# Commission Briefing Paper 4I-03

# Implications of Aging Infrastructure on Long-Term Preservation and Reconstruction Needs

Prepared by: Section 1909 Commission Staff
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## Introduction

This paper is part of a series of briefing papers to be prepared for the National Surface Transportation Policy and Revenue Study Commission authorized in Section 1909 of SAFETEA-LU. The papers are intended to synthesize the state-of-the-practice consensus on the issues that are relevant to the Commission's charge outlined in Section 1909, and will serve as background material in developing the analyses to be presented in the final report of the Commission.

This paper summaries industry information about the long-term preservation and reconstruction needs of the Nation's aging infrastructure, including highways, transit, rail, and waterways. The paper stresses the need to better manage our assets through monitoring conditions, timely system preservation actions, and the use of more efficient methods and materials when reconstructing infrastructure.

Information on the current physical condition and operation performance of different components of the surface transportation system is found in several papers under Module II of the Commission work plan.

## Background and Key Findings

Addressing the long term preservation and reconstruction needs of the U.S. transportation system presents a significant ongoing challenge, particularly as the existing infrastructure continues to mature. While age alone is not a sufficient absolute determinant of when a particular infrastructure component should be replaced, it is important to recognize that older components may tend to deteriorate more quickly or require more aggressive investment that would a newer components in otherwise similar condition. The extent to which this phenomenon exists or is captured in current analytical procedures varies widely between different types of transportation infrastructure.

Analytical models used to project future highway and bridge needs for the U.S. Department of Transportation's (U.S. DOT) *Conditions & Performance (C&P) Report* produce estimates of the cost to periodically resurface, rehabilitate, reconstruct and replace the existing highway and bridge infrastructure, as well as to expand that infrastructure, where appropriate. However, in predicting future rates of deterioration of various components of the highway and bridge infrastructure these analyses are based primarily on the current conditions of those components and do not factor in their chronological age. Some experts have expressed concerns that this approach may tend to significantly understate the true costs of future reconstruction activities. To the extent that age (independent of current conditions) is a relevant factor in pavement and bridge deterioration, this would have particularly significant implications for the Interstate

System.  We have just celebrated the 50th Anniversary of the Interstate System in 2006, and many of its segments were constructed within a relatively narrow time period, compared to other subsets of the highway system which have expanded more gradually.  At the very least, there is significant potential for future Interstate reconstruction needs to be "lumpy" (i.e., concentrated within certain time periods), which will need to be recognized in designing strategies for financing them.  Research is currently underway to investigate these concerns, and identify potential linkages between age and future pavement and bridge performance.

The age of transit infrastructure and equipment is included in the National Transit Database, and is used by the FTA to develop its condition ratings for these transit assets.  Thus, the transit conditions measures reported in the *Conditions and Performance Report* should reflect any trends in the aging of the Nations' transit infrastructure and conditions over time.  The useful lives of transit assets fall into a wide range, with smaller agency-owned bus vehicles having relatively short lives of less than 10 years, and rail assets such as structures and tunnels having asset lives of 100 years or more.  Transit rail assets also include stations and communication, train control, traction power and revenue collection systems, and facilities for maintenance and rehabilitation.  All transit assets require continual rehabilitation and replacement.

During the last decade, the U.S. freight rail industry's move to capture the economic benefits of heavy-haul trains caused much of the Nation's rail network to be replaced with more robust, heavy-duty rail.  The outlook for bridges and tunnels is less promising, however. The replacement costs of these structures are extremely high, and they increasingly suffer from functional obsolescence due to the growing presence of double-stack intermodal trains and today's heavy freight cars.  There is concern about the railroads' ability to generate sufficient capital to rebuild or replace key bridges and tunnels, particularly for the Nation's smallest railroads (Class III).  Innovative solutions such as public private partnership or third party financing may need to be considered to address future needs (these funding issues are discussed in more detail in Commission Paper II-D-01, "Condition and Performance of the Freight Rail Industry").

The United States relies on an extensive marine transportation system.  Waterways and ports provide intermodal links to 152,000 miles of rail; 460,000 miles of pipelines; and 45,000 miles of interstate highways.  Information on the age and condition of the Nation's port facilities is limited, largely due to the significant private sector role in the operation of such facilities. Waterway usage is increasing, but the facilities are aging; many U.S. Army Corps of Engineers-owned or -operated locks are well past their planned design life of 50 years. Of the 257 locks on the more than 12,000 miles of inland waterways operated by the U.S. Army Corps of Engineers, nearly 50 percent are functionally obsolete. By 2020, that number will increase to 80 percent. The cost to replace the present system of locks is more than $125 billion.

## Aging Infrastructure as a Policy Issue

In considering the issues associated with aging infrastructure, it is important to recognize that the chronological age of a given component of the surface transportation system is generally not a direct concern in and of itself. Instead, the problem may be that an older piece of infrastructure is more likely to be in deteriorated condition due to the wear and tear associated with weathering and continued use over time. It may also be less likely to meet current design standards (which are periodically updated) and more likely to be functionally inadequate due to the gap between current utilization rates and the uses envisioned at the time of its original design.

The key concern from a policy perspective, then, is the current condition and performance of the system and its projected state in the future. With respect to age, what is important is the way in which it may interact with condition and performance. In some cases, data on the age of different infrastructure components may be readily available, but direct data on its condition may not be, leaving age to serve as a proxy measure for conditions. In other cases, an older facility may tend to deteriorate more quickly from the fatigue of repeated use or require more aggressive treatments than a newer facility in otherwise similar condition, making age an important factor to be considered in modeling condition, performance, and investment over time.

Another age-related issue concerns the effect of large cohort groups on the pattern of future investment needs. One result of major infrastructure investment programs such as the Interstate Highway program or the rapid development of large transit systems is that a significant amount of infrastructure may fall into a relatively narrow age range. If replacement needs are a simple function of age, then this may result in large portions of the system needing to be replaced at approximately the same time, creating a significant "bump" in investment needs. This bump could be exacerbated if, while replacing one aging element of a structure, an agency were to decide to replace other components of the structure prematurely in an effort to keep replacement work within a single work period.

Such effects may be attenuated, however, to the degree that other factors (such as ongoing maintenance and rehabilitation actions and variations in usage rates and environmental conditions) affect the useful service life of transportation assets. In fact, the important feature of aging infrastructure is generally the projected remaining service life, rather than age. Such a concept may be limited, however, by the difficulty in defining the terminal condition states for transportation facilities.

A final issue for aging transportation assets is that older assets may have been built to standards that have been superseded by newer requirements, which replacement facilities would be required to meet. This is especially common for safety design standards and vehicle emissions and accessibility requirements. In some cases, the replacement action may be primarily motivated by the desire to upgrade to modern standards. In others, however, the need to upgrade may make it impossible to undertake lesser rehabilitation actions without triggering the newer requirements, making such actions infeasible and thereby increasing the complexity and cost of addressing age-related deficiencies.

## Aging Highway and Bridge Infrastructure

The relationship between aging roadway pavements and the condition of the system is difficult to address, both quantitatively and conceptually. The Highway Performance Monitoring System (HPMS) does not include information on the age of pavements, making it impossible to directly determine whether the average age of pavements has been increasingly significantly over time. Also, since pavement data from HPMS are also the primary input for the Highway Economic Requirements System (HERS), used to project future pavement performance and investment, age is not included as a direct factor in such analyses. Perhaps more importantly, however the nature of highway pavement design and management practices makes it difficult to determine what the relevant "age" is, since different layers may have been installed, overlaid, or removed at different times as part of different rehabilitation actions.

The primary measure of pavement condition used for both reporting and modeling is the International Roughness Index (IRI). This measure focuses on the condition of the roadway surface, which is what affects users directly. However, if age-related distresses occur primarily in the substructure of roadway pavements, then this indicator may not do a very good job of reflecting the impact of aging infrastructure on system condition.

The age of highway bridges is included in the National Bridge Inventory (NBI) data, which covers bridges on all public roads. Of the bridges currently on the Interstate highway system, approximately 17.4 percent were constructed during the 1950s, 44.0 percent were constructed during the 1960s, 20.0 percent were constructed during the 1970s, and 16.1 percent were built in the 1980s or later. Only 2.5 percent of bridges date from before 1950 (2006 C&P, p. 11-9.) However, bridge investment and condition modeling tools such as AASHTO's Pontis bridge management software and FHWA's NBIAS (which uses the same bridge modeling approach as Pontis) do not use age as a predictor of the condition of bridge elements. As a result, any age-related issues independent of current bridge element conditions would not be captured in analyses (such as USDOT's *Conditions and Performance* reports and AASHTO's *Bottom Line* reports) that use such tools.

FHWA is currently undertaking research to isolate an age-related component for modeling condition and investment on both pavements and bridges. While it is plausible that the current exclusion of age as a direct input in the data used to support these modeling processes might affect their outcomes, it is difficult to quantify what these effects might be. It is also conceptually unclear to what extent improvement needs should be determined based on the age of the infrastructure (as opposed to its physical condition), with many in the pavement and bridge management community arguing that effective preventive maintenance, rehabilitation, and load enforcement strategies could conceivably extend the useful service lives of highways and bridges to the point that age becomes effectively irrelevant. Also, in many places highways have been reconstructed and bridges replaced well in advance of the end of their expected useful lives due to the need to correct functional or capacity deficiencies that are not directly related to age. Nevertheless, to the extent that age is important as an independent determinant of future investment needs, the current processes for analyzing investment in USDOT's *Conditions and Performance* reports and AASHTO's *Bottom Line* report could potentially be underestimating such needs. More information on the current condition and performance of the Nation's highways and bridges is presented in briefing paper 2A-01, which summarizes material from the 2006 Conditions and Performance Report.

## Aging of Transit Infrastructure and Equipment

Transit service is provided through many different types of infrastructure and equipment. These assets represent a wide array of useful service lives, from vehicles or components that last only a few years to tunnels that remain in service after more than a century of use. Like other transportation system assets, this equipment and infrastructure is subject to ongoing preventive maintenance and rehabilitation, which can greatly extend its service life.

Unlike highways, which are largely used by private vehicles whose age and condition characteristics are not considered part of the aging infrastructure issue, transit vehicles are considered an essential asset in the provision of transit service. Transit vehicles, however, are complex pieces of machinery, with different components that may be replaced or refurbished on very different cycles. In most cases, key components such as engines and wheelsets will be replaced many times before the structural body of the vehicle itself warrants retirement. Also, like other sophisticated technologies, the components used in transit vehicles often become economically or functionally obsolete well before their physical condition has deteriorated.

Other transit infrastructure such as maintenance facilities and stations may also be subject to periodic rehabilitation activities that can significantly improve the quality and condition of the assets. In some cases, only the exterior walls may remain from the original construction. The age of such facilities, and its relation to its physical condition, could thus be much less certain than for other types of infrastructure.

The age of transit infrastructure and equipment is included in the data supplied by transit operators in urbanized areas to the National Transit Database (NTD). In years past, the average age of transit assets was used as the primary measure of physical conditions, implicitly assuming a linear relationship between condition and age. Over the past decade, FTA has conducted a number of condition assessments of different transit asset classes, which have yielded more refined, non-linear asset deterioration curves based on both age and other factors. These curves have then been applied to the NTD data to yield condition ratings on a 1 to 5 scale (where 5 is “excellent”).

As is described in briefing paper 2B-01, the primary data from the NTD used to generate the condition ratings is the age of transit assets. As a result, the condition measures reported by FTA should accurately reflect any trends in the aging of the Nation’s transit infrastructure and equipment over time. As that paper notes, the average age and condition of rail and bus vehicles has been stable or improving in recent years, while the age of maintenance facilities and other assets has increased slightly over time. Also, average ages are influenced by both the replacement of existing assets and by new assets supporting the expansion of transit service, which could mask or dampen the impact of other, older transit systems on average condition ratings. More information on the physical condition of the Nation’s transit infrastructure is found in paper 2B-01.

## Aging of Rail Infrastructure

Unlike highway and most transit infrastructure, rail infrastructure is privately owned. As such the scope of and policy approaches to aging rail infrastructure are different than in other modes of transportation. U.S. private railroads have market incentives to maintain healthy networks; the past two decades have seen railroad networks shrink in gross size (track-miles) while improving operations and infrastructure to carry more freight more safely.

As one indication of the health of the rail network, freight rail safety has improved markedly in the last 20 years. For example, accidents per million train-miles declined from 11.43 in 1980 to 4.08 in 2005 (a 64 percent reduction) and derailments fell from 5,442 to 2,280 (a 58 percent reduction) over the same period. In addition, the number of fatalities, injuries, and illnesses per hundred full-time equivalent railroad employees on duty declined about 79 percent (from 11.17 in 1980 to 2.36 in 2005).

While many factors—some not related to infrastructure—have contributed to these safety improvements, this picture is certainly indicative of a healthy system. During the last decade, the industry's move to capture the economic benefits of heavy-haul trains (also called Heavy Axle Loading—HAL) caused much of the Nation's rail network to be replaced with more robust, heavy-duty rail (weighing 130 pounds per yard or more). During this time, capital expenditures on roadway and structures more than doubled from $2.6 billion in 1990 to $5.4 billion in 2005.

There are two possible exceptions to this sanguine view of the condition of rail infrastructure: bridges and tunnels. While the functional engineering lifespan of these structures are very long, their replacement costs are extremely high. The first concern is functional obsolescence; this is to say that the size and configuration of some tunnels are not adequate to handle double-stack intermodal trains, and today's heavy freight cars are stressing some older bridges to their design limits and beyond.

Another concern is the railroads' possible inability to generate sufficient capital to rebuild or replace key bridges and tunnels. Innovative solutions such as public private partnerships or third-party financing may need to be considered to address future needs (these funding issues are discussed in more detail in Commission Paper 2D-01, "Condition and Performance of the Freight Rail Industry"). In particular, many of the Nation's smallest railroads (Class III), while generating revenues sufficient for day-to-day operations, lack capital for major infrastructure repair or replacement.

The Federal Railroad Administration (FRA), unlike public highway agencies that directly own and maintain their bridges, does not have a justification to maintain detailed records and qualitative data on bridges and tunnels owned by the railroads themselves. The FRA policy on the safety and management of railroad bridges, found in the Federal Register at 65 FR 52669, explains the difference between railroad and highway bridge issues, and the different approaches taken by FRA. Without that detailed information presently at hand, further analysis in conjunction with the individual railroads will be needed to identify existing and potential constraints on the Nation's railroad network resulting from aging or obsolescent bridges and tunnels.

## Aging of Water Transportation Infrastructure

U.S. waterways consist of a system of rivers, lakes and coastal bays improved for commercial and recreational transportation. The Nation's water transportation infrastructure plays a vital role in the movement of domestic and international freight. International trade has dramatically increased over the last ten years due to shift from manufacturing in the United States to Asia. Carriers are also employing larger ships, which require deeper channels.

Port facilities are either owned by public port authorities and leased to private sector operators, or are owned directly by the private sector. Public port agencies own approximately one-third of the U.S. deep-draft marine terminal facilities. Ports are responsible for dredging of berthing areas and access channels connecting the port facilities to Federal navigation channels. Marine terminal operators and ocean carriers have shown no reluctance to provide the capital for modernizing and growing these facilities (Christopher Koch, "Government Policy and Action Regarding Improvement of the Nation's Intermodal Transportation Infrastructure"). Problems do exist, however, in gaining access to land and permits for facility expansion.

The American Society of Civil Engineers (ASCE) reports that more than 90 percent of the Nation's top 50 ports in foreign waterborne commerce require regular maintenance dredging. Although not an issue of "aging" per se, maintenance of channels is critical. These ports move approximately 93 percent of all U.S. waterborne commerce each year. If these ports are not dredged, many port facilities and navigation channels will be non-navigable in less than a year (ASCE, Navigable Waterways). Capital investment in public water resources infrastructure, however, has decreased by 70 percent over the last 30 years. In the 1970s, the U.S. Army Corps of Engineers' civil works annual construction appropriations were in the $4 billion range, but by the 1990s the funding dropped to an average of $1.6 billion per year (ASCE, Navigable Waterways).

The U.S. Army Corps of Engineers maintains more than 12,000 miles of inland waterways and owns or operates 257 locks at 212 sites on inland waterways. Barges using these waterways carry about one-sixth of the nation's intercity freight by weight, at a cost per ton mile about half that of rail, or one-tenth that of trucks. Waterway usage is increasing, but the facilities are aging; many Corps-owned or -operated locks are well past their planned design life of 50 years. Of the 257 locks on the inland waterways operated by the Corps, nearly 50 percent are functionally obsolete. By 2020, that number will increase to 80 percent. The cost to replace the present system of locks is more than $125 billion (Upper Mississippi, Illinois & Missouri Rivers Association, River Currents, Summer 2005).

The identified capital needs for the locks far exceeds the currently available resources in the Waterway Trust Fund, into which barge operators currently pay a tax of 20 cents per gallon on diesel fuel. The Corps of Engineers reports that the trust fund has steadily decreased over the past decade as barge towboats have become more fuel-efficient. The fund had only $250 million as of October 2006. At the same time, spending to repair aging locks from the 1930s on the Ohio, the Mississippi and other rivers has increased sharply. The administration has proposed higher fees for barge operators ("Bush administration plans new barge fees," Associated Press, February 6, 2007). One means of raising these revenues could be in the form of new fees linked to how often barges go through existing locks, although the barge industry will very likely oppose added fees.

## Responses to Aging Infrastructure

There are a number of promising approaches for extending the lifespan of aging infrastructure. Although these methods cannot eliminate the need for reconstruction and rehabilitation, they can spread the need out over a sufficiently long period as to enable a more measured response to the replacement need. When replacement is ultimately necessary, new methods and technologies to build longer lasting structures more quickly offer promise for efficient, cost-effective replacement that minimizes impacts on system users.

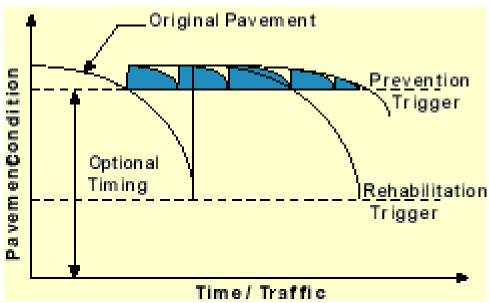
**Transportation Asset Management:** Transportation asset management is a systematic, policy-driven, performance-based process of maintaining, upgrading, and operating physical assets. It combines quality information and engineering principles with sound business practices and economic theory, providing tools to facilitate an organized, logical approach to decision-making. The benefits of transportation asset management include extending the useful life of physical assets, minimizing the life-cycle costs of capital investments and ongoing maintenance and operations, and maximizing benefits while minimizing inconveniences to surface transportation customers. As such, transportation asset management has a critical role to play as the Nation responds to the challenge of modernizing and expanding its infrastructure (see Commission Briefing Paper 4I-02, "The Role of Asset Management in the Surface Transportation System," for a much more detailed exposition of transportation asset management).

**Management Systems:** A key to managing aging infrastructure is to have thorough data on the condition, dimensions, age, maintenance history, and other relevant parameters pertaining to the transportation assets. Over the last two decades, State and local governments, transit agencies, and private companies have implemented various inventory management systems to monitor and manage their surface transportation assets. As noted in Paper 4I-02, virtually all state DOTs have inventory information for their major infrastructure categories and monitor conditions periodically, especially in the form of bridge and pavement management systems. Increasingly state and local transportation agencies employ systems to monitor safety, traffic congestion, transit assets, and tunnels. Some agencies employ tools attached to the management systems to predict future performance and to evaluate the costs and benefits of alternative preservation and investment strategies. It is critical that agency decision-makers make full use of their management system tools for resource allocation. Improved inspection techniques, through the use of new and innovative equipment, are also necessary to better ensure the safety of the traveling public.

Even with these inventory management tools and data, however, there remain many unknowns about the performance and degradation of structures and materials over time, and the long-term effectiveness of maintenance, repair, and rehabilitation strategies. In addition, with the recent move to higher performance materials and advanced structural systems, high-level, long-term performance and durability are assumed, but not demonstrated at this time. Careful monitoring will play a critical role in refining information about these structures and materials.

**System Preservation:** A critical element of transportation asset management is system preservation. System preservation is the planned strategy of treating assets at the optimum time to maximize their useful life, enhancing asset longevity while lowering lifetime costs. Preserving transportation assets also results in increased safety and higher user satisfaction.

Preservation treatments must be carefully selected based on good inventory management data, and may not be appropriate for certain assets, particularly those already showing extensive wear. For instance, in the case of highway pavements, treatments must be carefully selected and must be applied when the pavement is still in relatively good condition without structural damage (see figure). Preventive maintenance treatments may include crack sealing, chip seals, slurry surfacing and hot mix asphalt (HMA) thin overlays that will bolster ride quality, provide surface drainage and friction, and correct surface irregularities.




Preservation treatments are generally lower-cost surface improvements and offer little or no structural enhancement. They do, however, rejuvenate the asset surface by addressing the effects of environmental aging and minor surface defects before the asset deteriorates further and requires rehabilitation or reconstruction, which is much more costly and time consuming. No treatment can ward off asset deterioration forever, but the strategies and techniques of asset preservation can significantly slow the rate of deterioration. The implementation of system preservation often requires a change of philosophy from reactive "worst-first" maintenance to preventive maintenance.

The transit industry has developed and embraced the concept of preventive maintenance to extend the useful lives of transit assets. For example, track renewal is a programmed preventive maintenance. Similar capital programs include transit vehicle overhauls to ensure full useful lives of buses, rail cars, and ferries and are a regular part of the transit industries plan to address aging systems and extend their useful life to the fullest extent possible. Preventative maintenance also plays a critical role in private sector management of rail and port facility infrastructure.

**Changing the Way Infrastructure Is Built:** Because all assets, regardless of how well maintained, will eventually wear out, best practice methods and materials should be applied when reconstructing these components of the surface transportation system. A detailed discussion of best practice methods and materials is provided in Commission Briefing Paper 4I-01, "The Potential of Advanced Construction Materials Techniques and Technologies to Allow Capacity Increases with Reduced Community Disruption."

Paper 4I-01 notes that historically, transportation procurements have focused on identifying the lowest initial investment cost rather than minimizing the ongoing lifecycle costs of building and maintaining transportation infrastructure over time. Similarly, investment decisions driven by low initial cost usually have not considered the economic costs of traffic delays, safety, or quality-of-life associated with construction projects. Against the backdrop of limited resources and pressure to implement as many projects as possible, the challenge is to make investment decisions that will achieve long-term lifecycle savings. Key means for achieving these goals include:

- Mainstreaming lifecycle cost decisions into planning, design, and implementation;
- Accounting for the economic benefits of accelerated construction;
- Reducing emphasis on minimizing initial implementation costs;
- Supporting research on new materials and quantitative systems analysis;
- Using design-build, public-private partnerships, and other innovative procurement and financing methods;
- Providing flexibility to use research funds to respond to new ideas and findings;
- Documenting and incentivizing best practices; and
- Promoting and disseminating best practices through programs such as the Highways for LIFE pilot program and the Accelerated Construction Technology Transfer (ACTT) program.

A great deal of innovative and advanced technology is applied to special projects but has not risen to the level of common practice. Without dramatic changes in how the transportation community promotes, delivers, and deploys innovations and technologies, the realization of better ways of building transportation infrastructure could take decades. Innovative programs such as the FHWA's new Highways for LIFE pilot program could help bring about this cultural change in a few years rather than decades, through the use of incentives, technology partnerships, and technology transfer, communication, and stakeholder involvement.

## References

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## CONSOLIDATED COMMENTS FROM MEMBERS OF THE BLUE RIBBON PANEL OF TRANSPORTATION EXPERTS - PAPER 4I-03

One reviewer commented as follows:

This paper addresses the long term preservation and reconstruction needs of the U.S. transportation system including highways, transit, rail and waterways. The implication of age being one of the parameters for determining long term preservation and reconstruction needs has been discussed, along with the availability of age information for the corresponding transportation infrastructure facility.

The paper notes that for highway pavements, age information is not available in HPMS and HERS and pavement rehabilitation decisions are based on other parameters such as IRI, which may not do a good job if the distress is in the pavement substructure. For highway bridges, age information is present in bridge databases but performance modeling tools such as Pontis do not use age as a predictor of bridge condition. For the transit infrastructure, aging may be reflected in condition ratings, which are used in formulating preservation and reconstruction plans. For the freight rail industry, the engineering life span of the structure is quite long. However, it is questionable if the rail industry can raise sufficient capital to rebuild itself.

For the water transportation infrastructure, regular maintenance dredging of the ports presents a more significant challenge than aging. The paper notes that many of the U.S. Army Corps owned locks are well past their planned design age. The age information on the nation's port facilities is limited. The extent of impact of age on the infrastructure preservation and reconstruction varies widely among transportation assets. An important observation made in the paper is that most of the interstate system was constructed in a narrow time period and hence the replacement activities might come in a "lump". However, the paper notes that such lumps can be attenuated due to factors such as ongoing maintenance which would make age an irrelevant factor. The paper concludes by discussing the approaches that can help in extending the lifespan of the aging infrastructure. These include strategies such as the development and use of transportation asset management systems, proper system preservation and changing the way infrastructure is built.

The deterioration of infrastructure facilities is dependent greatly on the usage. However, aging can represent both usage and weather effects. Consequently, expected preservation and reconstruction needs should be estimated in terms of both load and time domains.

Reference is missing to the following statement on page 6, paragraph 4: "….and today's heavy freight cars are stressing some older bridges to their design limits and beyond". In fact, references are missing at several places of the draft.

An age-based analysis of the various transportation infrastructure systems indicating how the service lives has been affected by rehabilitation and preservation activities will provide a better understanding of whether age is a significant parameter for estimating reconstruction and preservation needs.