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United States Government Accountability Office
Washington, DC 20548

November 14, 2012

The Honorable John J. Duncan, Jr.
Chairman
Subcommittee on Highways and Transit
Committee on Transportation and Infrastructure
House of Representatives

The Honorable Frank LoBiondo
Chairman
Subcommittee on Coast Guard and Maritime Transportation
Committee on Transportation and Infrastructure
House of Representatives

Subject: *Information on Materials and Practices for Improving Highway Pavement Performance*

The nation's more than 4 million miles of roads are key to the economy, facilitating the movement of goods and people. Although highways are highly durable and can last for decades, they deteriorate from traffic wear and tear, inadequate drainage, construction deficiencies, and weather. Keeping them in good condition requires substantial resources: public entities spent more than $180 billion in 2008 on highways, with about $40 billion coming from the federal government. Despite these outlays, the Federal Highway Administration (FHWA) estimates that these funding levels are insufficient to maintain or improve the condition of the nation's highways through 2028.[1] Further, the major source of federal surface transportation funding—federal motor fuel tax revenues deposited into the Highway Trust Fund—is eroding.[2] The Congressional Budget Office estimates that, as of March 2012, to maintain current spending levels and account for inflation from 2013 to 2022, the Highway Trust Fund will require more than $125 billion over what it is expected to take in during that period.[3]

As a result, state highway agencies, the entities that are ultimately responsible for keeping most major highways in good repair, will need to develop strategies for doing so at reduced costs.[4] One potential strategy is using more cost-effective materials and practices. With this in mind and in response to your request, this report describes (1) selected materials and

[1] U.S. Department of Transportation, Federal Highway Administration, *2010 Status of the Nation's Highways, Bridges and Transit: Conditions and Performance Report to Congress* (Washington, D.C.).
[2] The Highway Trust Fund is an account established by law to hold and distribute federal highway user taxes (e.g., federal excise taxes on fuel) that are dedicated for highway- and transit-related purposes. It is composed of two accounts: the Highway Account and the Mass Transit Account. See GAO, *Highway Trust Fund: All States Received More Funding Than They Contributed in Highway Taxes from 2005 to 2009*, GAO-11-918 (Washington, D.C.: Sept. 8, 2011).
[3] Congressional Budget Office*, March Fiscal Year 2012 Baseline Projections for the Highway Trust Fund* (Washington, D.C.: 2012).
[4] Each of the 50 states, plus Washington, D.C., and the Commonwealth of Puerto Rico, has a highway agency.

practices that states can use or are using to improve the performance of pavements, including what is known about their costs and benefits, if any, and (2) challenges, if any, to using these materials and practices.

To address our objectives, we first conducted a literature search to identify potential materials and practices that were reported to increase the durability and the life of pavements, thereby improving performance. To supplement the materials and practices identified in our literature search, we reviewed and analyzed relevant documentation and interviewed officials from FHWA headquarters, asphalt and concrete industry groups, a tollway authority, and the American Association of State Highway Transportation Officials (AASHTO), as well as pavement researchers from four transportation research organizations.[5] We then identified and interviewed officials from seven state departments of transportation (DOT)—chosen based on their reported use of materials and practices to improve pavement performance, the number of highway miles they managed, and geographic diversification—to obtain additional information about materials and practices and challenges to their use.[6] The selection of states was intended to provide a strong understanding of states' experiences and was not intended to be generalizable.

Through these efforts, we identified and compiled a list of potential materials and practices for further evaluation. We assessed each potential practice on whether it (1) has the potential to cost-effectively improve pavement performance by increasing durability or extending pavement life or has the potential to reduce life-cycle costs—costs associated with constructing and maintaining a pavement over its lifetime, and (2) is currently available for states to use. We eliminated materials and practices that did not meet these criteria. We also identified available cost information and additional benefits provided by these materials and practices using the same resources.

We then verified the accuracy and completeness of the list by identifying a list of stakeholders who have relevant expertise in the use of materials and practices with the potential to improve pavement performance. We identified potential stakeholders with a range of expertise in concrete, asphalt, and highway operations from government, industry groups, and transportation research organizations. From this group, we selected nine stakeholders who represented a range of expertise and affiliations, and provided them a data collection instrument that displayed the initial list of materials and practices we had compiled for their review and comment. We asked them if they concurred, did not concur, or did not know whether each material and practice has the potential to cost-effectively improve pavement performance by increasing durability or extending pavement life, or reduce life-cycle costs. We also asked them to identify any materials and practices that meet these criteria that we did not include in the list. We received eight responses, which we analyzed to identify any materials and practices that a majority of the respondents did not concur with. As a result of these responses, we removed two practices from our list and did not add others. We organized the materials and practices into five categories to facilitate their presentation, shown in tables 2 through 6. In addition, after each table, we discuss some considerations associated with the choice of materials or practices by highlighting a few examples. Prior to distributing the data collection instrument, we tested our validation process with three officials from FHWA and one individual from a private engineering firm. We made modifications to the instrument as a result of these tests. We believe our resulting list reflects materials and practices that may have the potential to improve pavement performance; however, the list was not meant to be exhaustive, and we acknowledge that there may be some materials and practices we did not identify.

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[5] We interviewed officials from the National Center for Asphalt Technology, National Concrete Pavement Technology Center, Texas A&M Transportation Institute, and Western Research Institute.
[6] We interviewed DOT officials from Georgia, Iowa, Minnesota, Tennessee, Texas, Utah, and Washington.

To identify challenges to using these materials and practices that states might encounter, we conducted a literature search and interviewed DOT officials from seven states. We analyzed the information we obtained and categorized challenges into four areas.

We conducted this performance audit from January 2012 to November 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

In summary, our literature review and discussions with stakeholders having relevant expertise resulted in the identification of 40 materials and practices that may contribute to improving the performance of pavements, extending service life, and reducing life-cycle costs. These materials and practices cover a range of uses and applications across the stages of a pavement's life cycle, from initial design and construction through maintenance and preservation cycles, and at the time of reconstruction. Several challenges exist to states' use of these materials and practices. In particular, some materials and practices may not be applicable or beneficial to all states, a decentralized and segmented highway industry may impede change, and resource constraints and procurement methods may limit states in implementing new approaches to building and maintaining their highways. However, FHWA, AASHTO, and states have developed several programs that address these challenges through research, training, and information and outreach programs.

Background

In the United States, state and local governments own about 96 percent of the more than 4 million miles of roads. State DOTs are responsible for constructing, repairing, and maintaining most major highways, including the Interstate Highway System. These agencies generally contract with private sector companies to perform these activities. The federal government provides funding to states through a series of programs collectively known as the federal-aid highway program. Each program that provides funding specifies how it can be used—such as for construction, reconstruction, and preventive maintenance activities—and specifies eligible project types. Highways supported by federal aid represent about one-fourth of all roads, but about 85 percent of all miles traveled annually occur on them (see table 1).

Table 1: Ownership of U.S. Roads by Length in Miles and Vehicle Miles Traveled, 2008

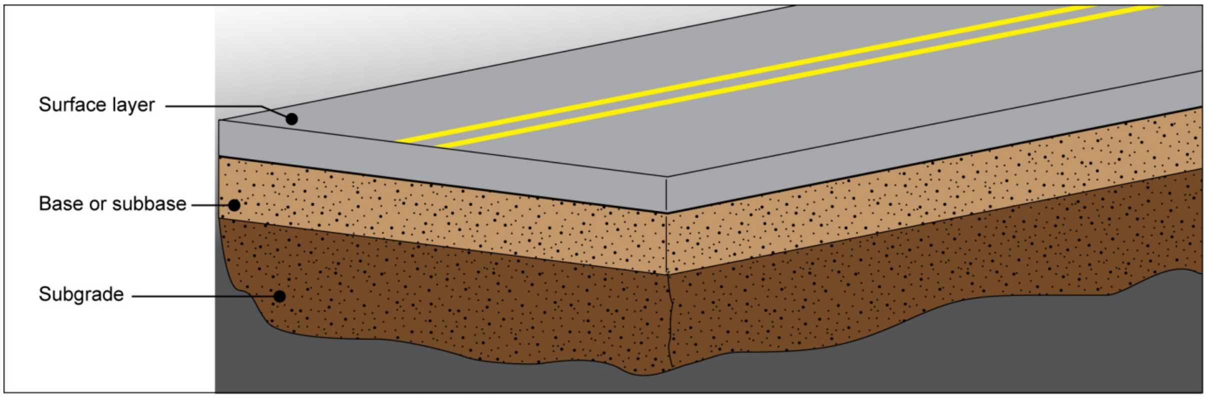
Owner	Miles supported with federal aid	Miles not supported with federal aid	Total miles
Federal	6,596	124,962	**131,559 (3%)**
State	562,170	222,141	**784,311 (19%)**
Local	418,564	2,667,888	**3,086,452 (76%)**
Other	7,188	49,832	**57,020 (1%)**
Total	**994,518 (24%)**	**3,064,823 (76%)**	**4,059,341 (100%)**
Vehicle miles traveled (millions)	**2,534,647 (85%)**	**458,058 (15%)**	**2,992,705 (100%)**

Source: GAO analysis of FHWA data.

Note: Percentages may not add due to rounding. Other includes state park, state toll, other state agency, other local agency, and roadways not identified by ownership. Road lengths and vehicle miles traveled include Puerto Rico.

Highway pavement consists of several layers of durable material. Lower layers of a pavement typically consist of crushed, compacted rock (base or subbase) built on a compacted earthen roadbed (subgrade). The surface layer, upon which vehicles travel, is typically constructed of asphalt or concrete. According to FHWA, of all of the miles of roads supported with federal aid, about 91 percent have asphalt surfaces, about 5 percent have concrete surfaces, and 4 percent are unpaved.[7] Figure 1 illustrates a typical pavement structure.

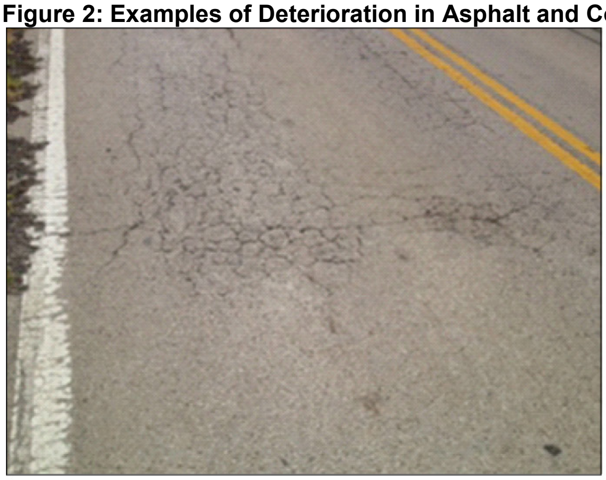
Figure 1: Typical Pavement Structure



Source: GAO.

All pavements deteriorate over time but numerous factors—including increased traffic, water intrusion into the pavement layers, freeze/thaw cycles or other weather events, and instability of the roadbed or base layers—can accelerate this aging process. Truck traffic, in particular, contributes to pavement deterioration, because heavier loads are many times more damaging than lighter loads. Evidence of deterioration may be apparent on the surface layer, as shown in figure 2.

Figure 2: Examples of Deterioration in Asphalt and Concrete Pavements



Source: GAO.

Alligator cracking of asphalt pavement.

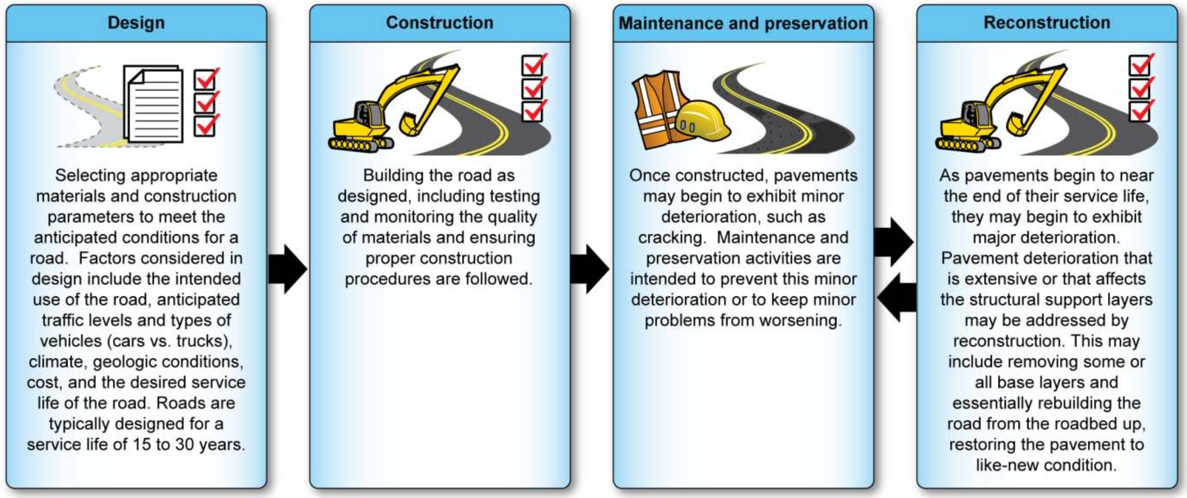
Source: GAO.

Transverse crack in concrete pavement.

The activities performed by state and local governments, or their contractors, to build and keep pavements in good condition can be organized into four stages, corresponding to different points of a **pavement's** life: (1) design, (2) construction, (3) maintenance and preservation, and (4) reconstruction (see figure 3).

[7] Federal Highway Administration, *Highway Statistics 2008: Federal-Aid Highway Length – 2008 Miles by Type of Surface (Table HM-31)*, (October 2009), the most recently available data.

Figure 3: Stages of a Pavement's Life Cycle



Source: GAO.

Designs that appropriately consider factors specific to the highway, such as anticipated traffic levels, and construction that meets the design specifications are essential to ensuring long-lasting roads. Likewise, maintenance and preservation activities can improve the performance of deteriorated pavements and prolong their life by preventing minor problems from getting worse and correcting major problems that accelerate deterioration. Over time, a pavement may undergo multiple cycles of maintenance and preservation before reconstruction is necessary. In addition, throughout these stages, states and contractors perform a number of tests, such as testing asphalt and concrete materials before they are applied to a road, and use quality assurance and quality control practices, such as testing the thickness of new asphalt or concrete, to ensure that pavements meet established standards.

Materials and Practices That Can Improve Pavement Performance, Reduce Life-Cycle Costs, and Provide Other Benefits

<u>Selected Materials and Practices</u>

Our review of existing literature and discussions with stakeholders having relevant expertise resulted in the identification of 40 materials and practices—6 materials and 34 practices—that may contribute to improving the performance of pavements, extending service life, and reducing life-cycle costs. Of the 40, 6 are materials that could be used in the construction, maintenance and preservation, or reconstruction stages of a pavement's life. The remaining 34 are practices; 9 of the practices relate to design and testing, 13 are practices that could be used in the maintenance and preservation stage, 8 are practices that could be used in the construction or reconstruction stages, and 4 could be used as part of quality assurance and quality control activities affecting construction, maintenance and preservation, or reconstruction work.

Pavement Materials

Table 2 describes six pavement materials that could be used in projects during the construction, maintenance and preservation, or reconstruction stages of a pavement's life cycle to affect performance. Some can improve the performance of the pavement and base materials and increase the durability of the road, while other materials—such as reclaimed asphalt or recycled concrete—may yield roads with performance characteristics similar to those constructed with new materials but at a lower cost.

Table 2: Pavement Materials

Material	Description
Modified asphalt binders	Synthetic or natural material added to asphalt to enhance pavement properties. Includes polymers, chemical modifiers, rubber, fibers, fillers, and biobinders/bioasphalt.
Reclaimed or recycled material	Re-use of materials into new pavements. Includes asphalt and concrete pavement, asphalt shingles, and ground tire/crumb rubber.
Blended or performance cements	Material added to the more typical portland cement to enhance concrete pavement properties or reduce costs. Includes pozzolans, slag cement, fly ash, and limestone.
Concrete curing compounds	Material applied to newly poured concrete to inhibit water evaporation and ensure proper concrete curing.
Geosynthetics	Synthetic polymeric materials used for a variety of purposes in pavement structures, such as reinforcement, separation, and drainage. Includes geotextiles, geomembranes, geogrids, geocells, and erosion control products.
Corrosion-resistant reinforcement for concrete pavement	Materials that resist corrosion and deter corrosion-related damage to concrete. Includes fiber-reinforced polymer bars, discrete fibers, stainless steel, and epoxy-coated steel.

Source: GAO.

In reference to reclaimed or recycled materials, officials from each of the states we met with said that they allow the use of reclaimed asphalt in asphalt paving projects, typically allowing it to comprise up to 20 percent of the asphalt, and some states have investigated use of higher levels. Reclaimed asphalt can replace other, more expensive materials when making asphalt for pavements. For example, Washington estimates it saves $15 million to $20 million annually by using reclaimed asphalt. Similarly, recycled concrete is commonly used in base or subbase layers of pavement structures and in a more limited capacity in new concrete mixes. Using recycled concrete may be less costly, in part because of reduced disposal and transportation costs. Georgia officials told us that they not only use recycled concrete but have approved a recycling center to accept concrete from sources other than pavements for use in road construction.

Concerning use of geosynthetics, officials from all the states we talked with have used geosynthetics in base or subbase layers of a pavement structure. Used in this way, the materials can improve the stability and strength of those layers. Geoynthetics can also be used in the surface layers of asphalt pavements where it may keep water from penetrating to the lower pavement layers and may reduce the transfer of cracks from an old pavement to a new pavement overlay. However, officials from two states expressed concerns that using geosynthetics in this way may create challenges for future pavement repair. For example, one pavement preservation practice involves milling, or removing the surface layer of an existing asphalt pavement, and replacing it with a new layer of asphalt (see table 4). According to one official, geosynthetics used in pavement surface layers might interfere with operation of the milling equipment and lead to additional effort to separate geosynthetic material from the asphalt millings before they are reclaimed.

Pavement Design and Material-Testing Practices

Table 3 describes nine design and material-testing practices affecting pavement performance that correspond to the design stage of the pavement life cycle. These include using different pavement types, such as the use of warm-mix asphalt (WMA) or two-lift concrete pavements, and tools that designers could use to predict pavement performance.

Table 3: Pavement Design and Material Testing Practices

Practice	Description
Performance testing of asphalt binder	Testing to predict how the binder in asphalt will perform, using procedures such as the Multiple Stress Creep Recovery test and the Asphalt Binder Cracking Device.
Performance testing for asphalt design mix	Testing to predict how asphalt design mixes will perform using equipment such as the Asphalt Mixture Performance Tester.
Using Mechanistic-Empirical Pavement Design Guide	A tool that predicts the performance of a pavement being designed based on mechanistic-empirical principles.
Optimizing aggregate used in pavements	Consideration of aggregate (granular material, such as sand, gravel, crushed stone, or recycled concrete) characteristics—such as shape, angularity, and texture—in the mix design of asphalt and concrete pavements to improve performance.
Warm-mix asphalt (WMA)	Asphalt mix produced and placed at lower temperatures—ranging from 30 to 120 degrees Fahrenheit lower—than traditional hot-mix asphalt.
Stone matrix asphalt	Asphalt mix consisting of coarse aggregate, high asphalt cement content, filler, and fibers.
Continuously reinforced concrete pavement (CRCP)	Concrete pavement without contraction joints that is reinforced using continuous steel bars throughout its length.
Two-lift concrete pavement	Concrete pavement made of two layers: a thick lower layer that can include materials that are less resistant to wear and a thinner surface layer made of more wear-resistant materials.
Precast concrete panels	Sections of concrete pavement that are made off-site and assembled on-site for construction and repairs.

Source: GAO.

In reference to the practice of using WMA, FHWA included it as part of its Every Day Counts Initiative to promote innovation; FHWA reported that, as of 2009, more than 40 states had constructed WMA projects.[8] All of the states we spoke with have constructed WMA projects. According to the National Asphalt Pavement Association, WMA comprised at least 15 percent of the asphalt pavement market as of 2010, and in combination with reclaimed asphalt, WMA's use offers significant potential for maintaining well-performing pavements at reduced costs.

In addition, according to FHWA, the use of precast concrete panels in highway projects may provide pavements in less time and at lower total cost—considering both construction and user costs—than using traditional cast-in-place concrete construction methods. For example, an FHWA Highways for Life demonstration project used precast concrete panels to replace sections of I-66 in Virginia.[9] FHWA reported that the as-built project yielded about a 7 percent savings over the estimated cost of the alternative reconstruction method using cast-in-place concrete. Also, Utah officials said that they use precast concrete panels in areas requiring rapid pavement repair, such as on highly trafficked highways.

Pavement Maintenance and Preservation Practices

Table 4 describes 13 maintenance and preservation practices affecting pavement performance that could be used during the maintenance and preservation stage of the pavement life cycle. These practices include approaches to monitoring the condition of

[8] FHWA's Every Day Counts Initiative is designed to get effective, proven, and market-ready technologies into widespread use. This and other FHWA programs are discussed later in this report.
[9] FHWA's Highways for Life is a grant program to demonstrate and promote innovative technologies and accelerate their adoption by the highway community.

pavements and examples of specific maintenance and preservation treatments that can be used to cost-effectively sustain road networks.

Table 4: Pavement Maintenance and Preservation Practices

Practice	Description
Evaluating pavement condition using non-destructive technology	Using tools such as deflection testing devices (e.g., falling weight deflectometer), ground penetrating radar, ultra-sonic and impact echo devices, and other nondestructive testing devices that can be used to noninvasively evaluate the condition of pavements.
Pavement management/preservation system	A network-level, long-term strategy that uses an integrated, cost-effective set of pavement maintenance and preservation practices.
Thin or ultra-thin asphalt overlay on asphalt pavement	Applying a thin (generally 1.5 inches or less) layer of asphalt over an existing asphalt pavement.
Mill asphalt pavement and resurface with asphalt overlay	Removing the surface layer of an existing asphalt pavement and replacing it with a new layer of asphalt.
Cold in-place recycling of asphalt pavement	Removing existing asphalt pavement, mixing it with new asphalt, and placing the re-mixed material as a base layer for a subsequent asphalt overlay.
Surface preservation treatments for asphalt pavement	Various thin surface treatments applied to asphalt pavement, involving the application of liquid asphalt and, in most cases, aggregate.
Microsurfacing for asphalt pavement	Spreading a thin mixture of polymer-modified asphalt emulsion, mineral aggregate, mineral filler, water, and other additives on an asphalt pavement.
Diamond grinding for concrete pavement	Removing surface imperfections of a concrete pavement using diamond saw blades.
Dowel bar retrofit for concrete pavement	Installing metal reinforcing bars across joints or cracks that exhibit poor load transfer.
Partial-depth repair for concrete pavement	Removing and replacing small, shallow areas of a concrete pavement to restore localized areas of deterioration.
Full-depth repair for concrete pavement	Removing and replacing a segment of concrete pavement through the depth of the concrete slab to restore areas of deterioration.
Joint sealing for concrete pavement	Applying sealant material to the spaces between jointed concrete pavement sections.
Crack sealing for asphalt and concrete pavements	Applying sealant material to cracks in asphalt or concrete pavements.

Source: GAO.

In reference to maintenance and preservation practices, according to FHWA, applying treatments to roads in good condition is more economical than reconstructing them after they deteriorate: each dollar spent now on pavement preservation could save up to six dollars in the future. However, FHWA reports that state DOTs have historically allowed pavements to deteriorate to fair or poor condition before taking steps to reconstruct them—a costly, time-consuming activity. Pavement management/preservation systems can help states monitor the condition of their roads and make decisions to optimize the use of resources by applying appropriate preservation treatments at the proper time.

Several states we spoke with (Georgia, Utah, and Washington) are expanding their use of lower-cost surface preservation treatments. Georgia, for example, began using a preservation practice involving thin asphalt overlays in 2007.[10] According to Georgia officials, the cost of this practice is significantly less than the cost of a thicker asphalt overlay that they would otherwise place. In addition, Washington has begun using an asphalt pavement surface preservation treatment typically used on low volume highways to maintain higher-volume asphalt highways. The treatment—known as a “chip seal”, in which liquid

[10] Georgia DOT officials referred to their practice as “micromilling”—removing a thin layer of asphalt from a road and replacing it with a new, thin layer of asphalt.

asphalt sprayed on a pavement is covered with aggregate and rolled to embed it—generally provides less additional service life to a pavement than milling and replacing the asphalt surface.[11] However, the life-cycle cost of a chip seal treatment is about one-third that of milling and replacing the asphalt surface, according to state officials, and the treatment's use should result in lower maintenance and preservation costs over the life of the pavement.

Pavement Construction and Reconstruction Practices

Table 5 describes eight practices that could be used during the construction and reconstruction stages of the pavement life cycle to affect pavement performance. These practices include specific approaches to building or rebuilding roads that may enhance their durability.

Table 5: Pavement Construction and Reconstruction Practices

Practice	Description
Subbase and base layer treatments	Using cement, asphalt, geosynthetics, or other materials to improve the subbase or base layers of a roadway.
Intelligent compaction	Using compaction equipment that measures compaction levels and provides feedback to allow adjustments to ensure base materials and asphalt are compacted completely and correctly.
Asphalt structural overlay for asphalt pavement	Adding pavement layers to increase the pavement's load-carrying capacity.
Full-depth reclamation for asphalt pavement	Pulverizing the existing asphalt pavement and mixing it with the underlying base material for use as the base for a new asphalt surface layer.
Concrete overlay (whitetopping) for asphalt pavement	Applying a layer of concrete (generally 2-11 inches) over an existing asphalt pavement.
Asphalt overlay for concrete pavement	Applying a layer of asphalt over an existing concrete pavement.
Rubblization/crack and seat with asphalt overlay for concrete pavement	Fracturing existing concrete pavement into small pieces (less than 3 feet) and placing a new asphalt pavement over this base.
Concrete overlay for concrete pavement	Placing a layer of concrete (generally 2-11 inches) over an existing concrete pavement.

Source: GAO.

According to FHWA, properly compacting pavement materials, such as subbase rock and asphalt, is one of the most important elements in constructing long-lasting pavements. Compacting equipment with intelligent compaction systems can ensure that pavement material is compacted correctly and completely. Three of the seven states we met with (Georgia, Minnesota, and Texas) participated in a study aimed at accelerating the implementation of intelligent compaction, working with equipment suppliers, for example, to increase awareness of the technology.

In addition, since the early 1990s, according to FHWA, the use of whitetopping has grown significantly in the U.S., as newer techniques for bonding the new concrete to the old pavement have allowed for use of thinner concrete layers (2 to 6 in.) over existing asphalt pavements. A potential benefit to whitetopping repair is the durability of concrete, which results in a greater interval between reconstruction treatments compared to use of an asphalt overlay. Colorado has conducted many whitetopping projects and, of the states we spoke with, Iowa officials said that whitetopping is used extensively on county roads in their state.

[11] "Aggregate" is granular material, such as sand, gravel, crushed stone, or recycled concrete.

Quality Assurance and Quality Control Practices

Table 6 describes four quality assurance and quality control practices that could be used during the construction, maintenance, or reconstruction stages of a pavement's life cycle to affect performance. These practices include specific devices that can be used and actions that can be taken to ensure constructed work meets the level of quality intended by the design.

Table 6: Quality Assurance and Quality Control Practices

Practice	Description
Infrared thermography for asphalt pavement	Devices that non-destructively measure temperature variation in asphalt as pavements are constructed to identify possible quality problems.
Smart Cure System	A system of devices that provides on-site, real-time recommendations to achieve optimal concrete curing based on ambient conditions.
Magnetic imaging tomography	A non-destructive testing device that determines the thickness of fresh concrete pavement.
Warranties	A warranty establishes the expected performance of a product (such as a newly constructed road or repair of an existing road) and the responsibility to repair or replace defects for a defined period.

Source: GAO.

According to FHWA, "infrared thermography"—equipment that measures the temperature of asphalt as it is placed by a paving machine—can help ensure asphalt is placed at the appropriate temperature, which is a critical factor in preparing uniform, high-quality pavements. Knowing the temperature helps to better identify and immediately correct parts of the road where temperatures are not sufficiently uniform and failures are likely to occur. Officials in four of the states we spoke with (Georgia, Minnesota, Texas, and Washington) said their states have experimented with the use of infrared equipment on paving machines. A Minnesota DOT evaluation of infrared thermography (see table 6) and intelligent compaction (see table 5) concluded that both practices can be used as effective quality assurance tools to improve pavement performance.

In addition, FHWA encourages the use of pavement warranties and notes that the most benefit comes from long-term performance warranties (generally ranging from 10 to 20 years). While use of warranties shifts some risk to the contractor—which can raise project costs —FHWA notes that increased contractor responsibility should allow greater freedom for innovation. None of the states we spoke with said they are currently using warranties. Officials from five states that had used or considered using warranties noted that contractors may be challenged to provide long-term warranties because of the cost of holding a bond over the term of the warranty.[12]

<u>Potential Cost Savings of These Materials and Practices Varies and Can Be Assessed Using Life-Cycle Cost Analysis</u>

By improving the durability or extending the service life of pavements, the materials and practices described in the preceding tables may decrease the life-cycle costs of a pavement—that is, the costs associated with constructing and maintaining a pavement over its lifetime.[13] The cost of a pavement is dependent on a range of factors that may be specific to an individual state or project, including climate, traffic, and geologic conditions.

[12] A bond, secured through a surety, guarantees contractor performance throughout the warranty period.

[13] GAO will be conducting work during the next year on best practices for calculating life-cycle costs and benefits for federally funded highway projects, as mandated by the recent adoption of 23 U.S.C. § 503(b)(3)(D)(ii) by the Transportation Research and Innovative Technology Act of 2012. Pub. L. No. 112-141, Div. E, Title II, § 52002(b), 126 Stat. 405, 866-875 (July 6, 2012).

For example, constructing a pavement in a northern state that experiences frequent freeze-thaw cycles may involve different factors than constructing a pavement in a southern state that rarely does. Likewise, constructing a pavement to accommodate high levels of truck and other vehicle traffic may involve different factors than constructing a pavement to accommodate relatively low levels of traffic.

A state DOT may conduct a life-cycle cost analysis to compare construction and maintenance alternatives—and the possible materials and practices associated with each—in determining approaches to building and maintaining pavements. For each alternative, the analysis provides projections based on initial costs, such as material and construction costs, and future costs—such as maintenance, user, and reconstruction costs—over the life of a project. For example, a state may perform life-cycle cost analysis to compare the costs of using asphalt or concrete as surface layer materials to construct or reconstruct a road.

Some states we met with had used life-cycle cost analysis to inform key decisions. For example, in 2005, Utah DOT assessed two of its existing asphalt surface preservation treatments—an open-graded surface course and a chip seal—and found the chip seal treatment to be much more cost-effective.[14] The analysis showed that expanding the use of chip seals and limiting use of open-graded surface courses to certain high volume roads could result in a savings of over $2 million per year. Similarly, the Georgia DOT conducted a life-cycle cost analysis to compare the costs of using conventional asphalt and stone matrix asphalt (see table 3). While stone matrix asphalt is more expensive than conventional asphalt, it is highly durable and can provide a 30 to 40 percent increase in pavement life. In its analysis, Georgia considered that the stone matrix asphalt would need less frequent maintenance and repair, resulting in estimated annualized costs that were 37 percent less than using conventional asphalt. This analysis led Georgia to select use of stone matrix asphalt based on its overall lower life-cycle cost.

Some Materials and Practices May Provide Additional Benefits

Some of the materials and practices described in the preceding tables offer additional benefits, beyond improving pavement performance, for example:

- Incorporating reclaimed or recycled materials (see table 2) into highway pavements provides an environmental benefit by making use of a material that might otherwise be disposed of and reducing the amount of new material needed.
- Using precast concrete panels (see table 3) can provide a benefit to users of the road under repair. Concrete that is placed on-site may take several days to cure, and during that time, affected lanes must remain closed to traffic. Conversely, precast panels may be driven on immediately, thereby reducing the inconvenience to drivers.
- Following the principles of a pavement management/preservation system (see table 4) can provide sustainability benefits because these tools seek to minimize the amount of natural resources used over a pavement's life cycle.

Potential Challenges to Implementing Materials and Practices

Although the materials and practices identified in this report may offer states opportunities for savings and improved pavement performance, certain factors could prevent states from implementing them. In our review of literature regarding these factors, we identified challenges in four areas that could affect the extent to which state DOTs implement

[14] An "open-graded surface course" is an asphalt pavement treatment that is water-permeable. Its use can reduce spray from water on the road and provide a quieter ride.

materials and practices. In our interviews with state DOTs, officials also identified challenges in these same areas. FHWA and others have developed several ongoing programs and efforts to overcome these challenges.

Literature Review Identified a Range of Challenges

Our literature review identified challenges in the following four areas that might prevent state DOTs from implementing materials and practices:

- *Suitability of Materials and Practices:* In some cases, a particular material or practice may not be applicable or beneficial to all states. Because of differences in climate, sources of raw materials, and other factors, a material or practice that works well for one state may not work well for another. For example, two-lift concrete pavement (see table 3)—which allows lower quality aggregates to be used in a lower level of the pavement—may be beneficial in a state where good aggregates for pavement have to be transported in at a high cost. However, in a state with an abundant supply of good aggregates, using two-lift construction may not be cost-effective. In other cases, a state may find that a material or practice has not been sufficiently tested, or that the results of testing are not sufficiently quantifiable. This is in part because, given the long-lasting nature of pavements, the results of testing or using a practice may not be known for 10 years or more. Finally, highway pavement systems are complex, and interaction between different components makes it difficult to understand how the implementation of a material or practice may affect other components.
- *Structure and Culture of the Industry:* As we and others have previously reported, the highway industry is highly decentralized and segmented.[15] There are about 35,000 different federal, state, and local entities responsible for constructing, operating, and maintaining U.S. highways. In addition, there are many private companies of many sizes and specialties that carry out highway design work and much of the highway construction work, and that supply materials, equipment, and services used by public agencies. As a result, it takes time to overcome implementation challenges in each agency to achieve widespread use of a material or practice. In addition, a number of reports have pointed to a cultural resistance to change in the highway industry. State DOTs and other public agencies are risk averse because success can bring minimal rewards and the cost of failure can be high. As a result, an agency's leadership may not provide sufficient support and direction to encourage innovation. Likewise, highway contractors may be reluctant to invest in new technologies without an assurance that a state DOT will share the risk of using them.
- *Resources:* Insufficient funding to implement new materials and practices can limit states' use of them, as the budget or cost required may exceed the level management is willing to support. Limited staff resources because of decreased agency size, staff turnover, or lack of staff with technical expertise may also prevent a state DOT from implementing a material or practice. As a result, staff may not have time or expertise to take on the additional workload required to implement a material or practice, such as writing new specifications for the practice.

[15] GAO, *Highway Technology: The Structure for Conducting Highway Pavement Research*, GAO/PEMD-88-2BR (Washington, D.C.: Nov. 13, 1987); GAO, *Highway Infrastructure: Federal-State Partnership Produces Benefits and Poses Oversight Risks,* GAO-12-474 (Washington, D.C.: Apr. 26, 2012); Transportation Research Board, *Special Report 261 The Federal Role in Highway Research and Technology* (Washington, D.C.: 2001); and Transportation Research Board, *Special Report 296 Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life* (Washington, D.C.: 2009).

- *Procurement and Specifications*: Public agencies use procurement methods that can inhibit them from implementing new materials and practices. The low bid system, whereby a state DOT accepts the lowest bid that meets the terms of a public proposal, may limit both the state's and contractors' ability to introduce innovation that might cost more to construct, but have a lower life-cycle cost. Some agencies use an initial cost criterion to determine whether to use a new practice; although a new practice can be initially more costly than an existing practice, it might provide lower costs over its lifetime. Implementing a new technology may require a DOT to revise its specifications to allow its use. Most highway agencies have their own specifications and revising them may require the coordination of several organizational entities, increasing the difficulty of the task. Finally, state DOTs may find it is not always easy to use proprietary products. These products are usually not allowed, because they could limit competition and may not conform to a state's standard design specifications.

<u>State DOTs Identified Challenges Similar to Literature Review</u>

In our interviews, state officials identified challenges they experienced in implementing new materials and practices similar to the suitability, culture, resources, and procurement areas identified above. Most examples they provided, however, involved issues with the suitability of materials and practices.

- *Suitability of Materials and Practices:* In at least three instances, state officials reported that they had success with a practice that had not worked well in another state. For example, in Texas, officials stated they use CRCP (see table 3) extensively and have had good experiences with them. However, Iowa officials said they have used CRCP in the past but believe them to be cost-prohibitive and have experienced good performance with jointed concrete pavements. In addition, Georgia has used stone matrix asphalt (see table 3) on its Interstates and other high-volume highways because of its durability. However, in the neighboring state of Tennessee, officials stated that they evaluated stone matrix asphalt, decided the initial cost was too high, and have not widely adopted its use.

  A state DOT may be less willing to implement a practice that is not well-understood or not perceived to have sufficient benefits. For example, Minnesota officials said they tried requiring extended warranties (see table 6) but found the costs prohibitive for contractors to bond the projects over the warranty period. Because these costs are passed on to the DOT in the form of higher bids on contracts, the officials said they determined that the increased costs were greater than the benefit provided by the warranties and discontinued the practice. Also, Washington officials stated that they have not used two-lift concrete (see table 3) because they know their locally available materials and current construction practices work well.

  Materials and practices that have not been sufficiently tested may present a challenge. For example, Washington officials told us that even though there might be research on a particular practice, they will not necessarily implement it until they verify reasonable performance and that the practice will work on their state's roads. In addition, Tennessee officials stated they used recycled shingles (see table 2) on a few projects and are planning more, but additional testing is needed. They stated that specifications routinely allowing the recycled shingles could be up to a year away.

  Potential or actual interactions between different paving materials may also present a challenge to implementing new materials and practices. According to state officials, Georgia specifications allow up to 40 percent reclaimed asphalt pavement (see table

2), but contractors typically use less—about 25 to 30 percent—because using more can prevent them from complying with other specifications designed to decrease pavement deterioration. Similarly, Utah specifications allow blended cements (see table 2), and state officials said that they generally perform as well as standard concrete mixes. However, these officials have found that blending cement with locally sourced limestone does not allow the concrete to strengthen quickly and thus should not be used in cases where this characteristic is desired.[16]

A negative experience with a practice may prevent a state from using the practice again. Tennessee officials said they used recycled tire rubber (see table 2) in three asphalt paving projects in 1993 and 1998, and two of the pavements failed early, so they did not adopt further use of the material.[17] Utah officials said they stopped using geosynthetics (see table 2) in pavements because they found it was not as effective in inhibiting the transfer of cracks from the old pavement to the new pavement overlay as expected.

- *Structure and Culture of the Industry:* Tennessee officials stated that they are open to looking at new materials and practices but are not willing to get too far ahead of everyone else. In addition, states may meet resistance from contractors when implementing materials and practices that are new to them. Georgia and Minnesota officials stated that they had received resistance from contractors to implementing the use of intelligent compaction (see table 5) or infrared thermography (see table 6). For example, Georgia DOT officials stated that they had received resistance from contractors to implementing the use of intelligent compaction because the costs to purchase the equipment is high, and the investment in equipment, without a requirement from a state for its use, is difficult to justify. Minnesota DOT officials said that they had also received resistance from some contractors to implementing the use of infrared thermography because it brings added complexity and the investment in equipment without a commitment from the state for its future use was difficult to justify. While one of the contractors that purchased an infrared paving bar has continued to use it, another contractor only used it on the job for which it was required. Similarly, Utah officials stated that while the use of optimized grading of aggregates for concrete pavement (see table 3) could be beneficial, the implementation has been very slow due to industry's resistance to making costly required changes to concrete plants. Utah officials noted that while they are modifying their specifications to allow the use of a wider range of materials and practices, it is up to the contractors to include them in their bids to the state.
- *Resources*: Minnesota officials stated there are more materials and practices they would like to evaluate than available funds or staff to do it. As a result, they use professional engineering judgment to select materials and practices to evaluate based on the likelihood of implementation. Georgia officials stated that with the continued downsizing of staff, they will have little expertise remaining in their organization to change specifications to allow new materials and practices. Iowa officials noted that reduced travel because of budget reductions is sometimes a challenge, resulting in a reduction of the staff's ability to adequately understand new materials and practices and implement them.
- *Procurement and Specifications:* Minnesota officials wanted to try intelligent compaction (see table 5) on a project but could not require its use because they lacked a specification. As a result, they worked with an equipment manufacturer and

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[16] This characteristic, known as "high early strength," refers to concrete that achieves its specified strength at an earlier age than normal concrete. High early strength concrete used in repair or construction projects, for example, can carry traffic within a few hours after the concrete is placed.
[17] Tennessee officials told us that they used recycled tire rubber in an asphalt paving project in 2011 that is currently performing satisfactorily.

distributor to outfit compaction equipment with intelligent compaction systems and conducted two pilot projects. Based on these pilot projects, officials developed contract specifications pertaining to intelligent compaction systems. They expect to start using these specifications in contracts beginning in 2013. Texas officials stated they wanted to use a promising new aggregate in their concrete pavements that improves concrete quality. However, the material is only produced by one manufacturer, limiting their ability to specify it in requests for contract proposals. Similarly, Utah officials wanted to use proprietary asphalt materials in their cold in-place recycling (see table 4) and full-depth reclamation (see table 5) practices. Although they cannot specify proprietary products, the officials said that their effort to change to performance-based specifications might enable them to overcome this challenge. Performance specifications require a contractor to meet functional criteria such as strength and durability, without prescribing use of specific materials or practices. As a result, contractors may choose to use proprietary materials or practices to meet performance requirements.

Agencies Have Implemented Various Programs and Efforts to Overcome These Challenges

FHWA, the Transportation Research Board (TRB), AASHTO, and states have developed several programs that address the challenges of developing new materials and practices through research, training, information and outreach programs, demonstration projects, and other incentives.[18] The following are some of the programs the agencies and organizations have in place to promote the use of pavement materials and practices and other highway improvements.

FHWA

FHWA works with state, industry, and trade associations' stakeholders to develop and implement new materials and practices through the following programs:

- *Advanced Concrete Pavement Technology Products Program*: A national technology transfer effort to improve the long-term performance and cost-effectiveness of the nation's concrete pavement highways by identifying, refining, and delivering the available technologies that can enhance the performance of concrete highways. Some of the materials and practices the program is advancing include mechanistic-empirical concrete pavement design (see table 3), concrete overlays (see table 5), and the use of recycled materials (see table 2).
- *Every Day Counts Initiative*: A program designed to get effective, proven, and market-ready technologies into widespread use. Warm-mix asphalt (see table 3) is one of the practices the program has featured.
- *Highways for Life:* A grant program to demonstrate and promote innovative technologies and accelerate their adoption by the highway community.[19] We observed a demonstration project partially funded by this program that included four of the materials and practices we identified in the previous section of this report, including use of optimized aggregate (see table 3 and fig. 4), intelligent compaction

[18] TRB is a unit of the National Research Council within the National Academy of Sciences whose mission is to provide leadership in transportation innovation and progress through research and information exchange. TRB is supported by state transportation departments, federal agencies, including the component administrations of the U.S Department of Transportation, and other organizations and individuals interested in the development of transportation.

[19] This program was authorized as a pilot program under section 1502 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), Pub. L. No. 109-59, 119 Stat 1144, 1236-1237 (2005).

(see table 5), geosynthetics (see table 2), and curing compounds (see table 2 and fig. 5).[20]

Figure 4: Concrete Plant Producing Optimized Aggregate Concrete for the Highways for Life Project in Tarrant County, Texas, 2012

Source: GAO.

Figure 5: Application of Concrete Curing Compound at the Highways for Life Project in Tarrant County, Texas, 2012

Source: GAO.

- *Long-term Pavement Performance Program*: A 20-year study of in-service pavements across North America. The program's goal is to extend the life of highway pavements through various designs of new and rehabilitated pavement structures using different materials and under different loads, environments, subgrade soils, and maintenance practices. One of the more recent results of this

[20] The project included construction of a 2.2 mile section of continuously reinforced concrete pavement in Tarrant County, Texas, on FM 1938 from SH 114 to Randol Mill Road. FHWA, through its Highways for Life Program, provided a grant of $1 million on this estimated $16.5 million project.

study is guidance on selecting the most effective pavement preservation treatments for asphalt pavement (see table 4).

- *Transportation Pooled Fund Program*: Interested states, FHWA, and other organizations may pool funds and other resources for new areas of research, planning, and technology innovation or to provide information that will compliment or advance previous efforts in these areas.
- *International Technology Scanning Program:*[21] An FHWA program to help states and industry access innovative materials and practices from other countries. The program helped entities adapt and put into practice highway innovations without spending research funds to re-create advances already developed by other countries. Past scans included providing information on asphalt and concrete pavements, pavement preservation (see table 4), superior materials, reclaimed or recycled materials (see table 2), and many other non-pavement related topics.
- *Technology Innovation and Deployment Program:* Section 503(c)(3)(C) of Title 23, United States Code, now requires that the Secretary of Transportation obligate at least $12 million per year to accelerate the deployment and implementation of new pavement innovations and technology.[22]

TRB

TRB also has several programs that are providing additional research to and helping to share information regarding new materials and practices with states.

- *National Cooperative Highway Research Program (NCHRP):* Conducts research in problem areas that affect highway planning, design, construction, operation, and maintenance nationwide. Its efforts include helping state DOTs put the findings to early use in the form of policies, procedures, specifications, and standards. Two subprograms are involved within NCHRP:
  - The Innovations Deserving Exploratory Analysis program funds research into innovations for design, construction, materials, operations, maintenance, and other areas of highway systems.
  - The U.S. Domestic Scan Program is designed to identify materials and practices being used within the United States that might be beneficial to other states and then disseminate those materials and practices to others.
- *Strategic Highway Research Program (SHRP):* The first Strategic Highway Research Program (1988 to 1993) changed asphalt pavement design by producing a new method for designing pavements that reduced distress, resulting in better performing and longer lasting pavements. The second Strategic Highway Research Program (SHRP 2) (2006 to 2015) was authorized by Congress to address some of the needs related to the nation’s aging highway system, including renewal of roads through construction methods that produce long-lived facilities. Some of the work related to pavements undertaken in SHRP 2 includes precast concrete pavement technology (see table 3), infrared thermograpghy (see table 6), and ground penetrating radar (see table 4).

[21] This program was conducted under section 5206 of SAFETEA-LU, known as the International Highway Transportation Outreach Program, Pub. L. No. 109-59, 119 Stat., 1795-1796.

[22] 23 U.S.C. § 503(c)(3)(C) as amended by the Transportation Research and Innovative Technology Act, § 52003, 126 Stat., 879-880.

AASHTO

AASHTO has groups to assist DOTs in overcoming the challenges of implementing materials and practices.

- *National Transportation Product Evaluation Program:* Evaluates materials, products, and devices for use in highway and bridge construction. The program's goal is to provide cost-effective evaluations for state DOTs by eliminating duplication of testing and auditing by the states and manufacturers that provide products. Some of the materials and practices being evaluated include warm-mix asphalt (see table 3), joint sealing for concrete pavement (see table 4), crack sealing for asphalt pavements (see table 4), concrete overlays (see table 5), concrete curing compounds (see table 2), and geosynthetics (see table 2).
- *Technology Implementation Group:* Identifies and champions the implementation or deployment of a select few proven technologies, products, or processes that are likely to yield significant economic or qualitative benefits to the users. Some of the pavement technologies promoted include precast concrete pavement slabs (see table 3) and hot in-place asphalt pavement recycling.

State DOTs

Officials at some of the state DOTs we interviewed said that in addition to working with FHWA and others, they had their own efforts under way to evaluate and implement new materials and practices. For example, Minnesota officials told us the state created a $20 million innovation program in 2010 which can pay for the incremental costs associated with using practices such as intelligent compaction (see table 5).[23] In one case, the state paid a contractor to outfit its construction equipment to use intelligent compaction, thus reducing the reluctance of the contractor to bid the project and buy equipment it might not use again. In another instance, the state used the funding to pay for a new asphalt-patching material for use by its maintenance division. This purchase allowed the state to become familiar with the product and develop specifications for potentially continuing its use.

Agency Comments

We provided U.S. Department of Transportation (DOT) with a draft of this report for review. U.S. DOT did not comment on the draft report. We also provided each of the seven state DOTs we spoke to with a draft of relevant sections of this report for review. Each provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to congressional committees with responsibilities for surface transportation issues, the Secretary of Transportation, the Administrator of the Federal Highway Administration, and other interested parties. In addition, this report is available at no charge on the GAO website at http://www.gao.gov.

[23] The program was funded with $15 million in 2012.

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or stjamesl@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this correspondence. GAO staff who made key contributions to this correspondence are Michael Armes, Hal Brumm, William Carrigg, Bert Japikse, Justin Jarrett, Les Locke, Amy Rosewarne, Travis Thomson, and Elizabeth Wood.

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