amounts of plastic material. P.I. less than 15
Fair	6-9	4.0-5.0	Retain a moderate degree of firmness under adverse moisture conditions. Loams, salty sands, sand gravels with moderate amounts of clay and fine silt. P.I. 15-20
Poor	2-5	5.0-6.0	Soils containing appreciable amounts of clay and fine silt (50% or more passing -200). P.I. Over 20.

Table 4. Subbase Additions to Achieve a Minimum Foundation Support for the South African National Roads Agency (after South Africa/US Pavement Technology Workshop, 2000)

In Situ Subgrade CBR	Action
> 15	None, in situ subgrade strength sufficient to support structural layers.
7 to 15	Import a 150 mm (6 inch) thick layer with a CBR between 15 and 25.
3 to 7	Import a 150 mm (6 inch) thick layer with a CBR between 7 and 15 and import a second 150 mm (6 inch) thick layer with a CBR between 15 and 25.
< 3	Chemical/mechanical stabilization or remove and import new material or add additional cover to place poor quality in situ material below material depth (a depth that ranges from a maximum of 1,200 mm (48 inches) to a minimum of 700 mm (28 inches) and depends on the road category).

Table 5. Pavement Preservation Funding for Three Different Agencies

Year[b]	Overall Funding per Lane-Mile Per Year[a] (includes overhead, engineering and safety)		
	Washington DOT[c]	Nevada DOT	C&C of Honolulu
1994	-	-	$1,015
1995	-	$10,229	$1,248
1996	$7,234	$6,107	$1,113
1997	-	$3,893	$3,299
1998	$8,936	$9,924	$4,073
1999	-	$11,374	$3,672
2000	$7,715	$9,160	$4,159
2001	-	$6,260	$10,872
2002	$7,486	$7,634	$1,383
2003	-	$4,962	$1,767
2004	$6,719	$8,702	$8,792
2005	-	$ 8,931	$11,474
2006	-	-	$8,605
2007	-	-	$8,605
Average	$7,618	$7,925	$5,006
Standard Dev.	$824	$2,357	$3,839
Lane-km (Lane-miles)	28,744 (17,861)	21,082 (13,100)	5,610 (3,486)

Notes

a. Funding numbers not adjusted for inflation.

b. Data for WSDOT and Honolulu were reported by fiscal year (FY). For FYs that bridge two years (e.g., FY 2004-2005) the budget is listed for the second year (e.g., 2005).

c. Washington DOT (WSDOT) data is reported in 2-year biennial budgets. The number listed is an average of this budget over 2 years. Spending in each year of the 2-year budget is not required to be equal.

d. Abbreviations: DOT = Department of Transportation, C&C = City and County

Figures

Fig. 1. City and County of Honolulu new structural design requirements

Structural Design Requirements for New Asphalt Concrete Pavements

Applicability

The following standard applies to the design of new flexible pavements only. This standard is not applicable to the design of asphalt concrete resurfacing or the rehabilitation of existing pavement structures.

Design Life

New flexible pavements shall be designed for a minimum life of 40 years based on anticipated traffic. It is anticipated that over this life one or more surface layer rehabilitation efforts will be necessary to maintain the pavement in acceptable condition.

Pavement Materials

When specialized design with the participation of a geotechnical engineer is not required, pavement structure shall consist of the following three layers:

Table 1: Pavement Materials

Pavement Layer	Approved Materials[a]
Surface course	Mix #3, Mix #4, or other asphalt concrete materials approved by the City
Asphalt treated base course (second course)	Plant mix asphalt treated base, or other asphalt concrete materials approved by the City
Aggregate base course (first course)	Aggregate base course with a minimum CBR of 85, or other materials approved by the City

a. For material definitions, see *Standard Specifications for Public Works Construction*, September, 1986.

Subgrade Support

Required pavement structure is determined by the amount of support offered by the subgrade. Measurements of subgrade resilient modulus (M_R), resistance value (R-Value) or California Bearing Ratio (CBR) are acceptable. In order to use Table 3, M_R and R-Value measurements may be converted to CBR values using the following equations with the following limitations:

Table 2: Subgrade Support Conversion Equations

Conversion Equation	Limitation
$M_R(psi) = 1500 \times CBR$	Fine grained soils with a soaked CBR of 10 or less
$M_R(psi) = 1155 + 555 \times (R\text{-}value)$	Fine grained soils with an R-value of 20 or less
$R - value = \frac{1500(CBR) - 1155}{555}$	Fine grained, non-expansive soils with a soaked CBR of 8 or less

Other correlations between M_R, R-value and CBR may be used if they are substantiated by local data to the satisfaction of the City.

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Pavement Structure

Pavement structural design is divided into two classes depending upon expected pavement loading. Coordination with the City is required in order to determine existing or future plans for traffic, bus routes and development (including phased developments), all of which can affect expected loading.

Low-Volume Pavements

Low-volume pavements are those pavements likely to support relatively few loads over their design life. Their design is often controlled by constructability and the ability to accommodate future rehabilitation efforts. Low-volume pavements are defined as those pavements that meet all of the following criteria:

1. Fewer than 1 million equivalent single axle loads (ESALs) anticipated over the design life of the pavement. For a design life of 40 years, this gives 25,000 ESALs/yr if traffic growth is neglected.
2. No regular bus routes. This includes routes of City, school and private buses.

Table 3: Required Pavement Layer Depths for Low-Volume Pavements[a, b]

Subgrade CBR (%)	Expansion Value (%)	Surface Course	Asphalt Treated Base Course	Aggregate Base Course
> 10	0 to 3.0	2 inches	3 inches	6 inches
> 5 to 10	> 3.0 to 4.5	2 inches	4 inches	6 inches
> 3 to 5	> 4.5 to 6.0	2 inches	4 inches	12 inches
≤3	> 6.0	2 inches	Specialized design with participation of a geotechnical engineer	

a. Approved materials are listed in Table 1.
b. When measured values of subgrade CBR and expansion value give different designs, use the more conservative, or thicker, design.

Low-volume pavements may also be designed using methods discussed in the "High-Volume Pavements" section. If this is done, Table 3 shall represent minimum layer thicknesses.

High-Volume Pavements

Pavements that do not meet low-volume criteria are considered "high-volume" pavements because they must support an appreciable amount of loading and their design is likely controlled by this loading.

High volume pavement must be designed using an approved structural design method. Table 3 serves as minimum pavement layer thicknesses, when using approved design methods. The City has approved the following methods:

- American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures*, 1993 edition.
- *Pavement Design Manual, Revision March 2002*, prepared by Department of Transportation, State of Hawaii
- Asphalt Institute method as described in MS-1 *Thickness Design – Highways & Streets*, 9th edition. The software version of this method, SW-1, may also be used.
- Perpetual Pavement design as done by *PerRoad* software (version 2.4 or later) available for free from the Asphalt Pavement Alliance.

Other pavement design methods must be approved by the City.

This supersedes the Design Standards for Flexible Pavements dated February 6, 2002.

DEPARTMENT OF PLANNING AND PERMITTING CITY AND COUNTY OF HONOLULU	STRUCTURAL DESIGN REQUIREMENTS FOR NEW ASPHALT CONCRETE PAVEMENTS Sheet 2 of 2 Effective March 1, 2006	APPROVED: [signature] 2/6/06 DIRECTOR, DPP DATE

Fig. 1. City and County of Honolulu new structural design requirements