"Green Up" Color Coded Design Alternative Comparison System for Pavements

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Abstract

Several sustainability rating systems are currently available for pavement design and rehabilitation projects. These rating systems are fairly complex and some of them require the services of a third party, for a fee, or the expertise of certified individuals to evaluate and certify projects. Designers looking for sustainable pavement rehabilitation solutions on smaller projects and with limited budgets may not have the time and resources to use these existing rating systems. This paper describes the development of a simple, fast and convenient system that can be used to compare key sustainability features of different pavement design and rehabilitation alternatives. Four components are included in the analysis: materials, construction methods, surface properties and cost effectiveness. Colors are used to emphasize the sustainable aspects of a given alternative.

Background

In recent years, the civil engineering community has become more receptive to sustainability and sustainable design. Many rating systems have been developed to encourage and reward the use of sustainable practices in civil engineering design (Eisenman, 2012). One of the most known "green" rating systems is the Leadership in Energy and Environmental Design or LEED (US Green Buidling Council, 2013). In the LEED rating system, sustainable practices are rewarded with credits and more credits will earn a higher LEED certification. Different rating systems have been developed to evaluate:

- Commercial buildings and interiors
- Retail developments
- Schools
- Homes
- Neighborhoods

Specific to pavements, LEED includes a range of applicable credits falling in the following major categories:

- Storm water management – and the recommended use of porous pavements

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- Heat island effect reduction – and the recommended use of pavement surfaces with high Surface Reflective Index (SRI)
- Recycled content in infrastructure – and the recommended use of recyclable materials
- Construction waste management – and the recommendation to divert recyclable materials from disposal

Many other credits are included in LEED, for example for providing bike lanes, carpool lanes, building "walkable" streets, etc. However, pavement engineers are mostly concerned with the technologies and materials used to construct, maintain or rehabilitate a pavement structure.

Another very successful rating system used in the United States is Greenroads. This rating system was developed specifically for roadways and transportation infrastructure (Muench, Anderson, Hatfield, Koester, & Söderlund, 2011). Projects have to meet eleven requirements to be eligible for certification:

- Environmental review process
- Lifecycle cost analysis
- Lifecycle inventory
- Quality control plan
- Noise mitigation plan
- Waste management plan
- Pollution prevention plan
- Low impact development
- Pavement management system
- Site maintenance plan
- Educational outreach

In addition, projects receive points for using sustainable practices. More points will result in a higher level of certification.

In the United States, pavement engineers are most often confronted with the rehabilitation of existing pavements rather than new construction. In California for example, 81% of roads are managed by cities and counties. According to a recent study (Yapp, 2013), the overall condition of these roads is "at risk" and continues to deteriorate. In other words, these pavements are in need of maintenance and rehabilitation. At the same time, the funding available for maintenance and rehabilitation is only about a third of what is needed to prevent further deterioration. As a result, rehabilitation projects are often limited to restoring the structural and functional properties of the pavement and do not include any improvements such as widening or landscaping that could add more sustainable features to a project.

For such cases, where resources are limited, a simple system is proposed to evaluate possible rehabilitation alternatives in terms of sustainability. The proposed "Green Up" system focuses on structural pavement design aspects that the pavement engineer can control:

- The choice of materials: for example the use of recyclable materials such as fly ash in portland cement concrete or reclaimed asphalt pavement (RAP) in asphalt concrete;
- The choice of maintenance and rehabilitation strategies: for example the use of warm mix asphalt technology (WMA) to reduce harmful emissions and consumption of fossil fuels;
- Surface properties such as permeability, surface reflectivity (related to heat storage and the heat island effect) and noise;
- Cost effectiveness: the choice of alternatives that offer a lower ratio of life cycle cost per year of extended pavement life.

Because a combination of materials and technologies are typically used on any project, the combined effect of all the factors involved is usually summarized in the form of a numerical index. However, the use of indices requires accurate estimates of the effects of each of the factors considered towards achieving a "green" or sustainable solution. There are challenges in coming up with an overall numerical index of sustainability for a given design alternative:

- Sustainability is not easy to measure. One of the few physical measures generally accepted for environmental sustainability is the "carbon footprint" or the amount of greenhouse gas emissions associated with the production of a given material or a certain pavement rehabilitation technology. However, sustainability has social, economic and environmental aspects which are not necessarily captured by the carbon footprint.
- The type and condition of construction equipment varies from contractor to contractor and will change with time – hence there will be changes in the associated fuel consumption, energy efficiency and the resulting carbon footprint.
- In terms of sustainability, pavement design alternatives that provide longer life for lower life cycle cost are desirable. However, the cost of materials and technologies will change with time and varies from one geographic area to another.

To overcome some of these challenges, the proposed comparison system makes use of broad categories represented by colors and areas to convey a quick summary of the sustainability features of a project, as illustrated in Figure 1.

Comparing different design alternatives is easily achieved by producing similar graphical representations for two or more alternatives and then comparing them visually. More green indicates more sustainable design, materials and construction. More red is an indication of the opposite. Colors like Green-Yellow, Yellow and Orange are used to represent materials and technologies in between the two extremes:

- Green = Sustainable
- Red = Not Sustainable

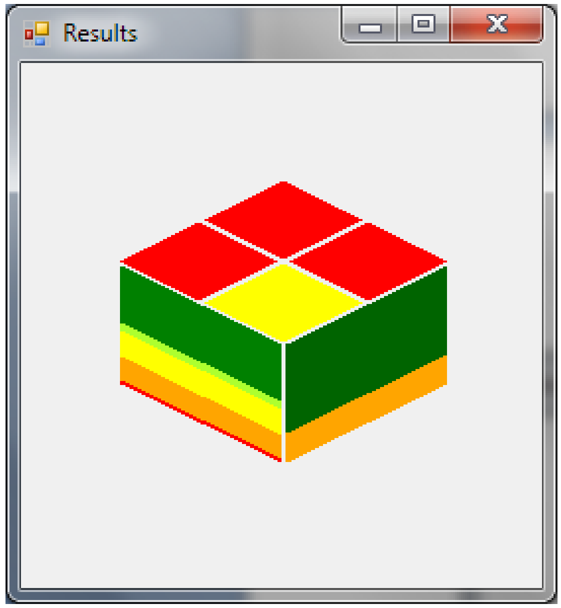

Figure 1: Color coded image generated with the Green Up system.

The image produced in this approach resembles the three sides of a cube. On the lateral sides of the cube, the areas covered with a certain color are an indication of the thickness of material or volume of work for a specific construction activity. The top face is divided in four diamonds which indicate:

- Surface permeability: left diamond on the top face of the cube;
- Surface reflectivity: top diamond on the top face of the cube;
- Tire-pavement noise: right diamond on the top face of the cube;
- Life cycle cost: bottom diamond on the top face of the cube.

Each of these categories is discussed in more detail in the next paragraphs. Note that there is no overall rating or numerical index associated to one design alternative. The purpose of the proposed system is not to rank alternatives but to allow engineers to identify and compare key sustainability features of different pavement rehabilitation alternatives.

Material Categories

The lower left face of the Green Up cube shows the different materials used in the pavement design or rehabilitation alternative. To differentiate between different materials in terms of sustainability, 5 major categories are being defined as described in Table 1.

The ranking and categories described in Table 1 are based on engineering judgment. At the top of the sustainability scale are pavement materials recycled in place. Recycling makes perfect sense from a sustainability point of view. When recycling can be performed in place, the need to transport materials to and from the job site is minimized or eliminated. In addition, the owner agency will spend less on new materials by making use of the materials they already paid for in the past, when the pavement was originally built.

Transporting construction materials requires the use of fossil fuels and results in the production of green house gases. Heavy truck traffic also contributes to the accumulation of damage on the pavements that carry these trucks from aggregate quarries to asphalt and concrete plants, to job sites, to storage areas or landfills. The larger the amount of materials imported or exported from a project, the larger the amount of fossil fuel used, greenhouse gas emissions produced and damage caused to existing pavements.

Table 1: Material Categories

Category	Color Code	Description	Examples
Recycled In-Place	Green Color	This category ranks highest on the sustainability scale. It includes materials recycled or reused in place, i.e. transportation to/from the job site is not required.	Asphalt concrete recycled in place, soil stabilization, Rubblized Concrete Pavement (RCP)
Recycled Import (Alternative Materials)	Light Green Color	This category ranks second on the sustainability scale. It includes materials stockpiled offsite that will be incorporated into the pavement. It also includes materials that are byproducts of other industrial processes.	Reclaimed Asphalt Pavement (RAP), Recycled Asphalt Shingles (RAS), crumb tire rubber, Recycled Concrete Aggregate (RCA), blast furnace slag, fly ash, etc.
Recyclable Export	Yellow Color	This category ranks third on the sustainability scale. It includes materials that will be removed from the road but can be stockpiled for future use in pavement projects or other civil engineering applications.	RAP, RCA, RCP, Reinforcing Steel
Virgin Import	Orange Color	This category ranks fourth on the sustainability scale. It includes virgin materials.	Asphalt cement, asphalt emulsion, portland cement, lime, virgin aggregate, interlayers, and other materials or additives that are not recycled/reused products
Non-Recyclable Export (Waste)	Red Color	The fifth and last category is reserved for materials that will be transported to a landfill with very little chances of reusing/recycling.	RAP contaminated with fines or other deleterious materials, damaged concrete pavement, etc.

Typically, the following materials fall into this first subcategory:

- existing asphalt concrete recycled in place through strategies like Cold In-Place Recycling (CIR) and Hot In-Place Recycling (HIR)
- existing asphalt concrete and underlying materials stabilized in place through strategies such as Full Depth Reclamation (FDR)

- existing portland cement concrete recycled into base by rubblization.

Ranking second in the materials subcategories are recyclable materials that will be imported and used in the proposed rehabilitation alternative. Typically, the following materials fall in this category:

- RAP and RAS which can be used for Cold Central Plant Recycling (CCPR), for Hot Mix Asphalt (HMA), High-RAP HMA or for Warm Mix Asphalt (WMA).
- RCA which can be used as unbound base or as aggregate for HMA or Portland Cement Concrete (PCC)
- Tire rubber to produce rubberized asphalt concrete
- Blast furnace slag which can be used in PCC and Geopolymer Concrete (GPC).
- Fly ash which can be used in PCC and Geopolymer Concrete (GPC).

Next on the sustainability scale are materials that can be recycled but cannot be used on the site (recyclable export). These materials will likely be transported off site and stored for future use in pavement structures. This category typically includes:

- RAP
- RCA
- A mix of asphalt concrete and base material generated through pulverization during FDR operations; in some areas this is called crushed miscellaneous base (CMB).

The next subcategory is reserved for virgin materials and it includes aggregates, binders (asphalt cement, asphalt emulsion, portland cement), additives, and interlayers. All these materials are produced from virgin sources/resources which are non-renewable. Continued consumption of non-renewable resources is not a sustainable practice.

The last category of materials and lowest on the sustainability scale are materials that will be disposed of in a landfill. This category may include contaminated RAP/RCA, damaged interlayers, etc. There is little hope that these materials will ever be used again, in a pavement structure or for other applications. The longer the materials sit in a landfill, the more likely they are to get contaminated with other waste.

To use the proposed comparison system, first estimate the volume of material(s) falling into each of the five categories described in Table 1. Then, on the left side of the cube, draw parallelograms that correspond in area to the total volume of material(s) in a certain category. The obtained image will be rough representation of the thickness of material in each category, as it would appear in a pavement cross-section.

An example is shown in Figure 2. To generate the image in Figure 2, we considered a pavement rehabilitation project where 1.5 inches of the pavement are to be milled (removed), then 3 inches of the remaining asphalt concrete is to be recycled in place (CIR) and a 1.5 inch hot mix overlay is to be applied over the CIR.

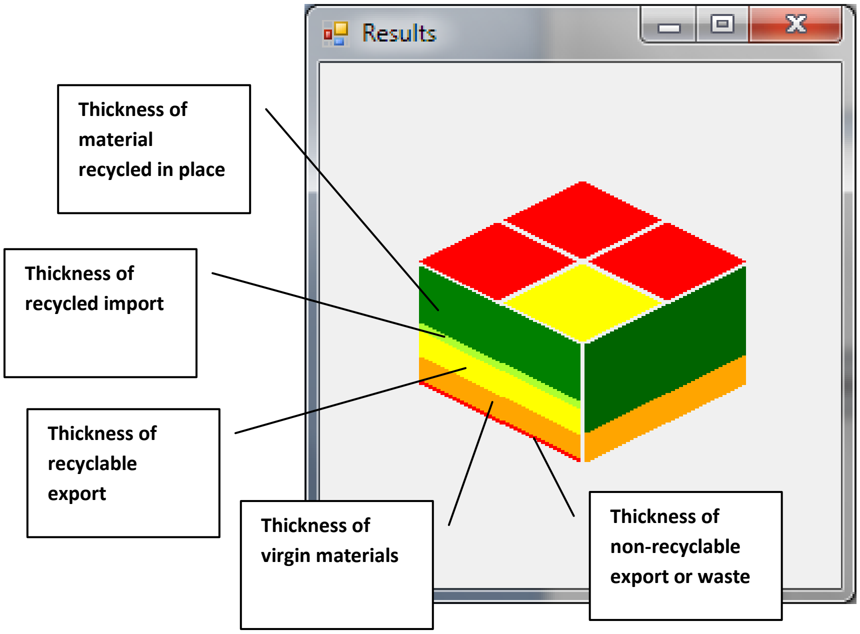

Figure 2: Breakdown of material categories.

Technology Categories

A similar approach is used to generate the right face of the Green Up cube. This time, technologies or construction processes are ranked in terms of energy consumption and greenhouse gas (GHG) emissions. In a 2003 Colas report, Chappat and Bilal summarize their findings on energy consumption and greenhouse gas emissions specific to different pavement construction and rehabilitation technologies (Chappat & Bilal, 2003). The authors identify several "levels" for energy consumption per unit of material:

- In situ treated soils – lowest level of energy consumption, on average 150 MJ/t;
- Cold mixes – 2.3 time more energy consumption than in situ treated soils;
- Hot and warm mixes – 4 times more energy than in-situ treated soils;
- Portland cement concrete – 6 times more energy than in-situ treated soils.

A similar grouping of technologies was done based on greenhouse gas emissions:

- In situ treated soils – lowest level of GHG, 10 to 20 kg/t;
- Cold and hot mixes – 3 times more GHG than in situ treated soils;
- Portland cement concrete – 10 times more GHG than in-situ treated soils.

As reported in the Colas study, portland cement concrete has the highest level of energy consumption and GHG emissions in comparison with other pavement construction and rehabilitation technologies. Although the construction process itself is not very different from other technologies, the manufacturing of the portland cement is responsible for the higher levels of energy and emissions.

Starting from the idea that different technologies can be grouped into broader categories, the Green Up systems uses four categories to differentiate between technologies in terms of energy consumption and greenhouse gas emissions. These categories are described in Table 2.

Table 2: Construction Processes Categories

Category	Color Code	Description	Examples
Cold	Green Color	Manufacturing and construction processes that make use of very little heat/energy and therefore generate very little emissions compared to other processes.	CIR, CCPR, FDR
Warm	Yellow Color	Manufacturing and construction processes derived from hot processes but where the mixing and compaction temperatures can be lowered with the addition of warm mix additive.	WMA
Hot	Orange Color	Construction processes that require considerable heating of materials	HMA, HIR
Big Foot	Red Color	Although a cold construction process, reinforced portland cement concrete has a significantly higher carbon footprint than other technologies.	Plain PCC, Reinforced PCC

Figure 3 was generated using the same example of mill (1.5 inch), CIR (3 inch) and HMA overlay (1.5 inch). As illustrated in Figure 3, the thickness of material produced or processed with the different categories described in Table 2 can be easily identified visually.

Surface Properties

Besides materials and technology, there are several key aspects specific to the surface of the pavement that can be related to sustainability:

Porosity or the ability of the pavement surface to allow rain water to drain through the pavement surface and infiltrate into soil. Three categories are proposed:

- Porous (Green Color)
- Impervious (Red Color)
- Not Applicable (Gray Color)

Several types of pavement surfaces fall into this category:

- Pervious concrete
- Porous asphalt concrete
- Some types of interlocking concrete pavement

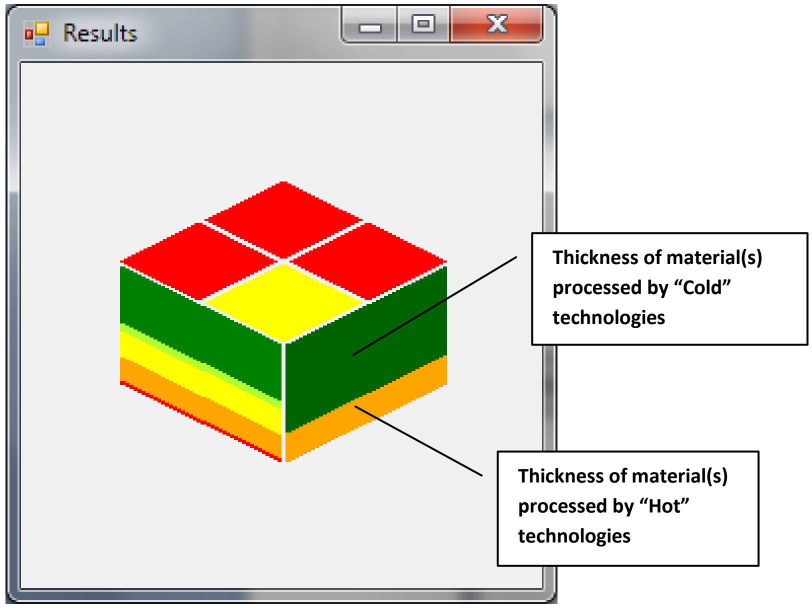

Figure 3: Breakdown of technology categories.

Surface reflectivity will influence the rate of cooling of the pavement after being exposed to sunlight during the day. In urban areas, pavements that take longer to cool down contribute to the so called "heat island" which contributes to increased energy costs and greenhouse gas emissions. To take into account surface reflectivity, pavement surfaces are divided into the following broad categories:

- Cool (Green Color): for pavements with high surface reflectivity
- Hot (Red Color): for pavements with low surface reflectivity
- Not Applicable (Gray Color): for pavements in rural areas or other scenarios where the heat island effect is not of interest.

Noise generated at the tire-pavement interface is a known source of noise pollution, especially in urban areas. The use of certain surface materials can minimize this noise to contribute to the overall sustainability of the pavement. The following categories are defined as far as noise:

- Quiet (Green Color): where surface materials or treatments are planned to reduce noise
- Noisy (Red Color): where the materials/technologies used do not reduce noise
- Not Applicable (Gray Color): for pavements where tire-pavement noise is not a nuisance.

The following technologies are recognized to provide lower levels of noise:

- Open-Graded Friction Course asphalt concrete
- Rubberized asphalt concrete
- Longitudinally diamond-ground portland cement concrete

Consider a pavement where the proposed rehabilitation alternative consists of milling the existing pavement, recycling in place, capping with a hot mix overlay and then adding an open graded friction course that will facilitate drainage and minimize noise. Figure 4 illustrates the use of the different color codes to describe the surface characteristics of this design alternative in terms of sustainability.

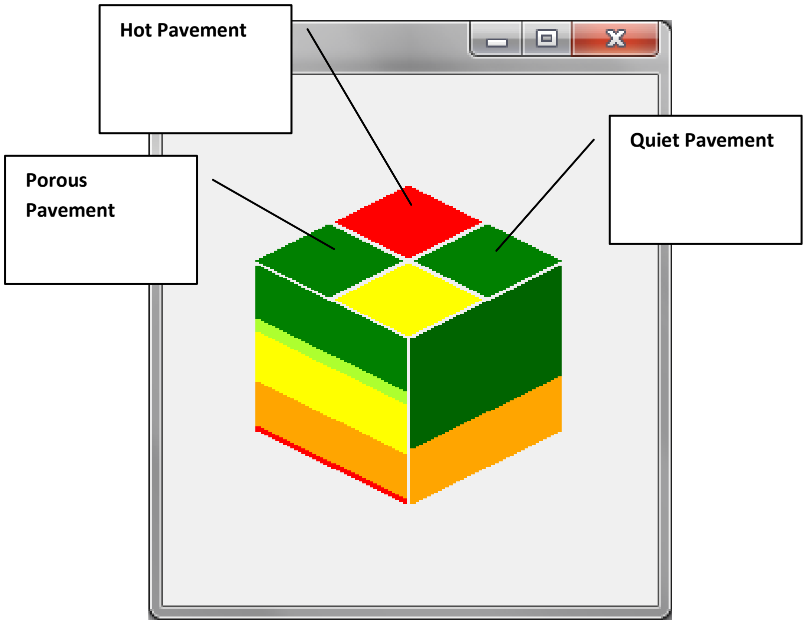

Figure 4: Breakdown of surface properties on the top side of the Green Up cube.

Cost Efficiency

The last element included in the Green Up comparison system is the cost of the strategy over the life of the pavement. Life and cost considerations are included to encourage designers to think long term and to plan and include in the cost of the proposed solution both the initial construction cost and the cost of future maintenance and rehabilitation.

Based on the expected service life of a pavement the following categories are identified:

- Perpetual: where the design recommendations together with future maintenance and rehabilitation recommendations ensure that the pavement could be maintained in service indefinitely. For practical purposes, perpetual pavements should last more than three generations or 75 years.
- Long Life: these are pavements that are designed to last more than two generations or 50 years.
- Normal: traditionally, flexible pavements are designed for 20 years life; rigid pavements for 40 years. These pavements will fall under the Normal category.
- Temporary: these are design alternatives that will extend the life of the pavement for less than 20 years.

To compare design alternatives in terms of cost, the total cost that will likely be incurred over the life of the pavement is divided by the number of years the pavement will be in service. The total cost includes the following basic elements:

- The cost of initial construction and the resulting life extension in years

- The estimated cost of preventive maintenance and the frequency
- The estimated cost of reactive maintenance and the frequency
- The estimated cost of subsequent rehabilitation and the resulting life extension

Based on the calculated yearly life cycle cost, a proposed rehabilitation scenario may fall into one of the following cost categories:

- High Cost
- Moderate Cost
- Low Cost

Based on the categories defined for pavement life and cost, Table 3 is used to determine the Cost Efficiency category of a given design alternative:

Table 3: Cost Efficiency Categories and Colors

Life Categories:	Temporary	Normal	Long Life	Perpetual
High Cost	Very Poor	Poor	Fair	Saver
Moderate Cost	Poor	Fair	Saver	Super Saver
Low Cost	Fair	Saver	Super Saver	Excellent

In Figure 5, the bottom diamond on the top surface of the Green Up cube bears the color corresponding to the cost efficiency category described in Table 3. Figure 5 illustrates the Green Up cube for the following scenario: Mill 1.5 inches, CIR 3 inches, HMA Overlay 1.5 inches. For California, United States, this scenario falls under the "Fair" cost efficiency category (Moderate Cost & Normal Design Life).

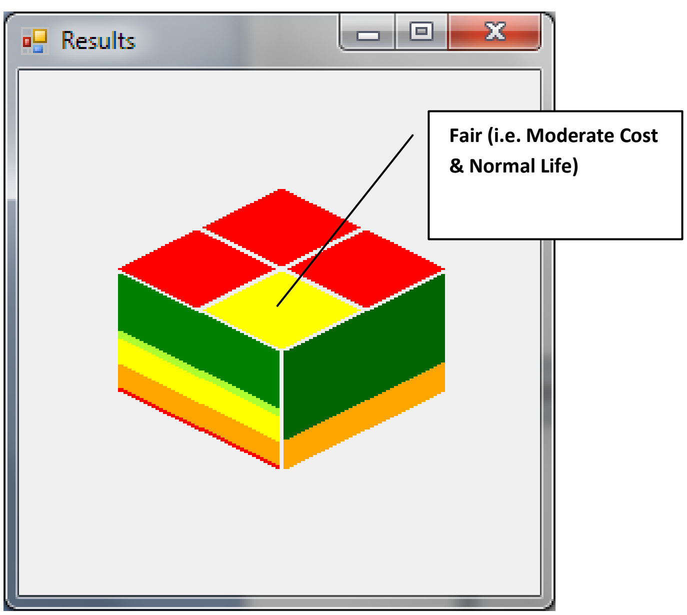

Figure 5: Bottom diamond on the top surface shows the color corresponding to the cost efficiency categories described in Table 3.

Green Up Software

It would be impractical and time consuming to generate the color-coded images specific to each design alternative manually. A software application has been developed for Windows PC's and it is available for download at: http://GreenUpPavements.blogspot.com. Any updates or improvements to the Green Up software will be made available at the same web site.

Green Up Example

In California's urban areas, many cities use the "mill and fill" approach to rehabilitate their pavements. Typically, 2 to 3 inches of the existing asphalt concrete is removed and replaced with new hot mix asphalt overlay. Milling is required because the final elevations of the pavement surface have to align with the existing concrete curb and gutter structures. This solution is also traditionally included in pavement management programs and the multi-year plans produced by pavement management software. However, it should be noted that the mill and fill method only removes distress at the surface of the pavement thus leaving the pavement susceptible to experience reflective cracking after 5 to 10 years of service.

A different approach is to recycle the existing asphalt concrete in place (CIR) and cap it with a thinner hot mix overlay. In order to maintain the same surface elevations, milling will also be required to make room for the hot mix overlay. The CIR layer provides crack-free support for the HMA overlay and will result in a longer life extension. Also, this alternative makes better use of the materials already available at the site. How do the two alternatives compare in terms of sustainability? The Green Up system and software was used to compare the following two possible designs:

1. Mill and Fill scenario:
    a. Mill 3 inches
    b. HMA Overlay 3 inches
2. Mill, CIR and Fill scenario:
    a. Mill 1.5 inches
    b. CIR 3 inches
    c. HMA Overlay 1.5 inches

The inputs required to use the software for this specific analysis are summarized in Table 4. The calculated values used to draw the Green Up cube images are summarized in Table 5. Figures 6 shows the two images side by side.

As shown in Figure 6, the two scenarios are similar in terms of surface properties: impervious, low reflectivity and noisy. Hence the red color for the top three diamonds. In terms of life cycle cost, both scenarios fall in the "Fair" category which corresponds to Moderate cost and 20 to 50 years design life (see Table 3).

Table 4: Green Up Inputs

Input	Scenario 1: Mill and Fill	Scenario 2: Mill, CIR and Fill
Milling thickness	3 inches	1.5 inches
- **How much of the removed material will be reused on the project**	0%	0%
- **How much of the removed material will be recyclable export (such as RAP)**	90%	90%
- **How much of the removed material will be taken to a land fill (waste)**	10%	10%
CIR thickness	-	3 inches
- **Percent Recycling Agent**	-	3.5%
- **Percent Recycling Additive**	-	0.5%
- **Percent Water**	-	3%
HMA thickness	3 inches	1.5 inches
- **Asphalt Content**	5%	5%
- **RAP**	25%	25%
- **Crumb Rubber**	0%	0%
Surface Drainage	Impervious	Impervious
Surface Reflectivity	Low	Low
Noise	Noisy	Noisy
Initial Rehabilitation		
- **Cost per unit area**	$20/SY	$20/SY
- **Life extension**	10 years	15 years
Preventive Maintenance		
- **Cost per unit area**	$2/SY	$2/SY
- **Frequency**	Every 4 years	Every 4 years
Reactive Maintenance		
- **Cost per Unit Area**	$3/SY	$3/SY
- **Frequency**	Every 6 years	Every 6 years
Subsequent Rehabilitation		
- **Cost per unit area**	$20/SY	$20/SY
- **Life extension**	10 years	15 years
Cost Level	Moderate	Moderate

Table 5: Green Up Calculated Parameters

Output	Scenario 1: Mill and Fill	Scenario 2: Mill, CIR and Fill
Thickness of materials:		
- **Recycled in Place**	-	2.88"
- **Recycled Import**	0.75"	0.375"
- **Recyclable Export**	2.7"	1.35"
- **Virgin Import**	2.25"	1.245"
- **Waste**	0.3"	0.15"
Thickness of materials processed by:		
- **Cold Technology**	3"	4.5"
- **Warm Technology**	-	
- **Hot Technology**	3"	1.5"
- **Big Foot Technology**	-	
Service Life	20	30
Yearly Cost	$3/SY/Year	$2.34/SY/Year

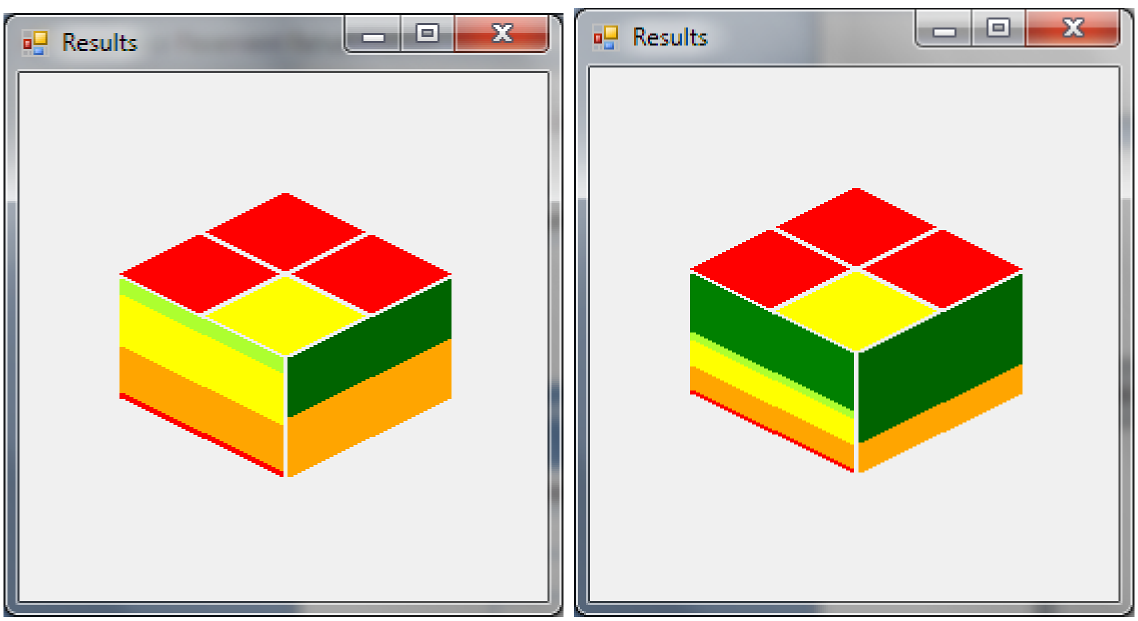

Figure 6: Green Up cube for Mill and Fill Scenario (left) and for Mill, CIR and Fill scenario (right).

The left side of the Green Up cube however tells a different story. The Mill and Fill scenario shows an almost 50/50 distribution of virgin material and recyclable export material. Also visible are lower proportions of recyclable import and waste. In comparison, the Mill, CIR and Fill scenario shows that almost half of the materials are recycled in place. The remaining materials consist of virgin material and recyclable export plus very little recyclable import and waste.

The right side of the cube shows that half of the materials in the Mill and Fill scenario are processed with a Cold technology while the other half uses a Hot technology. In comparison, 75% of materials are processed with a Cold technology in the Mill, CIR and Fill scenario and only 25% with the Hot technology.

Is one approach more sustainable than the other? Could we get even more "green" in the picture? Assume now that after seeing Figure 6 the designer decides to add a 1.5 inch open graded friction course which would help with surface drainage and minimize tire-pavement noise. The resulting Green Up cube is shown in Figure 7:

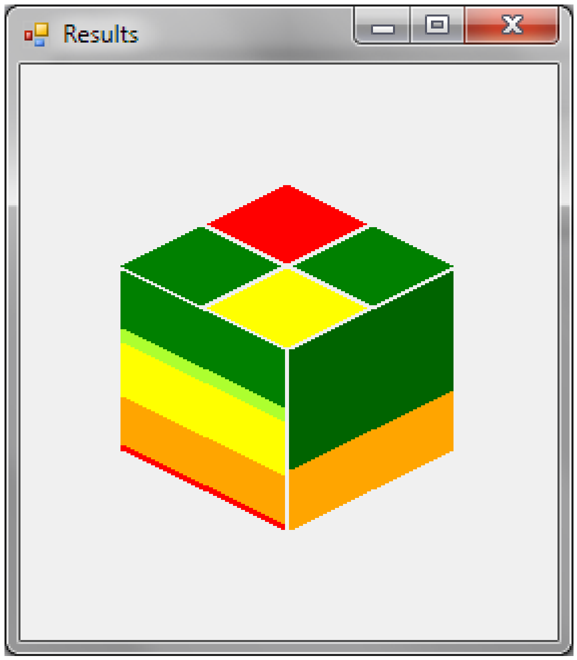

Figure 7: Green Up cube for modified Mill, CIR and Fill scenario.

Adding the 1.5 inch friction course requires that an additional 1.5 inches of the pavement be milled. For this reason, the Green Up cube is taller to show that a larger amount of material is being processed. Two of the diamonds representing surface properties change to green. The cost of the modified scenario is higher but the estimated life of the pavement is also higher and the scenario still falls under the "Fair" cost efficiency category.

Conclusions and Recommendations

The Green Up system provides design professionals with a method of comparing pavement rehabilitation alternatives in terms of four key sustainability features:

- Materials: based on the concept that material reusing and recycling is a sustainable practice;
- Technologies: based on the concept that reducing green house gas emissions and energy consumption is a sustainable practice;
- Surface properties such as:
  - Permeability: the ability to reduce the amount of storm water runoff;
  - Surface reflectivity: the ability to minimize the heat island effect;

  - Noise: and the ability to reduce noise pollution;
- Life cycle cost: based on the assumption that pavement rehabilitation solutions that cost less and result in a longer life extension are more sustainable.

Before using the Green Up system, designers should use the standards and methods appropriate to their project and jurisdiction to design pavements that are safe, smooth, and economically viable. After producing several design alternatives, the Green Up system can be used to compare and improve the proposed design in terms of sustainability.

The Green Up system was designed to be fast and simple. It limits the amount of information that needs to be provided by the user in an effort to minimize the amount of time needed to use the system. When time and resources are available, designers are encouraged to also use one of the more comprehensive sustainability rating systems such as Greenroads.

A software application has been developed to allow pavement engineers to use the method and generate the Green Up cube graphic in a matter of minutes. The Green Up software aims to help and educate at the same time. The "Green Up" button found on many of the user dialog boxes is a gateway to educational materials about sustainable pavement rehabilitation practices on the web. An example is shown in Figure 8.

Public and private road agencies could require the use of the Green Up comparison system to ensure that designers:

1. Develop more than one pavement rehabilitation solution for a given project, thus giving the owner options and allowing them to make educated decisions about which option to pursue;
2. Evaluate key sustainability features of the pavement and report on the sustainable practices used and the extent to which these practices were used.

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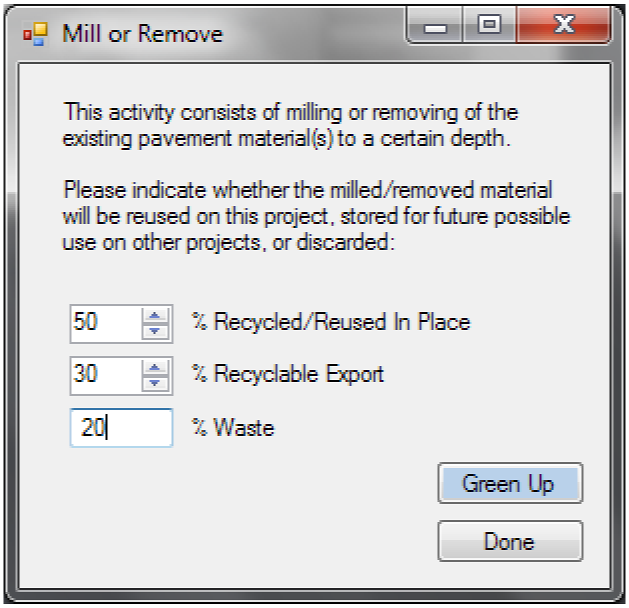

Figure 8: "Green Up" button provides links to web pages with more information on sustainable practices.