ECONOMIC AND ENVIRONMENTAL BENEFITS OF INCREASING THE USE OF CONCRETE PAVEMENTS IN PUERTO RICO

APC
ASOCIACIÓN PUERTORRIQUEÑA DEL CONCRETO

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Executive Summary

The purpose of this report is to present the advantages offered by concrete pavements as a sound infrastructure investment, when compared against asphalt pavements. Concrete is a more durable option, with lower lifetime costs than asphalt, it has less of an impact on the environment, is looked upon as a safer alternative in wet conditions, more cost effective for users, and generates a larger economic impact on the Commonwealth's economy because it is entirely locally. From the extraction of raw materials for cement production, to the ready-mix manufacturing, all value-added stays in Puerto Rico.

The key findings of this report are:

- Residents of Puerto Rico, due to the poor durability of asphalt roads, incur in significant overpayments for maintenance of the road infrastructure and transportation. These costs are threefold in the case of poorly maintained roads:
    - Residents must incur in additional vehicle operating costs, owing to repairs and replacement of vehicle parts and accessories;
    - They must incur in more time to travel, as poor maintenance of roads reduces the potential speed; and
    - Due to the costlier material, residents on average pay higher repair and reconstruction costs of public roads.
    - Luminescence in concrete roads provides better vision that prevents accidents consequently saving lives, reducing energy and electricity cost to taxpayers.

  Given that highways/roads in Puerto Rico are mostly government owned, with approximately 28,000 km of paved roads being managed by either the Commonwealth or its municipalities (78), taxpayers are bearing an excess cost burden due to the current grid's reliance upon asphalt. This is critical especially today due to the tight fiscal position of all levels of government.
- Asphalt prices are susceptible to changes in oil prices, being that this is a main component. Yet, even as the price of oil has decreased, the cost of asphalt remained relatively unchanged. As such, consumers have not seen any real cost benefits from asphalt pavements, despite a reduction in the price of one of its main components. On the other hand, in cases where the price of oil does increase, the cost of asphalt increases as well.
- According to the Federal Highway Administration reports (Federal Highway Administration, 2017), 73% of weather-related accidents in the US occur on wet pavement and 46% during rainfall. Asphalt pavements are less safe than concrete pavements, particularly during rainfall. This makes it very important that the pavement used in Puerto Rico, an Island whose roads are prone to flooding, can handle the adverse weather and provide safe driving conditions for commuters. Asphalt pavements have greater hydroplaning potential than concrete roads, and thus increase the probability of accidents during rainy weather conditions.

  - Asphalt pavements are flexible, and in time this forms vertical settlement in the wheel path, a phenomenon known as rutting. Rutting can create a physical depression on the pavement that accumulates water, increasing the hydroplaning potential. This thus increases the probability of accidents in wet asphalt pavement.
  - On the other hand, Portland Cement Concrete pavement is a moldable material when it is first placed and can be textured to provide good friction and performance in wet climates. Therefore, they also help reduce the hydroplaning potential in the roads providing a safer driving environment.
- Unlike asphalt pavements, which require routine minor maintenance every 2 to 4 years and resurfacing every 6 to 12 years, concrete pavements only require minor maintenance every 15 to 25 years and do not need resurfacing during its service life.
  - The low maintenance of concrete pavement has an added advantage of reducing work zones in the highway and road system. Work zones increase the risk of accidents in the highway and road system; less maintenance means less work zones, which could result in fewer accidents.
- Concrete roads are more sustainable than asphalt paved roads in terms of aggregate consumption. When performing maintenance works, the aggregates used for the base layer of the road must be replaced. Since the frequency of maintenance in the life cycle of the asphalt road is higher than in the case of concrete, the amount of aggregates it will demand throughout its life cycle will be greater.
- The aggregates used in the production of asphalt roads have negative environmental impacts on water, air, and the temperature near the pavement.
  - As rainwater cannot pass through the asphalt, the water accumulates and is redirected to water sewages where it mixes with other materials, from the erosion of the top layer of the pavement, that can be hazardous to human health. These ultimately end up deposited in a water source.
  - During the production of most asphalt types where high temperatures are needed, volatile organic compounds (VOCs) are released. These VOCs include carcinogens as benzene and toluene, which have poisonous effects that remain suspended in the atmosphere long after they're released from the original compounds.
  - Asphalt absorbs more solar radiation and retains it for longer periods. This means the asphalt gets hotter and stays hotter for longer. This can lead to urban areas being hotter than rural areas, as the ground absorbs more heat.

Economic Benefits of Concrete Versus Asphalt Pavements

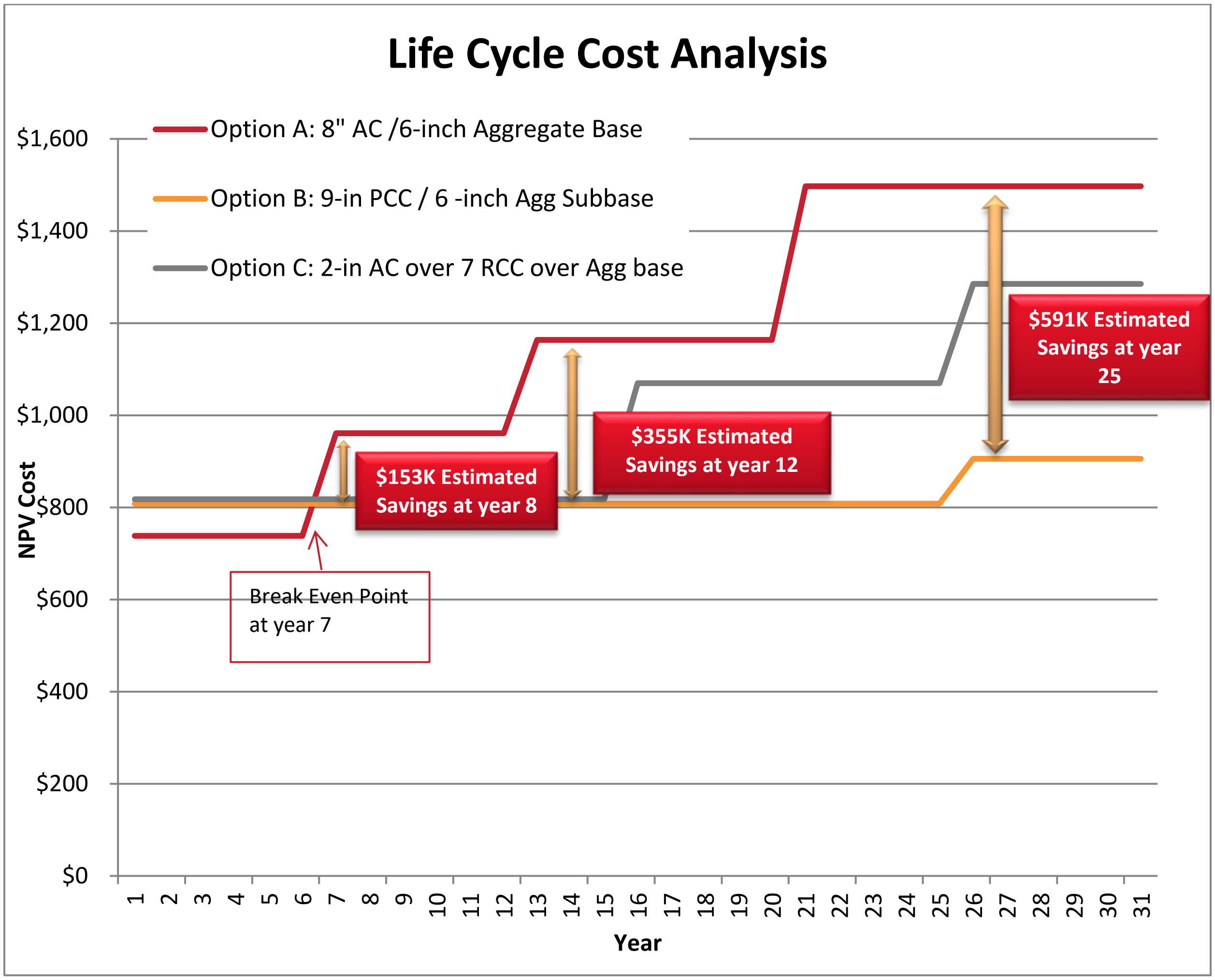
- Implementing Portland Cement Concrete Option B, the 9-inch Portland Cement Concrete Pavement, represents an estimated savings at the end of the 30-year evaluation period of $584,728, or 68% in savings to the owner at net present value (NPV). These savings include the return of the $69,886 of higher initial investment for the concrete pavement. Therefore, **by initially investing an additional $70K, pavement owners get almost five times the return on that investment**.

Table 5 – Summary of Initial and Lifetime Costs for All Options in Small Urban Areas

Description of Pavement	Initial Cost	% high	Salvage Value of Last Rehabilitation	30-year period Discounted 1.6% Salvage Value Applied		
				Net Present Accumulated Cost	Savings (With Salvage) Sub Total	Percent
Option A: 8" AC /6-inch Aggregate Base	$738,218	0%	($55,591)	$1,441,545	$584,728	68%
Option B: 9-in PCC / 6 -inch Agg Subbase	$808,104	9%	($48,713)	$856,817	$0	0%
Option C: 2-in AC over 7 RCC over Agg base	$817,695	11%	($107,616)	$1,177,569	$320,752	37%

- Using a Life Cycle Cost Analysis, the overall monetary benefit of investing in concrete over asphalt pavements was estimated over a 30-year period, both for initial and maintenance costs. The analysis found that by selecting a Portland Cement Concrete Pavement Option B over a Hot Mix Asphalt Pavement Option A reaches a breakeven point in the year 7. From that moment the much in need Commonwealth finances will start saving approximately **one hundred and fifty-three thousand dollars ($153,000.00) at year eight, three hundred and fifty-five thousand ($355,000.00) year twelve and five hundred and ninety-one thousand ($591,000.00) at year twenty-five.** Find Figure 9 Life Cycle Cost Analysis for Small Urban Areas National Highway System Classification.

Figure 9 – Life Cycle Cost Analysis of Pavements in Small Urban Areas



- There is an additional indirect benefit of having two competing industries supplying paving materials for roads and highways. Competition can help lower prices, thus benefitting the Government and the taxpayers.
- Given that cement is produced locally, investing in concrete pavement would also have a higher economic impact in Puerto Rico. Approximately 27% of the cost of asphalt is used to import Bitumen, which implies that 27% of the investment in asphalt pavements ends up outside the island and does not contribute towards generating more local jobs. One of the key economic indicators is the amount of cement bags consumed on a specific month. By investing on concrete pavement, this indicator will be immediately affected.
- If the Commonwealth and the municipalities invested 25% of each of their respective budgets for new road construction and maintenance for fiscal 2015 ($112 million) on concrete pavements, this could create 2,513 direct, indirect and induced jobs. Spending the same amount on asphalt payments would generate 1,834 jobs (direct, indirect, and induced), meaning a higher return for investing in concrete.

- Being Cement an Indicator used to measure economic development, a 10% increase in pavement our roads in concrete, will double production and sales statistics will show economic recovery.

Recommendations

The previous findings indicate that it's best interest of the local government and concerning authorities to leverage a local healthy concrete paving industry to promote economic growth and efficient use of public funds. Therefore, the following steps are proposed:

- Immediately identify various roads in need of rehabilitation and develop a bid package of design/build rehabilitation concrete overlay project to compete against asphalt.
- Develop a plan to achieve a reasonable balance in concrete rehabilitation and asphalt rehabilitation projects to be constructed five years from now.
- Develop combined professional group APC, AGC, CIAPR, DTOP, Municipalities to review and develop a revised Standard Drawings and specifications for concrete pavement construction and concrete overlays.
- Explore the possibility to incorporate the alternate bid alternate price described by the Federal Highway Administration Technical Advisory "Use of Alternate Bidding for Pavement Type Selection" T 5040.39 from December 20, 2012.

The PR Construction and Design Industry have long proven experience in concrete pavements construction and has the knowledge and equipment to immediately offer these services.

Introduction

Puerto Rico's Infrastructure and Advancements in Concrete

A country's infrastructure is one of the most important elements for its economic development. Lack of adequate infrastructure hinders the economy's capability to attract investment, produce competitively, and optimize the movement of human and capital resources. In the 2014-2015 Global Competitiveness Report by the World Economic Forum, Puerto Rico's overall infrastructure ranked 58 out of 144 economies in the world.[1]

Infrastructure investment, particularly in key areas such as transportation, must be done in way that helps maximize investment and development while minimizing the negative burdens upon taxpayers and the environment. To accomplish this, the public sector must invest in sustainable technologies and durable, high-quality materials. At the same time, Puerto Rico's government faces several challenges in the coming years, including:

1) a declining population;
2) an economy that has been in a recession since 2006; and
3) achieving a balanced budget.

The Commonwealth is expected to begin a process of reducing costs and restructuring its debt to balance the budget. To achieve the first objective, the Administration must identify areas where savings can be generated without affecting essential services. At the same time, the government must also better target investment into activities with the potential to jump-start economic growth as a means to fuel a sustained recovery. Wherever possible, technological advancements and changes in the usage of inputs should be considered as part of the new economic strategy.

This report shows that investing in concrete pavement is a viable change in the current infrastructure, which would provide significant long-term savings for the Commonwealth while allowing it to achieve its policy objectives by moving into economic recovery. Concrete pavements have many advantages, not only in terms of lower maintenance costs, but also in terms of road quality, safety and environmental footprint. At the same time, concrete generates a larger economic impact upon the Commonwealth than its alternative, asphalt, as it is a locally produced good.

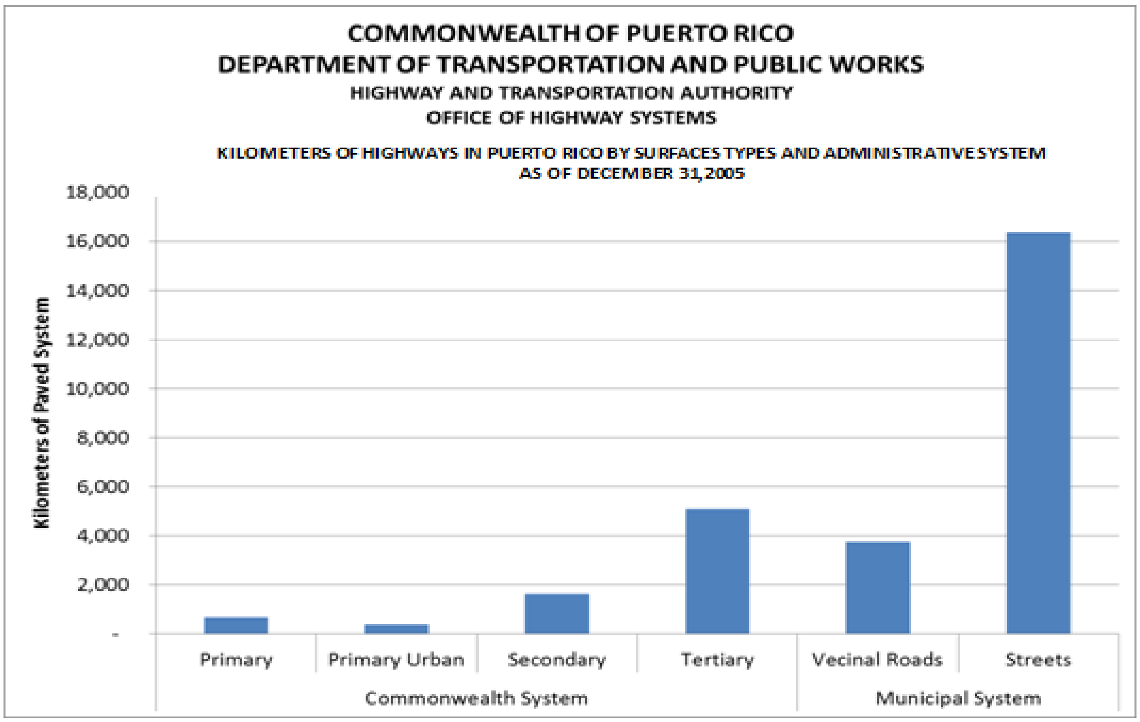
The report is divided into six sections. It begins with a brief introduction of Puerto Rico's Transportation Infrastructure and the advancements made in concrete. The following three sections describe in detail the benefits of concrete and its comparison to asphalt in 1) road safety, 2) environmental impact, and 3) durability and maintenance costs. Afterwards, both a Life Cycle Cost Analysis of concrete and asphalt pavements, is presented, followed by an estimate of the economic impact of investing in each type of material.

[1] World Economic Forum (2014). *The Global Competitiveness Report 2014-2015 – Country/Economy Profiles (Puerto Rico).* Obtained from http://www3.weforum.org/docs/GCR2014-15/PuertoRico.pdf.

Puerto Rico's Transportation Infrastructure

Highways/roads in Puerto Rico are mostly government owned. As of December 31, 2005, there were approximately 28,000 km of paved roads managed by either the Commonwealth or its municipalities (see Figure 1). In an effort to improve road maintenance and provide a better service to riders, the Commonwealth has used Public Private Partnerships (PPP), or long-term cooperative agreements between private and public sectors with the aim of reducing costs and improving services in any way possible. Usage of Public Private Partnerships has been greatly promoted during the last decade.

Figure 1 - Kilometers of Paved System in Puerto Rico



Currently, two highways and a bridge are being operated by PPPs. The PR-22 and PR-5 are administered by Metropistas, while the Teodoro Moscoso Bridge was developed as a green field project through a PPP.

The Commonwealth and its municipalities face several fiscal challenges in the coming years which will make investing in a dilapidated infrastructure very difficult. This will also foster the growth of PPPs as a vehicle for road management and maintenance. At the same time, this highlights that **the public sector will need to make smarter investments in road infrastructure so that the Island's transportation grid can be a key asset in economic growth**.

Technological Advancements in Concrete

This section details significant technologies that will continue to improve the state of concrete pavements in the future years. These advances make it possible for concrete pavements to achieve a higher level of durability, quality, and comfort to both the owner and users. In addition, they have had a significant impact upon the price of concrete and asphalt, which will be discussed in Section 0.

Mechanistic Empirical Design

The Mechanistic Empirical Design guidelines which consider stress/strain/deflection and analyze how damage to pavement is accumulated as well as the probability of damage occurrence, now allows for real world validation and calibration of data. This makes it possible for owners to accurately predict the performance of a specific pavement section, either in concrete or asphalt, through time and allocate the necessary resources to maintain a minimum required level of roughness (as measured by the IRI) in the pavement.

Recycling and Re-Usage of Concrete Pavements

Significant technological advances are currently underway in the recycling and re-usage of concrete pavements. For example, a prototype machine called Paradigm, which is an in-place recycling system for concrete pavements, is currently being developed in the United States. This machine breaks and crushes the concrete into the desired aggregate sizes and collects the reinforcing steel (Smith & Maillard, 2007). In addition, several improvements in concrete mix design and placement are leading to cheaper and more efficient concrete pavement construction. Most notable are:

- optimized grading mixtures;
- better understanding of the interrelation of the aggregates and cement; and
- improvements in construction methods; and
- advancements in equipment.

Smoothness of Concrete Pavement

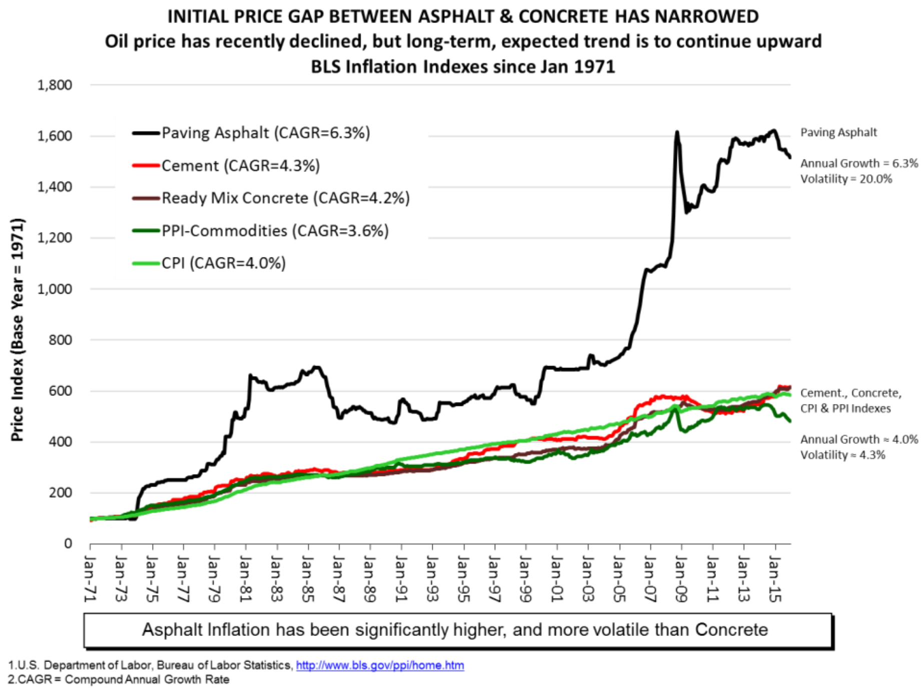
Other advances have helped to produce smoother concrete pavements than previously accomplished. This initial smoothness decreases the dynamic loading on the pavement structure and helps the pavement stay smoother for a longer period. The Nova Scotia Department of Transportation and Public Works (NSTPW) completed a five-year study on an adjoining section of asphalt and concrete pavement built in 1994 on Highway 104 TransCanada Highway [(NSTPW, October 1999)]. Results of the study, which concluded in 1999, showed both pavements performed well over the evaluation period. However, the concrete pavement section outperformed the adjoining asphalt pavement in both riding comfort and road smoothness.

These impacts will be discussed in the following section.

Trends in Prices of Concrete and Asphalt

The steep rise in the price of asphalt can be observed in Figure 2. Although the price of concrete has increased, it pales in comparison to the rise in the price of asphalt from 2005 to 2015.

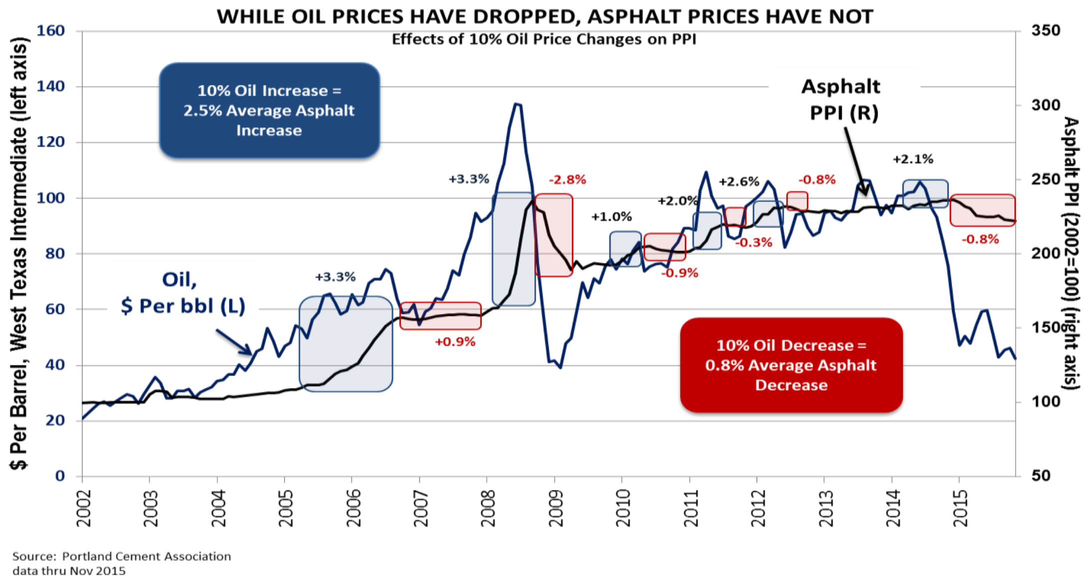
Figure 2 - Various Compound Annual Growth Rate



The inflation observed in the price of asphalt has outpaced that of the overall US economy (as measured by the CPI) and that of concrete and cement[2]. Asphalt, being a fossil-based material, is limited and subject to the fluctuations in price associated with oil. Yet, as can be seen in Figure 3, the cost of asphalt has decreased by only 0.8% while the price of oil fell 10% during the late 2014 to 2015 period. As such, consumers have not experienced any real savings in the cost of paving roads, even as its most important component has become less expensive.

[2] Figure 3 presents the US Bureau of Labor Statistics (BLS) price indexes, including the Consumer's Price Index (CPI).

Figure 3- Oil & Asphalt Prices



On the other hand, the cost of asphalt has indeed increased in cases when the price of oil did increase. Asphalt prices appear to be “downward sticky”, meaning that asphalt price increases are directly associated with oil prices increments, but in oil price drops asphalt does not follow this behavior (hence its description as “sticky”). In certain years, a 10% increase in the price of oil led to an increase of 2.5% in the price of asphalt, while a 10% oil price drop resulted in only a 0.8% drop in asphalt prices-.

Asphalt Prices and Future Demand for Oil

The long-term price trend of asphalt is one of increase, in response to the global demand for oil and its derivatives. More than 80% of the world’s primary energy supply currently comes from fossil fuels. Going forward, International Energy Administration’s (IEA) projections show that growth in energy demand will continue to be met overwhelmingly by fossil fuels (International Energy Agency, 2013). As future demand for oil is expected to increase**, this will undoubtedly affect the price of oil derivatives such as asphalt**.

In summary, the latest design, materials, and construction advances in concrete, combined with the volatility and long-term expected increase of asphalt prices, have narrowed the initial investment gap between asphalt and concrete. This makes investing in concrete rather than asphalt pavements a more feasible, accessible, and cost-effective alternative for pavement owners.

Safety Benefits of Concrete Pavements

This section compares the safety qualities of concrete vis-a-vis asphalt pavements. It aims to answer the following questions in the case of Puerto Rico: how does the pavement handle frequent rain and flooding? Does the pavement affect visibility? And what are its effects, if any, on roadway accidents?

Hydroplaning Effects and Rutting

During rainy days, which occur frequently in a tropical climate, vehicles are exposed to *hydroplaning*. This effect occurs when the tire is separated from the pavement surface by a layer of water, causing loss of steering and braking control. Several factors may contribute to hydroplaning potential such as tire wear, driver speed/experience and pavement surface characteristics. While all types of pavement (gravel, asphalt, or concrete) have the potential for hydroplaning, some are less susceptible.

In the case of asphalt pavements, their flexibility in time creates vertical settlements in the wheel path, a phenomenon known as rutting. This can create physical depressions on the pavement that accumulate water, increasing the hydroplaning potential.

On the other hand, Portland Cement Concrete pavement is a moldable material when it is first placed and can be textured to provide good friction and performance in wet climates. Contrary to asphalt and because of its rigidity, concrete pavements with these modifications are less susceptible to the rutting effect. Therefore, they also help reduce the hydroplaning potential in the roads. This a safety feature of concrete pavements, as they help reduce hydroplaning and by consequence the potential for accidents. It's important to remember that, according to the FHA, (Federal Highway Administration, 2017) among weather related accidents in the US, 73% occur on wet pavement and 46% during rainfall.

Roadway Accidents

Other factors associated with roadway accidents are visibility and stopping distance that into saving lives. Darkness on a roadway decreases driver visibility, thereby increasing the threat of possible hazards on the roadway. In fact, an industry report by the Portland Cement Association finds that night time fatality rates are approximately three times greater than during daylight hours (Gajda & VanGeem, 2001). The report also notes that concrete pavement reflects light in a diffuse manner, while asphalt reflects light in a slightly spectral manner.[3] Light hitting concrete pavement is reflected at all angles, therefore, illuminating a greater area of the roadway compared to asphalt pavements.

Another indirect benefit of concrete against roadway accidents is fewer work zones. Work zones increase the risk of accidents in the highway and road system. As concrete pavement requires less maintenance, it also means less work zones, which could result in fewer accidents.

Concrete pavements are also proven to have a shorter stopping distance than asphalt pavements.[4]

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[3] For a technical analysis of light emissions by type of pavement, see Appendix B.
[4] Count on Concrete for solutions that are durable, sustainable, and economical. ACPA Illinois Chapter Inc.

Puerto Rico recorded 304 fatal accidents in 2014 (National Highway Traffic Safety Administration, 2014), reducing this by any meaningful amount would by itself outweigh the initial costs of concrete payment.

Environmental Impact of Concrete Pavements

The construction, usage, maintenance, repair, and end-use processes of roads exert a significant toll on the surrounding ecosystems. For this reason, it makes sense to use building materials and designs that minimize the impact upon the environment. This section compares some of the direct and indirect environmental benefits of paving roads with Portland cement concrete as opposed to asphalt.

Impact in Water Quality

Health risks can arise when water supplies are degraded in quantity or quality. Therefore, it is important to understand the potential impact of a pavement on a community's water supply. This section presents potential impacts of asphalt and Portland Cement Concrete pavements.

Asphalt

One of the main characteristics of asphalt is that it is a waterproof substance, which prevents water from passing through it. The oily top layer of an asphalt road prevents rainwater from penetrating into it and being absorbed by the ground. All this water, having nowhere to be absorbed, accumulates and is redirected to water sewages where it mixes with other materials that can be hazardous to human health. These ultimately end up deposited in a water source.

Since asphalt is produced by refining petroleum, it is mostly composed of hydrocarbon chains. Most of the asphalt paved roads are produced by heating the mixture to temperatures between 150 and 190°C. This heat breaks down the chains, leaving the chemical substances found in petroleum on the top layer of the road. Similarly, road usage erodes the top layer of the pavement and releases the chemical substances in the asphalt. When rainwater runs off the surface of asphalt-paved roads, it washes down the degraded material found on the top layer, thus contaminating rainwater.

Recently, new technologies have been developed in the road paving industry to address the issues related to the waterproof properties of asphalt pavements, such as porous asphalt, that allows water to pass through and reduces the potential for flooding. While porous asphalt has been used successfully in many cities around the world (e.g. Portland, Oregon), usage of this technology is still very limited, as the material is too weak to be used in high traffic areas, In addition, porous asphalt needs continuous maintenance and cleaning because sediments clog the surface easily; also, oil and other pollutants are easily drained into the water collection system (Matchar, 2015).

Portland Cement Concrete

Portland cement concrete is a mixture of Portland cement, cementitious materials, aggregates (coarse and fine), water and other ingredients, which combine to form an artificial stone-like material. Once bound together, the raw materials inside the mixture fix the chemicals formed in the reaction, preventing their escape. This helps prevent degradation of water supplies in the vicinity.

Unlike porous asphalt, the configuration of the sediment layer of pervious concrete roads serves as filter for trapping sediments and pollutants before the water is released to the collection system and can collect up to 25.44 gal of water per minute per square feet. Pervious concrete can be used for various traffic conditions and is considered and recommended by the U.S. EPA as a Best Management Practice for storm water management. In the case of Puerto Rico, where roads are prone to flooding, using pervious concrete pavements can greatly reduce traffic jams associated with rain and other negative effects, thus implying less potential for accidents.

Impact in Air Quality

This section compares the impacts of concrete and asphalt production and composition upon air quality and temperature. Asphalt and Concrete pavements have very different production methods; thus, their production impacts upon air quality, as well as the duration of said impacts, vary significantly. Air temperature can also be affected by the composition and color of the pavement, as these determine the heat-absorbing and retaining qualities of the pavement.

Impact of the Pavement Production Method

Volatile organic compounds (VOCs) are released during the production of most asphalt types. These VOCs include carcinogens such as benzene and toluene, which have poisonous effects that remain in the atmosphere long after they are released from the original compounds. These compounds can also endanger human health by lowering immunity levels, causing nervous system disorders, and interfering with child development.

In comparison, the raw materials used in the concrete mix do not release dangerous chemicals or compounds to the atmosphere.[5]. This means less pollution and higher air quality on the vicinity of concrete-paved roads.

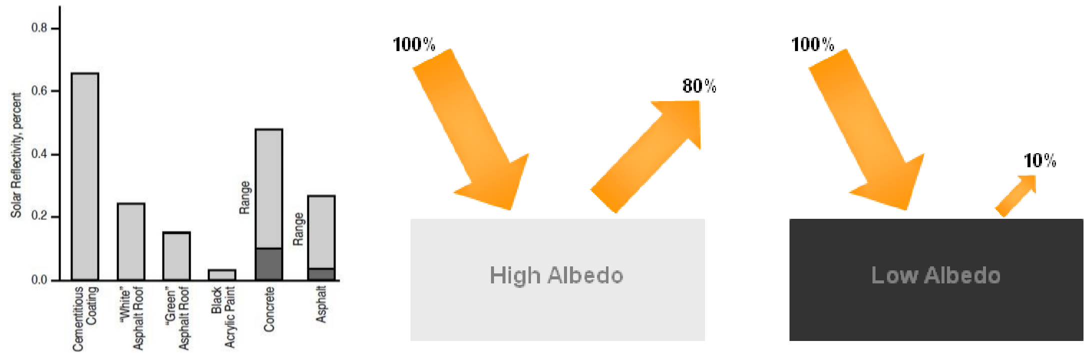
Impact of the Color & Composition of the Pavement

The color and composition of a material will affect its temperature once exposed to solar radiation. Materials painted in darker colors become hotter in shorter periods of time than lighter colors because of the way different colors absorb solar radiation. This characteristic is called the material´s "*albedo*" and is measured on a numeric scale from 0 to 1. Lower numbers on the scale indicate a higher absorbency rate, while higher numbers indicate more energy is reflected into the atmosphere.

As shown in Figure 4, **concrete has a higher albedo than asphalt, thus absorbing less solar radiation.** Compared to concrete, asphalt absorbs more heat and retains it for a longer period than concrete, which contributes to increasing temperatures in the surrounding area.

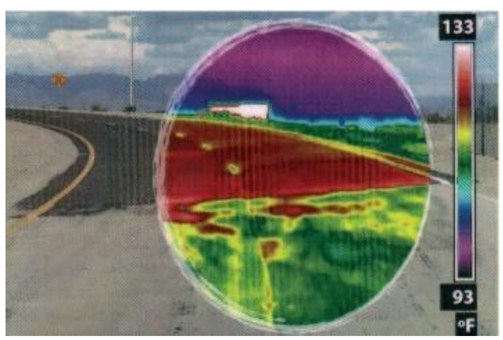
[5] See the toxicological section of the MSDS sheet of concrete products.

Figure 4 - Reflectivity of Select Materials



In addition to influencing albedo levels, the composition of a material influences its ability to release or transfer the stored heat to the atmosphere. This characteristic is known as *emissivity* and primarily affects the surface temperature. Various experiments have been conducted to understand the way in which different materials absorb and emit heat. For example, an experiment conducted in California on November 1993 found that with an ambient air temperature of 55°F, a Portland cement coating reached a temperature of 89°F, whereas a white-colored asphalt shingle registered 118°F in temperature (Berdahl & Bretz, 1994). Since both materials have a similar color, these results indicate that the emissivity rate of asphalt is lower, meaning asphalt stores heat for a longer time (See Figure 5).

Figure 5 - Thermal image of a road pavement at Mesa, Arizona[6]



With the increase of urban area temperatures, the probability of air pollution and smog also increases. Studies have shown for cities as Los Angeles, California, that the probability of smog increases in 3% for every degree Fahrenheit of temperature rise (Gajda & VanGeem, 2001). The EPA (United States Environmental Protection Agency) has recognized that the increase in air temperature, NOx (oxides of nitrogen) production and VOCs present in the atmosphere, all contribute to smog formation. Therefore, concrete pavements reduce the contribution of urban infrastructure upon smog formation.

[6] The temperature difference between the asphalt pavement at rear and the concrete pavement in the foreground is striking (Rens, 2009).

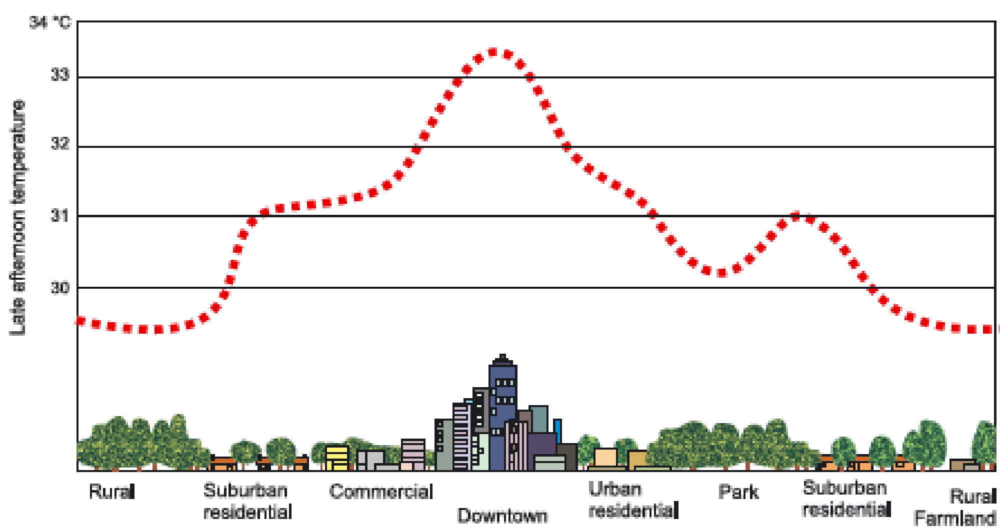
Potential Impact on Global Warming

As presented in the previous sections, the materials used in pavement production can impact air quality and the temperature of the surrounding area. Another area of concern with these materials is their long-term negative effect on global warming. A study published by the European Paving Concrete Association (Rens, 2009), examined the albedo effect and the relationship between the concentration of atmospheric CO_2 and net radiation, which is responsible for global warming. The study reported that a one-percent increase in the albedo of a surface corresponds to a reduction in radiation of 1.27 W/m². This reduction in radiation has the effect of slowing global warming (ibid). Compared to bituminous pavement, concrete pavement has an albedo of 10% to 15% and is thus equivalent to a reduction in CO_2 emissions of 25 to 38 kg per m² of area, according to the research estimates. Even the lower bound of 25 kg CO_2 per m² could result in a significant environmental benefit (ibid).

The Urban Heat Island Effect

Albedo and emissivity have a major impact upon the so-called *urban heat island effect*. The term is defined by the EPA as the tendency of urban areas to absorb and retain more heat than their rural counterparts. In a study published by Gajda and VanGeem in 2001, it was shown that *"the average temperature of urban areas is between 2° and 8°F warmer than surrounding rural areas"*, and that *"replacing grass and natural vegetation with concrete asphalt, and other building materials is the most significant cause of the urban heat island effect*" (Gajda & VanGeem, 2001, p. 3). An example of the urban heat island effect is presented in Figure 6.

Figure 6 - Illustration of the urban heat island effect[7]



Due to the high albedo and low emissivity of asphalt paved roads they increase the surrounding temperature to a higher degree than concrete roads.

[7] Graph acquired from (Rens, 2009)

Impact on Usage of Natural Resources

The oil used in asphalt pavements is a non-renewable resource. While recycling methods exist, resource depletion remains a concern for developments with asphalt over the long run and is likely to have significant impacts upon prices as well (see Section 0). This is not the case with limestone, the major raw material used for cement production. Available limestone reserves are estimated to account for approximately 10% of the total volume of sedimentary rocks readily available in nature; because of their large supply, they are less susceptible to price increases in comparison to the oil supply for asphalt.

Concrete pavement is also an inert material that can be **100 percent recycled**. Most concrete pavements that are demolished are sent to a crushing and screening installation. The concrete rubble is subsequently recycled and used as granular fill, as a base course for new pavement or as an aggregate for other types of concrete. In addition, the steel in the Portland Cement Concrete Pavements such as dowels and tie bars can be recycled (Cement Association of Canada Ottawa, 1993). Reusing the concrete pavement minimizes the amount of non-renewable resources required for a new pavement structure and eliminates potential material going to landfills. In addition, the short hauling distance for the aggregate reduces the cost of providing aggregates to the construction.

Concrete Overlays and Recycling of Current Infrastructure

Concrete pavement can be used for concrete overlays or “whitetopping”. This type of paving process uses the existing asphalt pavement structure as a strong base for the new concrete overlay. The known performance of the asphalt pavement minimizes the potential for pumping, faulting and loss of support in the new concrete pavement. No repairs are required in the existing Asphalt pavement, unless there are large areas of soft spots or the pavement ruts are over 50 mm. In other words, **the existing asphalt pavement can be reused as a base for the new Portland Cement Concrete Pavement structure**.

Currently existing concrete pavements can be reused through bonded overlays. These can be used to increase the pavement thickness when, for example, traffic patterns change, and a roadway is receiving substantially more traffic than originally designed for. If the underlying pavement is in good condition, a new layer of concrete can be placed over the existing PCCP by bonding the new layer to the old surface and matching the joint locations. This effectively increases the traffic capacity of the pavement structure and extends the pavement’s expected life.

Impact on Noise Pollution

Roadside noise levels are a public concern, especially when the pavement is in an urban environment. For this reason, many pavement producers are investing time and money to develop quieter pavement structures. In conjunction with the American Concrete Pavement Association (ACPA), the Cement Association of Canada is underway in conducting research to develop quieter concrete pavements.

When looking at the acoustic performance of different pavement types one needs to consider the pavement characteristics throughout the pavement’s service life and not just the as-constructed pavement condition. Most research to date shows longitudinally tined, astro-turf drag textures, and diamond grinding textures provide the quietest new construction techniques for concrete pavement, while diamond grinding provides the quietest rehabilitation strategy. Puerto Rico has much good experience diamond grinding our concrete pavements.

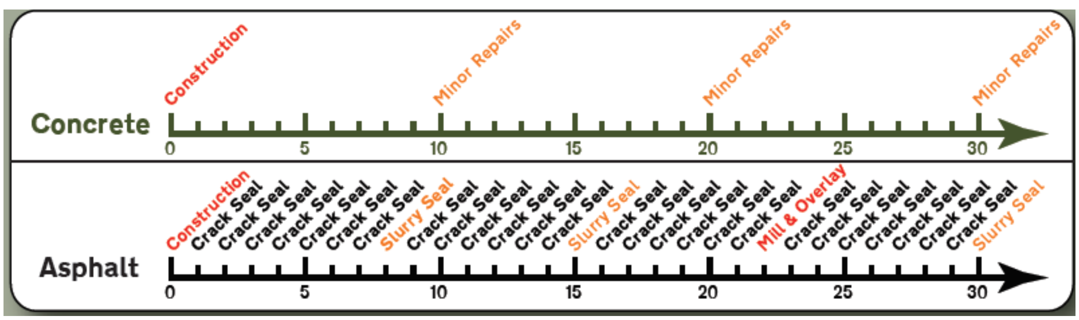
Life-Cycle Benefits of Concrete Pavements

This section details the life cycle benefits of concrete pavements in relation to the comparable costs of asphalt. The main advantages of concrete here presented are durability, longevity and cost-effectiveness. There is also an additional economic benefit of concrete pavements, which is discussed in Section **Error! Reference source not found.**.

Durability

One of the main advantages of concrete pavements is a longer maintenance cycle than asphalt paved roads. Service life of concrete roads is estimated to be around 30 years, while asphalt roads have an estimated service life of 17 years (Bienvenu & Jiao, 2013). In addition, asphalt roads require minor maintenance every 2 to 4 and resurfacing every 6 to 12 years, whereas concrete roads only require rehabilitation every 15 to 25 years and do not need resurfacing during their service life (American Concrete Pavement Association, 2009). Another indirect benefit of concrete pavements is the lower requirement of aggregates when performing road maintenance. With each maintenance, the aggregates used for the base layer must be changed: as the maintenance is higher in the asphalt roads, the amount of aggregates it will demand throughout its life cycle will be greater than the amount demanded by the concrete road. Therefore, **concrete roads are more sustainable than asphalt paved roads in terms of aggregate consumption.**

Figure 7 - Maintenance works for concrete and paved roads[8]



For the end user, costs of time lost during construction, rehabilitation, or maintenance represent $6,000 per year per passenger car and about $11,000 per truck[9]. A concrete pavement can reduce these costs because it has better long-term performance, which means fewer interruptions and thus leads to lower user costs.

Longevity

The longevity of concrete pavements is well documented. Numerous concrete highways in North America have lasted 50 years or more, supporting traffic volumes much greater than originally anticipated. Such long-lasting concrete pavements are not confined to one region of North America, nor

[8] Graph acquired from (American Concrete Pavement Association, 2009)
[9] Estimated from common industry uses and practices

to a specific type of environment or climate. A few notable U.S. examples are provided here (American Concrete Pavement Association, 2007):

- Interstate 10 in the San Bernardino Valley in California – originally constructed in 1946 as part of Route 66. Portions of this concrete highway are still carrying traffic today at an impressive volume of more than 200,000 vehicles per day. After being renewed three times by surface grinding during its more than 60-year life, this highway is a clear example of the longevity of concrete pavement (American Concrete Pavement Association, 2015).
- Belknap Place, one of the first concrete streets in San Antonio, Texas, was paved with concrete in 1914. It is still performing well today, 92 years after it was constructed (Taubert, 2006).

Route 23 through Kanabec County, Minnesota, was originally paved with concrete in 1948. According to a Minnesota Department of Transportation (DOT) pavement condition survey conducted in 2000, the 52-year old concrete pavement still has a present serviceability rating (PSR) of 4.1, or very good.

Life Cycle Cost Analysis – Small Urban Areas

When investing in the material for paving new or existing roadways, pavement owners must evaluate not only the initial cost of a pavement alternative, but also its maintenance and operating costs throughout the lifetime of the road. This section contains a detailed Life Cycle Cost Analysis (LCCA) for the different alternatives of pavement sections available for road reconstruction in Puerto Rico.

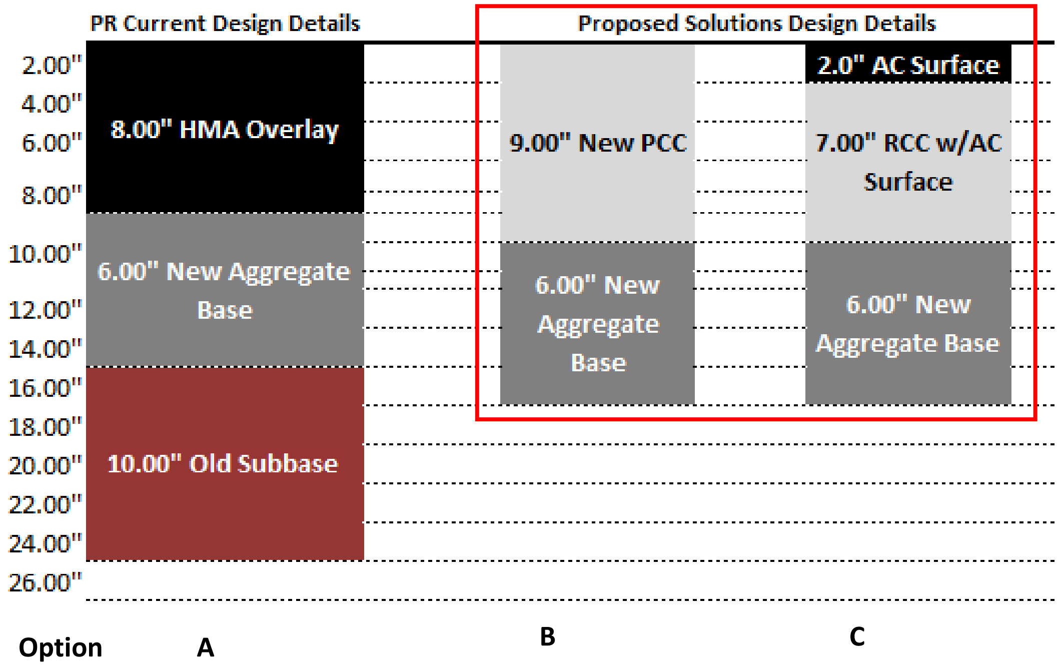
Key Assumptions

This LCCA compares the structurally equivalent sections of a Jointed Portland Cement Concrete Pavement, Asphalt Concrete Pavement, and a composite structure of Asphalt Concrete Surface Pavement over a Roller Compacted or Lean Concrete Base (RCC) over a 30-year period. The analysis assumes an existing road one mile long and seven meters wide to be reconstructed, with traffic equivalent to the National Highway System Small Urban Classification.[10] Figure 8 shows the three types of proposed pavement options[11]:

A. Puerto Rico Current Hot Mix Asphalt Reconstruction 8 inches over a 6-inch selected material granular base pavement [12];
B. Portland Cement Concrete Pavement Optimized Overlay Section of 9 inches (PCC); and
C. Asphalt Concrete (AC) surface of 2 inches, and a Roller Compacted Concrete (RCC) or Lean Concrete 7 inches base.

[10] Traffic equal or less to 12 million ESAL's
[11] Further details are presented in the Appendix A- Life Cycle Cost Analysis.
[12] This section was selected given that the asphalt concrete section of 8" of asphalt over a granular base of 6" is commonly used to reconstruct roads in PR.

Figure 8 – Equivalent Proposed Pavement NHS Small Urban: ESALs< 12 millions



- Surface Treat = DG, Surface Pro, Slurry Seal, thin AC, etc.
- ** AC Surface will need replaced.
- All joints in all concrete are single saw cuts and filled with hot pour sealant.

Comparison of Initial Costs

The following tables summarize the initial unit and total current costs for the three proposed options (A, B and C) in Figure 8.

Table 1- Initial Construction Costs for Asphalt Option A

Pavement Items:	Unit Cost Current	Units	Quantity	Subtotal
2-inch Asphalt Surface (S9.5C)-Mainline	$110.00	Ton	1,591	$175,051
6-inch Asphalt Base (B25.0C)-Mainline	$110.00	Ton	4,774	$525,152
6-inch Aggregate Base	$10.00	Ton	3,802	$38,016
	TOTAL COST PAVEMENT ITEMS =			$738,218

Table 2- Initial Construction Costs for Portland Cement Concrete Pavement Option B

Pavement Items:	Unit Cost	Units	Quantity	Subtotal
9" PCC Furnish	$122.65	CY	3,520	$431,728
9" PCC Placement	$17.00	SY	14,080	$239,360
9" Dowel Bar Cost	$8.00	Ft	8,448	$67,584
9" Joint Saw & Seal	$1.75	Ft	9,504	$16,632
9" Tie Bar Cost	$2.00	Ea	6,336	$12,672
9" Cure Cost	$0.15	SY	14,080	$2,112
6 -inch Agg. Subbase	$10.00	Ton	3,802	$38,016
Estimated Initial Construction Cost Option B				**$808,104**

Table 3- Initial Construction Costs for Asphalt over RCC or Lean Concrete Base Option C

Pavement Items:	Unit Cost	Units	Quantity	Subtotal
7" RCC Base Furnish	$112.00	CY	2,738	$306,631
7" RCC Base Placement	$18.00	SY	14,080	$253,440
7" Joint Saw & Seal	$1.75	Ft	9,504	$16,632
7" Cure Cost	$0.15	SY	14,080	$2,112
2" Asphalt Layer	$110.00	Ton	1,591	$175,051
6 -inch Aggregate Subbase	$10.00	Ton	3,802	$38,016
Rework Existing Base	$1.25	SY	14,080	$17,600
Estimated Initial Construction Cost Option C				**$809,482**

As can be seen, the initial construction costs of building Asphalt Option A have a clear advantage over the other options, as Portland Cement Concrete Option B is 9% more expensive while Asphalt over RCC or Lean Concrete Option C is 11% more expensive. However, as mentioned earlier it is important to look at lifetime costs, not only initial costs.

Table 4- Summary of Initial and Lifetime Costs for All Options in Small Urban Areas (No Salvage Value)

Description of Pavement	Initial Cost	% high	30-year period Discounted 1.6% No Salvage Value: Net Present Accumulated Cost	Savings (No Salvage): Sub Total	Savings (No Salvage): Percent
Option A: 8" AC /6-inch Aggregate Base	$738,218	0%	$1,497,135	$591,605	65%
Option B: 9-in PCC / 6 -inch Agg Subbase	$808,104	9%	$905,530	$0	0%
Option C: 2-in AC over 7 RCC over Agg base	$817,695	11%	$1,285,185	$379,655	42%

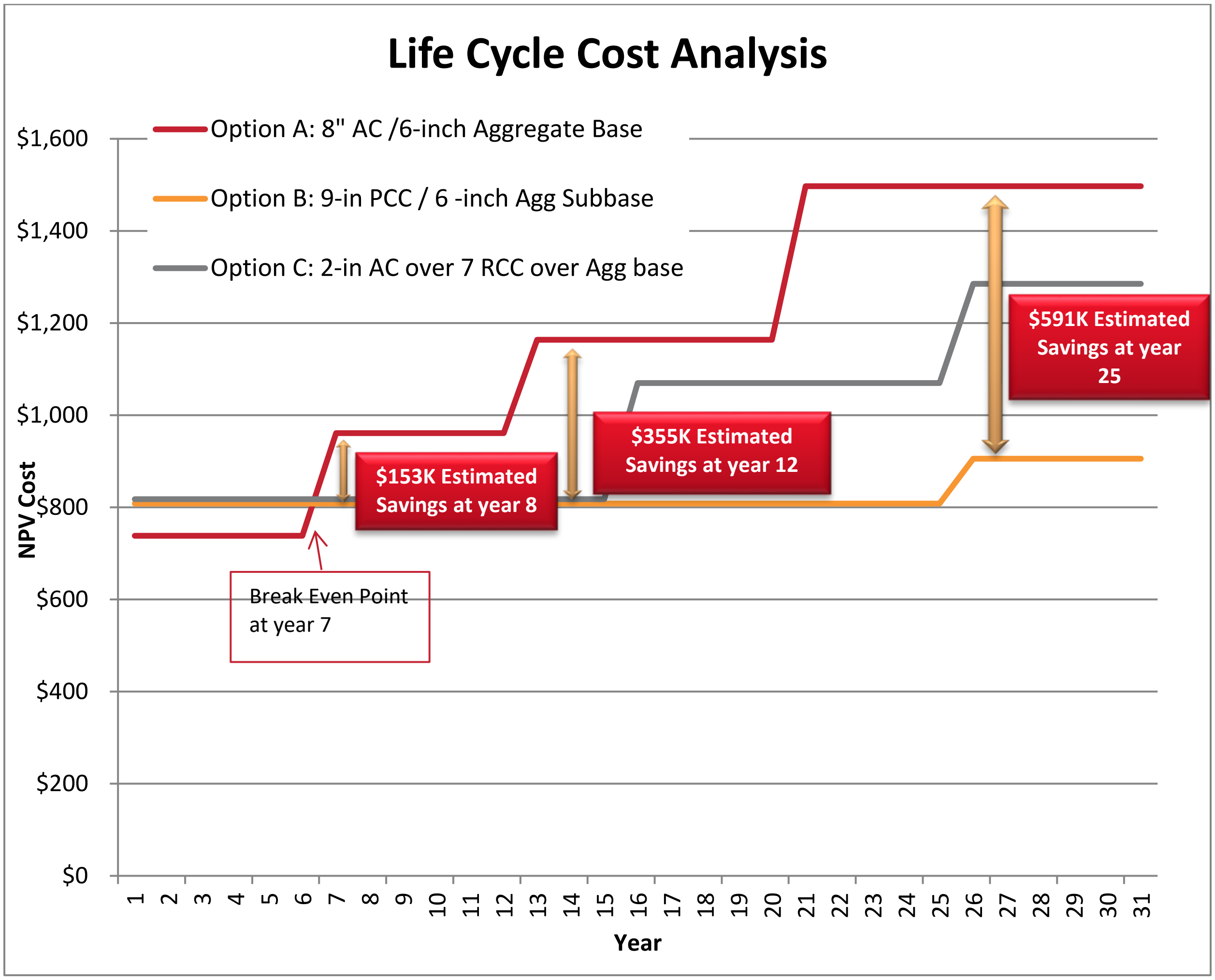
Comparison of Lifetime Costs

Implementing Portland Cement Concrete Option B, the 9-inch Portland Cement Concrete Pavement, represents an estimated savings at the end of the 30-year evaluation period of $584,728, or 68% in savings to the owner at net present value (NPV). These savings include the return of the $69,886 of higher initial investment for the concrete pavement. Therefore, **by initially investing an additional $70K, pavement owners get almost five times the return on that investment**. These savings are even more important when considering the Commonwealth's fiscal situation, and its need to reduce costs without affecting essential services. It would also make other potential PPP's more viable by reducing the lifetime costs for road maintenance of the new private operators. As presented in Figure 9 the break-even point in savings was estimated accumulating at around 7 years after the initial investment.

Table 5 – Summary of Initial and Lifetime Costs for All Options in Small Urban Areas

Description of Pavement	Initial Cost	% high	Salvage Value of Last Rehabilitation	30-year period Discounted 1.6% Salvage Value Applied: Net Present Accumulated Cost	Savings (With Salvage): Sub Total	Savings (With Salvage): Percent
Option A: 8" AC /6-inch Aggregate Base	$738,218	0%	($55,591)	$1,441,545	$584,728	68%
Option B: 9-in PCC / 6 -inch Agg Subbase	$808,104	9%	($48,713)	$856,817	$0	0%
Option C: 2-in AC over 7 RCC over Agg base	$817,695	11%	($107,616)	$1,177,569	$320,752	37%

Figure 9 – Life Cycle Cost Analysis of Pavements in Small Urban Areas



Short Term Impact in Economic Growth

This section presents the difference in economic impact of investing in concrete roads as compared to asphalt roads. The impact is measured by three factors: employment generated, total salary of said employment, and the indirect and induced impacts upon the economy (measured by the Gross National Product, or GNP) of investment in the construction sector.

Employment

The following table presents two scenarios for employment generated by investing in concrete roads and asphalt roads. For both scenarios, it was assumed that $60.9 million, or 25% of the $243 million invested by the PRHTA on new road construction and maintenance in fiscal 2015, was invested in either concrete or asphalt roads. In addition, it was assumed that municipalities would also spend 25% of their construction investment on concrete or asphalt roads. During fiscal 2015, municipalities spent $204.1 million on construction; if 25% of the aforementioned, were spent on the construction of roads, this would amount to $51.0 million. Therefore, the economic impact measured in this section amounts to a $112 million investment on road construction.

In the concrete pavement scenario, this would help maintain 1,139 direct jobs, as well as 843 indirect and 531 induced jobs, totaling 2,513 jobs. This estimate is based upon the Inter-Industrial Multiplier for construction. If the same amount were invested in asphalt, it would only generate 831 direct jobs, 615 indirect and 387 induced jobs in Puerto Rico, totaling 1,834 jobs. Therefore, investing in concrete pavement supports an additional 679 jobs when compared to the same investment in asphalt.

Table 6 – Estimated Employment Generated by Asphalt & Concrete Investment

Employment		
Employment	Concrete	Asphalt*
Direct	1,139	831
Indirect	843	615
Induced	531	387
Total	2,513	1,834

Source: PR Planning Board, InterIndustrial Multipliers. Estimates by Estudios Técnicos, Inc.

*Assumes that 27% of investment goes toward the import of Bitumen

The difference in the number of jobs generated in each scenario is the result of Bitumen imports for asphalt pavements. Close to 27% of the amount invested in asphalt pavement is used to import bitumen and has no impact on the local economy.

Salary

In the concrete pavement scenario, the generated employment would translate to approximately $52.0 million in salaries, with $25.0 million from direct employment alone. To estimate these total salaries, it was assumed that all direct employment would have an average salary equal to the Puerto Rico average for the Highway, street, and bridge construction sector ($21,935)[13]. Indirect and induced jobs were assumed to have salaries equal to the median household income for Puerto Rico in 2014 ($19,686)[14].

[13] Source: US Bureau of Labor Statistics (BLS), Quarterly Census of Employment and Wages (QCEW).

[14] Source: American Community Survey (ACS) 5- year estimates 2010-2014.

Table 7– Estimated Salary

Employment	Concrete	Asphalt*
Direct	$24,977,648	$18,233,683
Indirect	$16,597,604	$12,116,251
Induced	$10,447,894	$7,626,963
Total	$52,023,147	$37,976,897

Source: US Bureau of Labor Statistics (BLS), Quarterly Census of Employment and Wages (QCEW). American Community Survey (ACS) 5- year estimates 2010-2014. Estimates by Estudios Técnicos, Inc.

*Assumes that 27% of investment goes toward the import of Bitumen

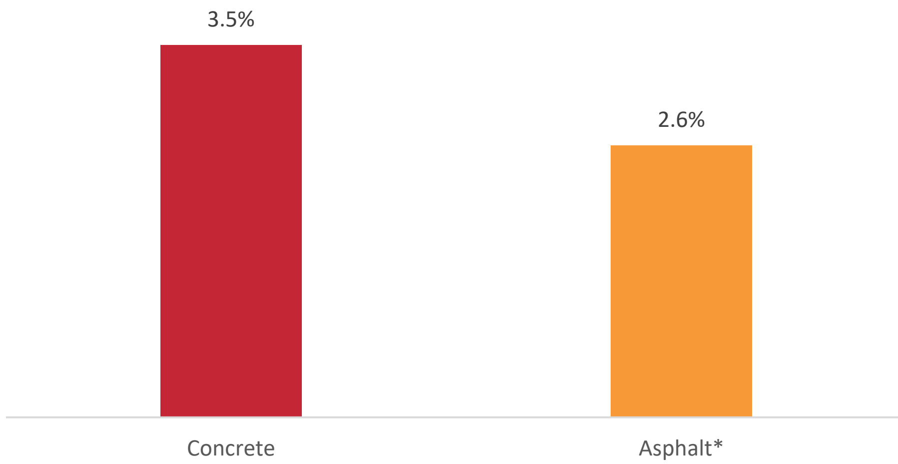
The same methodology and assumptions were used to estimate the salaries for the jobs generated by asphalt investment. Under said scenario, total salaries would amount to $38.0 million, with $18.2 million related to direct employment. The salaries generated by the additional jobs created by investing in concrete roads could also help increase personal consumption.

Investment in construction

In fiscal 2015, nearly $3.2 billion were spent in investment in construction[15]. Investing $112 million in concrete would represent 3.5% of current construction investment. If the same amount were invested in asphalt, the impact would be 0.9 percentage points lower, or 2.6%. As previously mentioned, the impact of asphalt is less than that of concrete because a main component of asphalt, Bitumen, must be imported. Thus, the impact on the local economy of investing in asphalt is roughly 27% less.

[15] According to the 2015 Statistical Appendix published by the Puerto Rico Planning Board, Table 2 Investment in Construction.

Figure 100 – Estimated Impact on Construction GDP



Source: the 2015 Statistical Appendix published by the Puerto Rico Planning Board. Estimate by Estudios Técnicos, Inc. Assumes that 27% of investment goes toward the import of Bitumen

Investing in durable concrete pavements can help the government improve the Island's infrastructure, while promoting an industry that generates local jobs. This is not the case with asphalt, as one of its main components, Bitumen, is an imported fossil-based material. Every dollar invested in concrete pavements has a higher multiplier effect in the local economy, as cement production does not have a significant import leakage.

An example of these indirect impacts is the fact that cement kiln operations are among the most important energy consumers of the local power authority (PREPA). In Puerto Rico's cement industry, kilns operations consume up to 100 Million KW/year, equivalent to a PREPA revenue of roughly $20 Million. The cement industry also makes large investments in the local economy; in the last five years alone, $40 million dollars have been made in capital investments on the Island.

Another indirect benefit not normally taken in to account is the benefit of having two competing industries supplying paving materials for roads and highways. Competition can help generate lower prices that benefit the Government and the taxpayers. Therefore, the economic impact of investing in concrete pavements goes beyond that of the estimates presented in this section.

Conclusions & Final Recommendations

Because of the poor durability of asphalt roads, the residents of Puerto Rico essentially incur in significant overpayments for maintenance of the road infrastructure. These costs are threefold in the case of poorly maintained roads:

- Residents must incur in additional vehicle operating costs, owing to repairs and replacement of vehicles parts and accessories;
- They must incur in more time and high fuel consumption to travel, as poor maintenance of roads reduces the potential speed;
- Due to the costlier material, residents on average pay higher repair and reconstruction costs of public road; and

The benefits of investing in concrete pavements can provide a resilient solution to the road infrastructure problem the island currently faces. Concrete pavements have been proven to be a:

- Safer options than asphalt pavements, with shorter stopping distances and better lighting conditions;
- Cleaner substitute, as asphalt pavements have a much more negative impact on the environment;
- Cheaper over lifetime of a road, in some cases by 40% or more; and
- Have a higher multiplier effect in the local economy, generating more jobs than asphalt pavements.

Another indirect benefit not normally taken in to account is the benefit of having two competing industries supplying paving materials for roads and highways. Competition can help generate lower prices that benefit the Government and the taxpayers. Therefore, the economic impact of investing in concrete pavements goes beyond that of the estimates presented in this section.

Recommendations

The previous findings indicate that it’s best interest of the local government and concerning authorities to leverage a local healthy concrete paving industry to promote economic growth and efficient use of public funds. Therefore, the following steps are proposed:

- Immediately identify various roads in need of rehabilitation and develop a bid package of design/build rehabilitation concrete overlay project to compete against asphalt.
- Develop a plan to achieve a reasonable balance in concrete rehabilitation and asphalt rehabilitation projects to be constructed five years from now.
- Develop combined professional group APC, AGC, CIAPR, DTOP, Municipalities to review and develop a revised Standard Drawings and specifications for concrete pavement construction and concrete overlays.

- Explore the possibility to incorporate the alternate bid alternate price described by the Federal Highway Administration Technical Advisory “Use of Alternate Bidding for Pavement Type Selection” T 5040.39 from December 20, 2012.

The PR Construction and Design Industry have long proven experience in concrete pavements construction and has the knowledge and equipment to immediately offer these services.

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APPENDIX A

I. Scope Description of the Life Cycle Analysis for a Small Urban ESALs< 12 millions

General Data

The road used for the analysis is shown in the Table 8.

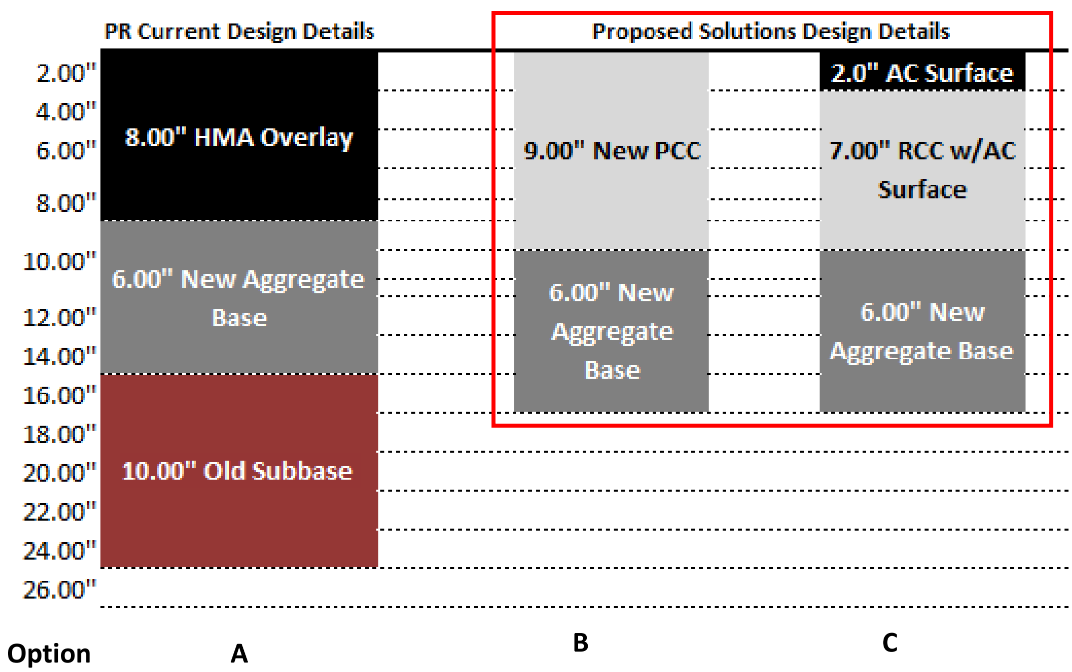
Table 8- Road Data

Road Data		
Road Length (ft)	5,280	= 1 mile
Road Width (ft)	24	

Equivalent Proposed Pavement NHS Small Urban: ESALs< 12 millions

The following analysis consist in provide one equivalent pavement reconstruction design for the current section (Option A) of 8.0-in of Hot Mix Asphalt Overlay (HMA- Specification 959) of PRHTA Standard Specification for Road Construction Manual, for NHS Small Urban roads (ESALs<12 millions) with a base of 6.0-in. of Aggregates (Specification 703-PRHTA).

Figure 8- Equivalent Proposed Pavement NHS Small Urban: ESALs< 12 millions



The option A, Hot Mix Asphalt Overlay, consider 2-inch Asphalt Surface (S9.5C)-Mainline, 6-inch Asphalt Base (B25.0C)-Mainline and a 6-inch aggregate base.

The option B, consist of 9.0-in of a new Portland Cement Concrete Overlay (American Concrete Pavement Association, publication TB021.03P) over existing base course with a base of 6.0-in. of Aggregates (Specification 703-PRHTA). It considers that the longitudinal joints will be spaced 12ft from each other's. The tie bars at the longitudinal joints will be spaced 20 inches center to center. While the transversal joints will be spaced 15ft, and the dowels 12 inches center to center shown in table 9.

Table 9- Joint Details

Longitudinal Joints Portland Cement Concrete Pavement			Transversal Joints Portland Cement Concrete Pavement		
Joints spacing	12.00	ft	Joints spacing	15.00	ft
Tie bar, spacing c/c	20.00	inch	Dowel bar, spacing c/c	12.00	inch

Another solution (Option C) is 7.0-in. of Roller-Compacted Concrete (RCC) from ACPA Guide Specification Version 1.2 or Lean Concrete (Specification 305-PRHTA Standard Specification for Road Construction Manual) with a 2.0-in. surface treatment; it can be Asphaltic Concrete, Diamond Grinding, etc. with a base of 6.0-in. of Aggregates.

II. Initial Costs

II.1. Economic Details for Option A

The initial cost details for the option A, the 8 inches of Hot Mix Asphalt Overlay with 6-inch aggregate base is show in the table 1.

Table 1 –Initial Cost for Option A

Pavement Items:	Unit Cost Current(A)	Units	Quantity(B)	Subtotal (C)
2-inch Asphalt Surface (S9.5C)-Mainline	$110.00	Ton	1,591	$175,051
6-inch Asphalt Base (B25.0C)-Mainline	$110.00	Ton	4,774	$525,152
6-inch Aggregate Base	$10.00	Ton	3,802	$38,016
	TOTAL COST PAVEMENT ITEMS =			**$738,218**

C= A X B

II.2. Economic Details for Option B

The initial cost details for the option B, the 9 inches of Portland Cement Concrete with 6-inch aggregate base is show in the table 2.

Table 2 –Initial Cost for Option B

Pavement Items:	Unit Cost(A)	Units	Quantity(B)	Subtotal (C)
9" PCC Furnish	$122.65	CY	3,520	$431,728
9" PCC Placement	$17.00	SY	14,080	$239,360
9" Dowel Bar Cost	$8.00	Ft	8,448	$67,584
9" Joint Saw & Seal	$1.75	Ft	9,504	$16,632
9" Tie Bar Cost	$2.00	Ea	6,336	$12,672
9" Cure Cost	$0.15	SY	14,080	$2,112
6 -inch Agg. Subbase	$10.00	Ton	3,802	$38,016
Estimated Initial Construction Cost Option B				**$808,104**

C=AXB

II.3. Economic Details for Option C

The initial cost details for the option C, the 7 inches of Roller Compacted Concrete with 2-inch asphalt layer and 6-inch aggregate base is show in the table 3.

Table 3 –Initial Cost for Option B

Pavement Items:	Unit Cost(A)	Units	Quantity(B)	Subtotal (C)
7" RCC Base Furnish	$112.00	CY	2,738	$306,631
7" RCC Base Placement	$18.00	SY	14,080	$253,440
7" Joint Saw & Seal	$1.75	Ft	9,504	$16,632
7" Cure Cost	$0.15	SY	14,080	$2,112
2" Asphalt Layer	$110.00	Ton	1,591	$175,051
6 -inch Aggregate Subbase	$10.00	Ton	3,802	$38,016
Rework Existing Base	$1.25	SY	14,080	$17,600
Estimated Initial Construction Cost Option C				**$809,482**

C=AXB

III. Maintenance Plan and Their Details

III.1. Maintenance Costs for Option A- 8" AC /6-inch Aggregate Base

During the life cycle of this pavement for maintenance is required to replace 2.0-inch of asphalt surface at year 6 and 12. Then in year 20 is needed to realize a 2-inch milling and place 3.25-inch asphalt surface mainline. The maintenance costs are long term, so we must apply a discount rate to determine the real cost. To compute net present value, it is necessary to discount future benefits and costs. This discounting reflects the time value of money. Benefits and costs are worth more if they are experienced sooner. All future benefits and costs, including no monetized benefits and costs, should be discounted. The discount rate to be used was determined using the Guidelines and Discount Rates of Federal Programs for the FHWA which is 1.6%. The salvage value is the estimated value of each maintenance item at the end of its useful life. As this analysis is being carried out for 30 years it is necessary to subtract the salvage value from the remaining years, according with the maintenance life. In this case only 2 years are remaining. The table 10 shows the total expenditures for option A.

Table 10: Total Expenditures Option A (30 years): 8" AC /6-inch Aggregate Base Pavement Structure

Description of Cost	Year (A)	Life (B)	Cost (C) (Todays $)	Real (D) DR = 1.6%
Initial Pavement Costs	0	6	$738,218	$738,218
2"ACOL	6	6	$245,071	$222,807
2"ACOL	12	6	$245,071	$202,566
2" Mill & 3.25" ACOL	20	12	$458,170	$333,543
Salvage Value (E)	30			**($55,591)**
Total Rehabilitation Costs				**$703,326**
Total Expenditures / LCCA		**Total**	**$1,686,530**	**$1,441,545**

D=C/ [(1+discount rate) ^A]

E= [(A+B-salvage value year) / B] *D

The details of each maintenance intervention are described in the following tables. The table 11 shows that in year 6 is needed to place 2-inch of asphalt concrete, and the analysis considers the costs of traffic control, engineering, inspection, and other incidentals. The same intervention is required at year 12, as shown in table 12.

Table 11: Description of Asphalt Concrete Preservation @ 6 yr.

Description of AC Preservation @ 6 yr.	Unit Cost Current	Units	Total Quantity	Year Applied	Current Cost
2-inch Asphalt Surface -Mainline	$110.00	Ton	1,591	6	$175,051
Other Incidental (mob, etc.- 10% of material cost)	$17,505	LS	1	6	$17,505
Traffic Control (20% of material cost)	$35,010	LS	1	6	$35,010
Engineering & Inspection (10% of material cost)	$17,505	LS	1	6	$17,505
		TOTAL COST YEAR 6 ITEMS =			$245,071

C=AXB

Table 12: Description of 2"Asphalt Concrete Overlay @ 12 yr.

Description of 2"ACOL @ 12 yr.	Unit Cost Current (A)	Units	Total Quantity (B)	Year Applied	Current Cost (C)
2-inch Asphalt Surface -Mainline	$110.00	Ton	1,591	12	$175,051
Other Incidental (mob, etc.- 10% of material cost)	$17,505	LS	1	12	$17,505
Traffic Control (20% of material cost)	$35,010	LS	1	12	$35,010
Engineering & Inspection (10% of material cost)	$17,505	LS	1	12	$17,505
		TOTAL COST YEAR 12 ITEMS =			$245,071

C=AXB

In year 20 the intervention is more aggressive because it requires 2-inch of milling and replace with 3.25- inch asphalt concrete. It considers a prime coat, asphalt patching in mainline and shoulders, traffic control, engineering, and incidental cost.

Table 13: Description of 2" Mill & 3.25" ACOL @ 20 yr.

Description of 2" Mill & 3.25" ACOL @ 20 yr.	Unit Cost Current (A)	Units	Total Quantity (B)	Year Applied	Current Cost (C)
2" Mill-Mainline	$1.00	SY	14,080	20	$14,080
3.25-inch Asphalt Surface - Mainline	$110.00	Ton	2,785	20	$306,339
Prime Coat (Mainline & Shoulders)	$1.90	Gals	3,520	20	$6,688
Asphalt Patching (mainline only)	$1.12	SY	141	20	$158
Incidental (mob, etc.- 10% of material cost)	$32,726	LS	1	20	$32,726
Traffic Control (20% of material cost)	$65,453	LS	1	20	$65,453
Engineering & Inspection (10% of material cost)	$32,726	LS	1	20	$ 32,726
	TOTAL COST YEAR 20 ITEMS =				**$458,170**

C=AXB

III.2. Maintenance Costs for Option B- 9-in JPCP / 6 -inch Aggregate Subbase

During the life cycle of this pavement for maintenance is required to make a diamond grinding and reseal joints at year 25. The following table shows the initial pavement cost, rehabilitation costs, and total expenditures. It considers salvage value and discount rate.

Table 14: Total Expenditures Option B (30 years): 9-in JPCP / 6 -inch Aggregate Subbase

Description of Cost	Year(A)	Life (B)	Cost (Todays $) (C)	Real DR = 1.6%(D)
Initial Pavement Costs	0	25	$808,104	$808,104
DG, Reseal Only	25	10	$144,883	$97,426
Salvage Value (E)	**30.00**			**($48,713)**
Rehabilitation Costs				**$48,713**
Total Expenditures / LCCA		**Total**	**$952,987**	**$856,817**

D=C/ [(1+discount rate) ^A]

E= [(A+B-salvage value year) / B]*D

The details of each maintenance intervention are described in table 15; it includes reseal 100% of joints and diamond grind to the surface. The costs consider traffic control and engineering.

Table 15: Diamond Grind and Joint Reseal @ 25 yr.

Diamond Grind and Joint Reseal @ 25 yr.	Unit Cost Current(A)	Units	Total Quantity (B)	Year Applied	Current Cost(C)
Reseal Joints (100% of Joints)	$2.00	LF	9,504	25	$19,008
Diamond Grind (100% of Surface)	$6.00	SY	14,080	25	$84,480
Incidental (mob, etc. - 10% of material cost)	$10,349	LS	1	25	$10,349
Traffic Control (20% of material cost)	$20,698	LS	1	25	$20,698
Engineering & Inspection (10% of material cost)	$10,349	LS	1	25	$10,349
		TOTAL COST YEAR 25 ITEMS =			**$144,883**

C=AXB

III.3. Maintenance Costs for Option C- 2-in AC over 7 RCC over Aggregate Subbase

During the life cycle of this pavement, it requires two interventions at years 15 and 25. The intervention consist in a milling of 2-inch and replace with 2-inch of asphalt concrete. The following table shows the initial pavement cost, rehabilitation costs, and total expenditures. It considers salvage value and discount rate.

Table 16: Total Expenditures Option C (30 years): 2-in JPCP / 7 -inch RCC Subbase / Agg Base

Description of Cost	Year(A)	Life(B)	Cost (Todays $) (C)	Real DR = 1.6% (D)
Initial Pavement Costs	0	15	$817,695	$817,695
2-in Mill / 2-in ACOL	15	10	$320,074	$252,258
2-in Mill / 2-in ACOL	25	10	$320,074	$215,232
Salvage Value (E)	**30.00**			**($107,616)**
Rehabilitation Costs				**$359,874**
Total Expenditures / LCCA		**Total**	**$1,457,842**	**$1,177,569**

D=C/ [(1+discount rate) ^A]
E= [(A+B-salvage value year) / B]*D

The maintenance details of this option are shown in the following tables. It consists of two interventions one at year 15 and other at 25. The intervention includes 2inch milling and replace with 2-inch of asphalt concrete. The costs consider prime coat, traffic control, engineering, and incidentals.

Table 17: Activities for 2-in Mill / 2-in Asphalt Overlay @ 15 year

Activities for 2-in Mill / 2-in Asphalt Overlay @ 15 year	Unit Cost Current (A)	Units	Total Quantity (B)	Year Applied	Current Cost (C)
Full Depth Repair (2 %)	$720.00	CY	55	15	$39,424
2" Mill	$1.00	SY	14,080	15	$14,080
2"Asphalt Concrete Overlay	$110.00	Ton	1,531	15	$168,432
Tack/Prime Coat (Mainline & Shoulders)	$1.90	Gals	3,520	15	$6,688
Other Incidental Costs (strip, mob, etc. - 10% of material cost)	$22,862	LS	1	15	$22,862
Traffic Control (20% of material cost)	$45,725	LS	1	15	$45,725
Engineering & Inspection (10% of material cost)	$22,862	LS	1	15	$22,862
	TOTAL COST YEAR 15 ITEMS =				**$320,074**

C=AXB

Table 18: Activities for 2-in Mill / 2-in Asphalt Overlay @ 25 year

Activities for 2-in Mill / 2-in Asphalt Overlay @ 25 year	Unit Cost Current(A)	Units	Total Quantity (B)	Year Applied	Current Cost (C)
Full Depth Repair (2 %)	$720.00	CY	55	25	$39,424
2" Mill	$1.00	SY	14,080	25	$14,080
2"Asphalt Concrete Overlay	$110.00	Ton	1,531	25	$168,432
Tack/Prime Coat (Mainline & Shoulders)	$1.90	Gals	3,520	25	$6,688
Other Incidental Costs (strip, mob, etc. - 10% of material cost)	$22,862	LS	1	25	$22,862
Traffic Control (20% of material cost)	$45,725	LS	1	25	$45,725
Engineering & Inspection (10% of material cost)	$22,862	LS	1	25	$22,862
	TOTAL COST YEAR 25 ITEMS =				**$320,074**

C=AXB

IV. Accumulated Cost per Option with Discount

The table 19 shows the accumulated costs per each year per option. It includes the total expenditures that are equal to the initial costs plus maintenance costs with discount. The salvage value is not considered in these calculations.

Table 19: Accumulated Total Expenditures per year with Discount

Description	Year	8" AC /6-inch Agg Base	9-in PCC / 6 -inch Agg Subbase	2-in AC over 7 RCC over Agg base
Accumulated Total Exp / year	0	$738,218	$808,104	$817,695
Accumulated Total Exp / year	1	$738,218	$808,104	$817,695
Accumulated Total Exp / year	2	$738,218	$808,104	$817,695
Accumulated Total Exp / year	3	$738,218	$808,104	$817,695
Accumulated Total Exp / year	4	$738,218	$808,104	$817,695
Accumulated Total Exp / year	5	$738,218	$808,104	$817,695
Accumulated Total Exp / year	6	$961,026	$808,104	$817,695
Accumulated Total Exp / year	7	$961,026	$808,104	$817,695
Accumulated Total Exp / year	8	$961,026	$808,104	$817,695
Accumulated Total Exp / year	9	$961,026	$808,104	$817,695
Accumulated Total Exp / year	10	$961,026	$808,104	$817,695
Accumulated Total Exp / year	11	$961,026	$808,104	$817,695
Accumulated Total Exp / year	12	$1,163,592	$808,104	$817,695
Accumulated Total Exp / year	13	$1,163,592	$808,104	$817,695
Accumulated Total Exp / year	14	$1,163,592	$808,104	$817,695
Accumulated Total Exp / year	15	$1,163,592	$808,104	$1,069,953
Accumulated Total Exp / year	16	$1,163,592	$808,104	$1,069,953
Accumulated Total Exp / year	17	$1,163,592	$808,104	$1,069,953
Accumulated Total Exp / year	18	$1,163,592	$808,104	$1,069,953
Accumulated Total Exp / year	19	$1,163,592	$808,104	$1,069,953
Accumulated Total Exp / year	20	$1,497,135	$808,104	$1,069,953
Accumulated Total Exp / year	21	$1,497,135	$808,104	$1,069,953
Accumulated Total Exp / year	22	$1,497,135	$808,104	$1,069,953
Accumulated Total Exp / year	23	$1,497,135	$808,104	$1,069,953
Accumulated Total Exp / year	24	$1,497,135	$808,104	$1,069,953
Accumulated Total Exp / year	25	$1,497,135	$905,530	$1,285,185
Accumulated Total Exp / year	26	$1,497,135	$905,530	$1,285,185
Accumulated Total Exp / year	27	$1,497,135	$905,530	$1,285,185
Accumulated Total Exp / year	28	$1,497,135	$905,530	$1,285,185
Accumulated Total Exp / year	29	$1,497,135	$905,530	$1,285,185
Accumulated Total Exp / year	30	$1,497,135	$905,530	$1,285,185

V. Benefits at years 8 and 12 (No Salvage Value Included)

The table 20 shows initial cost and the net present accumulated cost at 8-year period. The salvage value is not considered in these calculations.

Table 20: Summary of Costs per Equivalent Pavement Structure at 8-year period

Description of Pavement	Initial Cost(A)	% high	8-year period Discounted 1.6% No Salvage Value Net Present Accumulated Cost (B)	Savings (No Salvage) Sub Total (C)	Percent(D)
Option A: 8" AC /6-inch Aggregate Base	$738,218	0%	$961,026	$152,922	19%
Option B: 9-in PCC / 6 -inch Aggregate Subbase	$808,104	9%	$808,104	$0	0%
Option C: 2-in AC over 7 RCC over Aggregate base	$817,695	11%	$817,695	$9,591	1%

B=A+ Maintenance Costs Discounted
C=Difference between net present accumulated costs between one option and the other
D= (B: Option 1-Option 2)/B: Option 2 X100

The table 21 shows initial cost and the net present accumulated cost at 12-year period. The salvage value is not considered in these calculations.

Table 21: Summary of Costs per Equivalent Pavement Structure at 12-year period

Description of Pavement	Initial Cost(A)	% high	12-year period Discounted 1.6% No Salvage Value Net Present Accumulated Cost(B)	Savings (No Salvage) Sub Total (C)	Percent (D)
Option A: 8" AC /6-inch Aggregate Base	$738,218	0%	$1,163,592	$355,488	44%
Option B: 9-in PCC / 6 -inch Aggregate Subbase	$808,104	9%	$808,104	$0	0%
Option C: 2-in AC over 7 RCC over Aggregate base	$817,695	11%	$817,695	$9,591	1%

B=A+ Maintenance Costs Discounted
C=Difference between net present accumulated costs between one option and the other
D= (B: Option 1-Option 2)/B: Option 2 X100

The table 4 shows initial cost and the net present accumulated cost at 30-year period. The salvage value is not considered in these calculations.

Table 4- Summary of Initial and Lifetime Costs for All Options in Small Urban Areas (No Salvage Value)

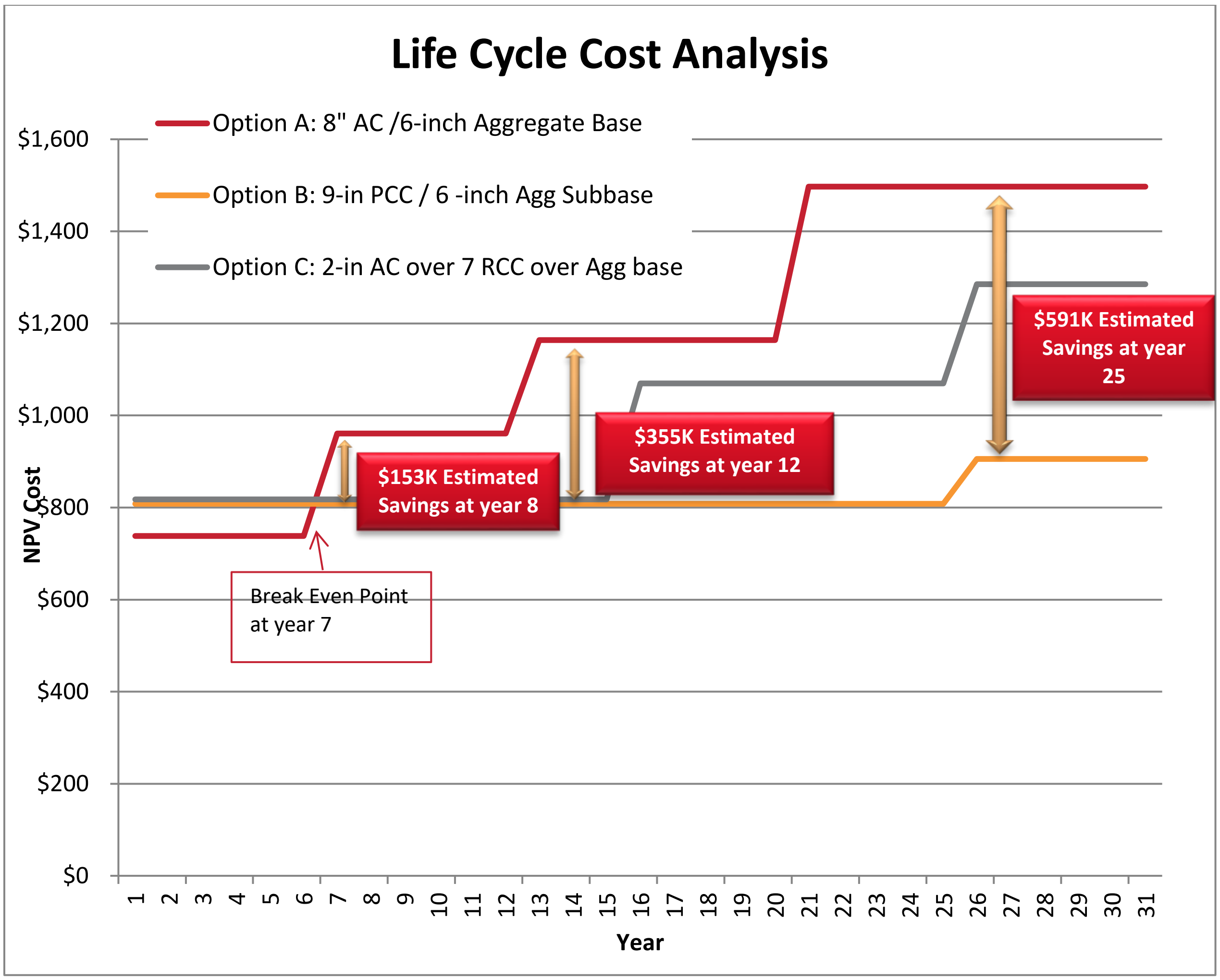
			30-year period Discounted 1.6% No Salvage Value		
				Savings (No Salvage)	
Description of Pavement	Initial Cost(A)	% high	Net Present Accumulated Cost (B)	Sub Total (C)	Percent (D)
Option A: 8" AC /6-inch Aggregate Base	$738,218	0%	$1,497,135	$591,605	65%
Option B: 9-in PCC / 6 -inch Agg Subbase	$808,104	9%	$905,530	$0	0%
Option C: 2-in AC over 7 RCC over Agg base	$817,695	11%	$1,285,185	$379,655	42%

B=A+ Maintenance Costs Discounted
C=Difference between net present accumulated costs between one option and the other
D= (B: Option 1-Option 2)/B: Option 2 X100

VI. Graph

The following figure compares the accumulated expenditure of each option and shows the estimated savings at year 8, 12, and 25. The figure not considers the salvage value.

Figure 9: Life Cycle Cost Analysis



VII. Total Costs and Savings with Salvage Value

The table 5 shows the initial costs, Salvage value of last rehabilitation and the net present accumulated costs with their savings for each pavement option.

Table 5: Summary of Costs per Equivalent Pavement Structure at 30-year period

Description of Pavement	Initial Cost (A)	% high	Salvage Value of Last Rehabilitation (B)	30-year period Discounted 1.6% Salvage Value Applied		
				Net Present Accumulated Cost (C)	Savings (With Salvage) Sub Total (D)	Savings (With Salvage) Percent (E)
Option A: 8" AC /6-inch Aggregate Base	$738,218	0%	($55,591)	$1,441,545	$584,728	68%
Option B: 9-in PCC / 6 -inch Aggregate Subbase	$808,104	9%	($48,713)	$856,817	$0	0%
Option C: 2-in AC over 7 RCC over Aggregate base	$817,695	11%	($107,616)	$1,177,569	$320,752	37%

B= Salvage Value of Last Rehabilitation

C=A+ Maintenance Costs Discounted+ Salvage Value

D=Difference between net present accumulated costs of one option and the other

E= (C: Option 1-Option 2)/C: Option 2 X100