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“Sustainable Transport Practices”
The wealth of knowledge accumulated during the 17th IRF World Meeting & Exhibition in Riyadh was the driving force behind our decision to launch the IRF Examiner as a freely available resource for the industry. With this seventh issue, the International Road Federation confirms its role as a leading provider of applied knowledge in areas of vital importance for the global community of road professionals.

H.E. Eng. Abdullah A. Al-Mogbel
IRF Chairman

Roads are the world’s first “social network”. They are fundamental building blocks for human and economic development whose impacts transcend national borders. The benefits of investments in roads have shown how transformative an infrastructure they can be for a wide range of beneficiary communities.

At the International Road Federation, we have tried to capture these connections with a simple slogan “Better Roads. Better World”. Since we were established 1948, our primary purpose has been to transfer the latest technologies and knowledge from those who have it to those who need it, and in doing so, promote an agenda of shared prosperity that flows from accessible, affordable and sustainable road networks. The IRF Examiner is an essential vehicle to this ambitious agenda.

C. Patrick Sankey
IRF President & CEO
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IMPLEMENTATION OF THERMOELECTRIC EFFECTS TO ROAD FACILITIES

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ABSTRACT
Energy harvesting stands alone as one of the most interesting techniques for approaching the global energy crisis without depleting natural resources. Road infrastructure energy harvesting technologies are a new research area that encompass technologies that collect the wasted energy occurred in road space such as pavements, external space and store it for later use. Energy surrounding roadways is available in many different forms including wind, solar, thermal and mechanical energy. In this study, the goal is to develop an energy harvesting system that can be installed in roadway barrier. The system can harvest energy from the temperature gradient between the barrier interior and surface using thermoelectric modules. This paper presents a trial energy harvesting system. The system will focus on the development of an energy harvesting system for energy utilization.

INTRODUCTION
Energy surrounds us and is available in many different forms, such as wind and solar energy or thermal and mechanical energy. One such naturally occurring energy source is the asphalt pavement that receives a daily abundance of solar energy, which dissipates as thermal energy in the pavement inner structure. The resulting augmented temperatures with the traffic loads affect dramatically the surrounding environment and the service life of the pavements through raveling and rutting incidents. What makes the concept of harvesting energy from pavements enticing is that they offer an existed infrastructure that its dimensions are endless. [Symeoni, 2012]

Mallick et al. (2009) emphasized that enhanced asphalt pavements that include an energy harvesting system, to reduce Urban Heating Island (UHI) effect, also clearly decrease rutting in asphalt pavements. In their study, they have conducted a large scale experiment to investigate the interaction among mechanisms like conduction, convention and radiation with the engineering parts of the whole system like the geometry of the pipes, the temperature of the inner water and rate of the flow fluid. Both wind speed and solar radiation were measured and solar radiation data were simulated with time. By using
only one pipe and a particular range of fluid flow rate, temperatures of several points in the slab were collected. In order to determine the temperature at different levels into the pavement, the experimental setup was first modeled in finite element method.

In general, they found good correlation between the experimental data from the slab and theoretical data from the simulation model regarding the input temperature at the pavement system and the surrounding air. They concluded that the distribution of the temperature in the slab and the cooling of the surface pavement is the diameter of the pipe were affected, however, the flow rate of the fluid did not affect significantly the temperature of the surrounding space and the slab. They found that the larger the pipe diameter becomes, the steeper temperature variations occurs from pipe to pavement surface as the larger diameter results in lower level of water temperatures and a higher rate of lowering the pavement surface. [Mallick et al. 2009; Mallick et al. 2011a; Mallick et al. 2011 b; Symeoni, 2012]

Xu et al. (2012) researched hydronic heating used to prevent ice formation and snow accumulation on road surface pavements with the purpose of improving driver safety. They adopted an extended Darcy law and continuity equation to describe water flow caused by moisture and temperature gradients. The developed model was capable of providing good simulations of the evolution of temperature and surface conditions during snowmelt. Simulation comparisons indicate that including the effects of melted snow on thermal properties is important in the simulation of temperature and surface condition during snow melting.

Photovoltaics (PV) were extending into new energy harvesting market. Photovoltaic noise barriers (PVNB) along motorways and railways permit one of the most economic applications of grid connected PV with the additional benefits of large scale power plants (typical installed power: more than 100 kWp) and no extra land consumption. Nordmann et al. [2000] had researched to reveal the large potential that could be interested for PV on noise barriers with the overall objective of raising the share of renewable energies for the EU’s electricity market. In contrast to many PV potential studies published before, this proposal is focusing on PVNB only, as one of the cheapest ways to implement large scale grid-connected PV installations.

As Wu et al. (2011) underlined “thermal collection starts as long as the temperature of the location of the pipes reaches the balance temperature needed by specific heat transfer flow rate, wind speed, irradiation intensity and other conditions”. The cooled pavement surface can improve its stiffness specifically in hot climatic conditions and may reduce or prevent permanent deformation, and hence extend the life of the pavement. [Stempihar, et al. 2012; Zhu, et al.2011].

Traditional thermoelectric systems are comprised of a number of doped semiconductor elements arranged electronically in series and thermally in parallel as shown in Figure 1 below. If heat is flowing between the top and bottom of the thermoelectric device (forming a temperature gradient) a voltage will be produced and hence an electric current will flow. [Wu, et al. 2011, Symeini, 2012] Harvesting thermoelectric energy mainly relies on the Seebeck effect that utilizes a temperature difference between the two ends of the device for driving the diffusion of charge carriers.

THERMOELECTRIC TECHNOLOGY

Thermoelectricity (TE) is the conversion of heat into electricity (Seebeck effect), or of electricity into heat or refrigeration (Peltier effect). The use of the Seebeck effect could allow heat to be saved, which would be otherwise lost. Although the conversion efficiency is very low, it has been enjoying renewed favor for several years, and novel research and development leads have been investigated, such as new materials and the structuring of matter at the nanoscale. This combination has led to active investigations worldwide, but without achieving the decisive breakthrough, which will give TE a prominent place among energy harvesting technologies. The most promising applications of TE, in the context of energy saving, concern thermal engine heat recovery (particularly in transport applications), and human body heat scavenging to power portable devices. TE for energy harvesting has several barriers to overcome: low conversion efficiency; toxicity; and low availability of chemical elements constituting part of the most interesting thermoelectric materials. In this context, the main challenges for nanotechnology are to demonstrate high efficiency improvement, and to display low cost implementation in thermoelectric materials.

Xi et al. (2007) investigated solar based driven thermoelectric technology and its applications were presented. Initially, a brief analysis of the environmental problems related to the use of conventional technologies and the benefits offered by thermoelectric technologies and renewable energy systems were outlined. Figure 1 describes a structure of thermoelectric module.
The aim of this paper is to apply thermoelectric energy harvesting technology to roadway facilities. As seen in Figure 2, concrete barriers are typically exposed to sunlight during daylight hours. The thermoelectrical module represents a technique that harvests energy from the different temperature based on Seebeck effect that utilizes a temperature difference between two ends of the devices for driving the diffusion of charge carriers. TE is possible to be used to capture free waste heat for electricity generation. [Wu et al. 2012a; Wu et al. 2012 b]. Wu et al. (2012a) has studied the implementation of thermoelectric modules on the surface of the pavements and has optimized their design by conducting simulations. The important observation behind the efficiency is a guaranteed high temperature difference between the upper and lower surface of the thermoelectrical module.

The research team evaluated concrete barrier, which absorbs solar energy during the daytime. The aim of the research team is to validate the energy harvested from the concrete barrier. As seen in Figure 2, the concrete barrier absorbs the solar energy from the roads surface. The research team in turn studied the energy harvesting properties from surfaces that serve as solar collectors.

An experiment was conducted in the laboratory using a small specimen and halogen lamp to simulate concrete barrier and sunlight. Figure 3 shows the entire experimental set up. Figure 3 (a) shows the data logger and data collect system. The output from TE was connected to data logger. Figure 3 (b) explains the halogen lamp 75W was used to simulate the solar energy to heat the surface of the TE module or cover plates.

**FIGURE 1**: Thermoelectric module basic structure (TEM) (Ahiska, et al. 2014)

**FIGURE 2**: Highway Concrete Barrier

**FIGURE 3**: Experimental set up

(a) Data collection system

(b) Simulated solar light

(c) Thermoelectric module and cooling sink
**Figure 3 (c)** shows a thermoelectric module is installed in the surface of concrete specimen and cooling sink to increase temperature difference between top and bottom of the thermoelectric module. The thickness of TE module involved here is only 0.50cm. **Figure 3 (d)** shows the TE case mounted to the concrete surface. Based on thermal conductivity, aluminum material was adopted to build a case for TE generator. Then the thermoelectric module with an aluminum case was installed on the surface of the concrete specimen, with or without the aluminum cover as shown in **Figure 3 (d)**. Two temperature signals (temperatures of upper TE module surface and lower TE module) are monitored through Dewesoft 7.0 and Dewasoft’s DS-NET data acquisition to collect voltage data of the TE module output. The experiment duration was about 5 hours. The goal was to install the thermoelectric module at the surface of barrier to utilize its high surface temperature.

**TEST RESULTS**

**Case 1: using cooling sink**

Figure 4 shows the test set up using a cooling sink. The experiment duration was five hours. As is shown in **Figure 4 (a)**, the TE module was placed on cooling sink (Type B) or on concrete surface (with cooling sink, Type A). The cooling sink was embedded into the concrete specimen in order to keep the same distance between the lamp and surface of the TE module. **Figure 4 (b)** plots the generated voltage verse time. From this figure, it can be seen that the produced voltage was significantly different as function of conditions, Type A and Type B. The slope first increase, reaches its highest value, and then slightly decreased from both Type A and Type B. After highest value, the generated output was decreased because of decreasing temperature variation between the top and bottom of the TE modulus. The lamp energy can be transmitted to the TE modulus.

There was a significant difference between Type A and Type B as shown in **Figure 4 (b)**. Type B with a cooling sink generated more voltage than Type A. Comparing Type A and Type B, Type B was 1.5 times higher than that of Type A. It indicated that a cooling sink generates more temperature difference between surface and bottom of the TE modulus. As the temperature gap increased, the energy production was higher as well.

**Case 2: Development of TE case**

The design and application of thermoelectric generators needs to be optimized for maximum efficiency. The geometric design needs to ensure there is a sufficient amount of heat flow that can be collected and converted, so that a relatively large thermal gap can be maintained. In this study, the research team designed the thermoelectric device case to improve efficiency as seen in **Figure 5**. **Figure 5 (a) and (b)** show the TE case’s photos and **Figure 5 (c) and (d)** describes detailed TE cases. The case is required to install on concrete barrier to prevent damage of TE modulus. As described in **Figure 5 (c) and (d)**, the geometry of the case was 5 cm height, 5 cm wide, and 5 cm in length made with an aluminate plate. **Figure 5 (b)** shows the voltage of the harvester from the TE modulus. As plotted at **Figure 5 (b)**, Case A represents the higher output voltage than that of Case B. The peak value of Case A is two times higher than that of Case B. As seen in **Figure 4 (b)**, the same trend was observed at **Figure 5 (b)**. The slope was dramatically increased to higher peak as time
passes by. Case A shows two times higher than that of Case B as described in Figure 5. It indicates that the cover made by aluminum should be directly contacted on surface of TE modulus. If there was a space between the cover and the TE modulus, the efficiency of the TE is decreased because of thermal conductivity.

CONCLUSION AND FUTURE RESEARCH WORKS

Harvesting energy in situ is near ideal for road facilities applications such as concrete barriers. This paper presented the implementation of a novel thermoelectric energy harvesting technology that harvest energy using the temperature difference between the surface and bottom of the thermoelectric module on road facilities. The conceptual framework for thermoelectric power generation from the thermal difference of road facilities is presented in this paper. The test set up performance was evaluated in simulated laboratory conditions. This study validated the feasibility of the TE concept as potential energy source for road facilities. The final destination of this study is to drive TE energy to improve road safety and to improve pavement service life in the future. Also, the optimum TE energy harvesting case will be developed in the future.

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REFERENCES


CHARACTERIZATION OF DEMOLITION MATERIAL AS UNBOUND PAVEMENT BASE LAYER

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ABSTRACT
The recycling of demolition material in pavement as a base or subbase layers can represent a sustainable alternative. This research evaluates the suitability of recycled concrete and bricks that blended with typical granular material. The blended material behavior was compared with typical granular base used in Egypt. For each aggregate source or blend of aggregate and recycled material, the specific gravity and absorption of the aggregate was measured. Los Angeles (LA) abrasion test was conducted to evaluate the resistance of the material to degradation. Standard Proctor test was conducted to find the optimum moisture content (OMC) and maximum dry density (MDD). The California Bearing Ratio (CBR) test was conducted on samples prepared at OMC and MDD as defined by standard Proctor test. CBR is an important property that is currently used to predict the layer resilient modulus in Egypt.

INTRODUCTION
The recycling of demolition material in pavement application can represent a sustainable alternative as they save natural resources and reduce the amount of material to be disposed in landfills. It is a common practice in many places in the world to use recycled bricks (RB) and recycled concrete (RC) in pavement applications (1-13). Petrarca and Galdiero investigated the use of RC on some local projects in New York and conducted more than 100 tests to evaluate the performance of RC as a base layer. It was found that crushed RC consistently met all requirements for excellent long-term performance as dense-graded aggregate base or subbase (3).

Chesner et al. reviewed the use of 19 waste and by-product materials reused in the highway construction. They reported that RC can be used in granular base, and embankment fill. The quality of recycled materials varied depending on source and blending RC with conventional aggregates was an option to meet strength requirements (4).

Research in United States provided a database that showed at least 36 states used reclaimed (recycled) concrete material in highway construction applications. At least eleven states allowed the use of RC mainly as an aggregate in granular base or subbase applications (5). The Illinois Department of Transportation allows the use of RC as a coarse aggregate in aggregate surface courses, granular embankments, stabilized bases, and subbase courses (6).

Bennert, and Maher evaluated the suitability of using RC as a base material in New Jersey. The testing of the recycled concrete, and their blends with the base material, showed that as the percentage RC increased in the blend CBR increased, resilient modulus increased, the blend’s permeability decreased and permanent deformation was reduced (7). Cooley et al. found that RC pavements are available as an option for the construction of gravel cushion and aggregate base course layers, and provided guidelines for using RC as a pavement base layer (8).

A recent research in Brazil showed that recycled construction and demolition waste had a resilient modulus similar to that obtained for a standard well-graded crushed stone (9).
RESEARCH OBJECTIVES

The reuse of recycled demolition materials as an aggregate in highway base construction has not received much attention up to now in Egypt and most of the demolished materials are still disposed off. The main objective of this research is to evaluate the suitability of using recycled concrete (RC) and recycled bricks (RB) resulted from demolished buildings as unbound pavement base or subbase layer. The recycled material behavior will be compared with typical granular base used in Egypt.

EXPERIMENTAL CONSIDERATIONS

This study compared the behavior of typical granular material used as a base layer to the behavior of recycled concrete (RC) and recycled bricks (RB) resulted from demolished buildings as an unbound pavement base layer. One source of aggregate, one source of RB and one source of RC were evaluated in this study. Blends of aggregate and the RC or RB were prepared. The recycled material content in the blend was either 40% or 60% of the total blended weight. Figure 1 describes the overall testing program showing all material and testing conditions that was used during this study.

For each aggregate source or blend the specific gravity and absorption of the aggregate was measured. Los Angeles abrasion (LA) test was conducted to evaluate the resistance of the material to degradation. Standard Proctor test was conducted to find the optimum moisture content (OMC) and maximum dry density (MDD). Samples were then prepared at OMC and MDD as defined by standard Proctor test. The California Bearing Ratio (CBR) for each of these samples was measured. CBR is an important property that is currently used to predict the layer resilient modulus in Egypt. Egyptian specification requires the material to possess a minimum CBR of 80 to be used as a base layer, and a minimum of 20 to be used as a subbase layer (14).

TESTING RESULTS AND ANALYSIS

Effect of Recycled Material on Gradation

Figure 2 presents the gradation for all evaluated materials. The results show that the recycled concrete had the least amount of fine particles; this caused the evaluated RC to be out of specification range used for typical base material in Egypt. Petrarca reported that the target gradation for RC materials does not have to be different than typical aggregates when the intended purpose is as an unbound granular pavement layer (8). The recycled brick had the lowest amount of coarse particles, reflecting breaking the material during the demolition process.

Effect of Recycled Material on Specific Gravity and Absorption

Figure 3 presents the specific gravity of all evaluated materials. It is clear that recycled bricks (RB) had much lower specific gravity compared to granular material and recycled concrete (RC). Figure 4 presents the absorption of all evaluated materials. Recycled brick had much higher absorption compared to the other evaluated material. Mixing the RB with granular material significantly reduced the absorption of the mix. It is not recommended to use material with high absorption capacity during pavement construction, as this reflects high air voids in the material matrix.

This was not expected for the RC because earlier research stated that RC differs from fresh aggregates due to the cement paste attached to the surface of the original crushed aggregates after the recycling process. The cement paste is highly porous and other contaminations cause lower particle density and higher porosity (2).
Effect of Recycled Material on Dry Density and Optimum Moisture Content

Standard Proctor test was used to find the MDD and OMC for all evaluated material. Figure 5 present the impact of using RC or RB on OMC and MDD. Recycled brick had the lowest MDD. Both recycled concrete and recycled brick had lower MDD and higher OMC compared to typical granular material. The low dry density was expected for the RB as it clearly has lower specific gravity, but it was not expected for the RC. The high OMC for RB may be attributed to the high absorption capacity and the fine gradation of the RB compared to the granular material and RC.
Effect of Recycled Material on Abrasion Resistance

Aggregates that are to be used as base-course for highway construction need to have high resistance to attrition due to truck loads and during the construction process (15). Los Angeles abrasion test was used in this study to evaluate the resistance-to-abrasion characteristics of aggregate and recycled material. The Egyptian specification requires the material to achieve loss of 50% or less in the LA test to be used as a base layer. The granular material and recycled concrete material achieved the required LA specification. It is clear that the recycled brick is too soft and would be subjected to degradation in field, as it produced a LA of 81%. Blending RB with the granular material improved its LA however, the mixture failed to achieve the required specification of 50%. This was not the case for RC as it had a LA value less than the specification limits, indicating good resistance of to degradation.
**Effect of Recycled Material on CBR**

CBR test is an important test that is currently used to define the material strength and resistance to deformation. CBR can be used to find the resilient modulus of a material, which is then used in pavement structural design. CBR is the main property current in use in Egyptian specifications to find the material strength, as advanced equipment needed to conduct resilient modulus test is not available.

CBR test results for all evaluated material are presented in Figure 7. Results shown in Figure 7 indicate that all evaluated material are not suitable as a base layer because the minimum accepted CBR for base layer in Egyptian specification is 80. Granular material had the highest CBR value. Recycled concrete had the lowest CBR with CBR of 45. Blending RC with granular material caused improvements in the CBR, however it did not result in the expected improving of the CBR. Recycled brick had a CBR of 60, and mixing RB with granular material improved its CBR significantly. Based on these CBR values, the RB and RC can be used as a pavement subbase layer.

**SUMMARY AND CONCLUSION**

The wide production of construction waste is a serious problem in Egypt, especially with the illegal disposal. The recycling of demolition material in pavement application as base or subbase layers can represent a sustainable alternative as they save natural resources and reduce the amount of materials to be disposed in landfills. However, the use of recycled demolition materials as an aggregate in highway base construction has not received much attention up to now.

This research aimed to evaluate the suitability of using recycled concrete and recycled bricks resulted from demolished buildings as unbound pavement base layer. The recycled material behavior was compared with typical granular base used in Egypt. The recycled material was blended with typical granular material and their behavior was evaluated.

For each aggregate source or blend of aggregate and recycled material, the specific gravity and absorption of the aggregate was measured. The LA abrasion test was conducted to evaluate the resistance of the material to degradation. Standard Proctor test was conducted to find the optimum moisture content and maximum dry density. The California bearing ratio test was conducted on samples prepared at OMC and MDD as defined by standard Proctor test. CBR is an important property that is currently used to predict the layer resilient modulus in Egypt.

The recycled brick had the lowest specific gravity followed by the recycled concrete followed by granular material. The recycled brick had the highest water absorption capacity followed by the recycled concrete followed by granular material. The recycled brick had the highest optimum moisture content and lowest maximum dry density followed by the recycled concrete followed by granular...
material. This was attributed to the high absorption capacity of the brick.

Granular material had the highest CBR value. Recycled concrete had the lowest CBR. Blending RC with granular material did not result in the expected improving of the CBR. Recycled brick had a CBR of 60, and mixing RB with granular material improved its CBR significantly.

Based on current testing results, recycled brick cannot be used a pavement base due to its low CBR and its low abrasion resistance. The recycled concrete cannot be used as a pavement base Layer due to its low CBR value. The recycled brick and recycled concrete can be used as a pavement subbase layer. Future research is expected to evaluate the effect of the demolition source and gradation on the recycled material properties.

REFERENCES
CO2 IMPACT OF TWO WHEELERS IN ASIAN COUNTRIES

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ABSTRACT
The National Institute of Land and Infrastructure Management (NILIM) in Japan and Institute of Road Engineering (IRE) in Indonesia have jointly studied the carbon dioxide (CO2) emissions impact of two wheelers in Asian countries. This paper shows the estimation of carbon dioxide emissions from road transport in Asian countries, taking into account the modal shift from two wheelers to four wheelers. In most Asian countries two wheelers are the most popular form of transportation. In Japan, Europe and the United States two wheelers are less common. Estimations predict that two wheel transport will be replaced by four wheel transport in Asian countries in the near future. Four wheelers prove to be safer than two wheelers while emitting more carbon dioxide at the same time.

INTRODUCTION
Most countries CO2 emissions are produced from the transport sector and account for approximately 10–30% of total emissions (International Road Federation 2010). Furthermore, road traffic is responsible for most CO2 emissions from the transport sector. While four wheelers account for the vast majority of road traffic modes in European countries, the United States and Japan, two wheelers account for the overwhelming share of road traffic in Asian countries other than Japan and South Korea (Figure 1). Although two wheelers pose a higher risk of traffic accidents than do four wheelers, they are also considered to deliver various advantages regarding the protection of the global environment and the handling of traffic congestion. Their specific advantages include less CO2 emissions, faster travel speeds on congested roadways and the impact on traffic capacity is greatly reduced (Japan Automobile Manufacturers Association Inc. 2009). Future expectations are that the overwhelming share accounted for by two wheelers will come to be occupied by four wheelers as these countries experience further economic growth. It is therefore possible that the overall global carbon dioxide emissions from road traffic may increase greatly.

The authors conducted a NILIM-IRE joint research effort to elucidate the advantages (i.e., global environmental load reduction effects) of road traffic composed of two wheelers; road traffic that is composed of two wheelers is friendly to the global environment. This paper shows the results, which is estimation of total CO2 emissions of road transport according to several scenarios of two wheelers ratios.
TRIAL CALCULATION CONDITIONS AND PROCEDURE

Indonesia was selected as the representative Asian country with widespread two wheeler ownership. Japan was selected as the representative country with scant two wheeler ownership. Road traffic modes of two wheelers and four wheelers were subjected to trial calculations. Buses and trucks were excluded from analysis. Figure 2 shows the trial calculation procedure. To conduct trial calculations of CO2 emissions and vehicle kilometers traveled per year the following formulae were used.

\[
\text{CO}_2 \text{ emissions} = (\text{emissions factor}) \times (\text{vehicle kilometers traveled per year}) \quad (1)
\]

\[
\text{Vehicle kilometers traveled per year} = (\text{mileage per vehicle per year}) \times (\text{number of vehicles owned}) \quad (2)
\]

Scenarios for the conversion of the road traffic mode from four wheelers to two wheelers are the scenarios, which are similar to traffic modes in Japan or Indonesia, the scenario which assumed that the ratio of two wheeler is the same as four wheeler, the scenario which assumed that the ratio of two wheeler is not the same as four wheeler (Table 1).
TABLE 1: Scenarios describing the conversion of the road traffic mode from four wheelers to two wheelers

<table>
<thead>
<tr>
<th>Scenario</th>
<th>4 wheelers</th>
<th>2 wheelers</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>100%</td>
<td>0%</td>
<td>Close to the road traffic mode in Japan</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>80%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Scenario 3</td>
<td>50%</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Scenario 4</td>
<td>20%</td>
<td>80%</td>
<td>Close to the road traffic mode in Indonesia</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>0%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

TRIAL CALCULATION

**Number of vehicles owned**

Four wheelers account for more than 90% of vehicular ownership in Japan, indicating that the two wheelers ownership rate is extremely small. By contrast two wheelers account for more than 60% of the number of vehicles owned in Indonesia. Thus the two wheeler ownership rate in Indonesia is comparable to that in other Asian countries (Figure 3). The numbers of vehicles owned in the above five scenarios are shown in Figure 4.

**Mileage per vehicle per year**

Mileage per vehicle per year was calculated by dividing the vehicle kilometers traveled per year by the number of vehicles owned. Because vehicle kilometers traveled in Indonesia are unknown, the average value for Asian countries was assumed. It was supposed that the mileage per vehicle per year, before conversion, would continue even with changes in the types of vehicle owned (Figure 5). The vehicle kilometers traveled per year in the scenarios is shown in Figure 6.
Changes in traveling speed resulting from the conversion of the road traffic modes

With the conversion from four wheelers to two wheelers, the road space originally occupied by four wheelers is replaced by that occupied by two wheelers; thus the road occupation area of the vehicles decreases. Consequently, it was expected that average travel speeds would increase because the traffic jam of the road decreased. By contrast, it was expected that average travel speeds would decrease when four wheelers replaced two wheelers. Therefore, trial calculations were conducted in regard to changes in travel speeds based on the conversion of the road traffic mode as follows (Table 2):

- Because travel speed data in Indonesia were unavailable, traffic volume survey data from the 2010 Road Traffic Census in Japan was used.
- By classifying travel speeds into six ranks of 10-km/h units, percentages of vehicle kilometers traveled in each rank were calculated based on 2010 Road Traffic Census data.
- Sections where average travel speeds close to the representative value of each rank (8, 20, 35, 45, or 55 km/h) were extracted from the 2010 Road Traffic Census data.
- The two wheeler ownership rate in Japan is closest to Scenario 1. Therefore, the average travel speed extracted in iii) was used as the average travel speed in Scenario 1.
- Based on road traffic theory (Japan Road Association 1984) in Japan, simulations were conducted on the sections to calculate changes in travel speed with the conversion of road traffic mode from four wheelers to two wheelers. However, it was supposed that for the rank 60 km/h and higher, no change in speeds would result from the conversion of the road traffic mode.
Based on the relationship between four wheeler travel speeds and CO2 emissions, CO2 emissions corresponding to average travel speeds for four wheelers following conversion of the road traffic mode were first calculated. Subsequently, by taking the weighted average of CO2 emissions factors based on the vehicle kilometers traveled ratio in the Road Traffic Census, CO2 emissions factors for four wheelers were obtained (Figure 7 and Table 3).

Regarding two wheelers, CO2 emissions corresponding to average travel speeds were first calculated based on the relationship between two wheeler travel speeds and CO2 emissions. Subsequently, by taking the weighted average of CO2 emissions factors based on the vehicle kilometers traveled ratio in the Road Traffic Census, CO2 emissions factors for two wheelers were obtained (Figure 8 and Table 4).

**TABLE 2: Results of trial calculations on average travel speeds following the conversion of the road traffic mode**

<table>
<thead>
<tr>
<th>Current travel speed class (km/h)</th>
<th>Average travel speeds following conversion of the road traffic mode (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1</td>
</tr>
<tr>
<td>2 wheelers 0%</td>
<td>8.9</td>
</tr>
<tr>
<td>2 wheelers 20%</td>
<td>18.5</td>
</tr>
<tr>
<td>2 wheelers 50%</td>
<td>32.7</td>
</tr>
<tr>
<td>2 wheelers 80%</td>
<td>47.3</td>
</tr>
<tr>
<td>2 wheelers 100%</td>
<td>50.1</td>
</tr>
</tbody>
</table>

**CO2 emissions factors by vehicle type**

<table>
<thead>
<tr>
<th>Current travel speed class (km/h)</th>
<th>Vehicle kilometers traveled ratio (%)</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
<th>Scenario 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average travel speed (km/h)</td>
<td>CO2 emissions factor (gCO2/km)</td>
<td>Average travel speed (km/h)</td>
<td>CO2 emissions factor (gCO2/km)</td>
<td>Average travel speed (km/h)</td>
<td>CO2 emissions factor (gCO2/km)</td>
</tr>
<tr>
<td>0 - 10</td>
<td>0.1</td>
<td>8.9</td>
<td>373.9</td>
<td>15.6</td>
<td>253.6</td>
<td>22.1</td>
</tr>
<tr>
<td>10 - 30</td>
<td>25.5</td>
<td>18.4</td>
<td>232.8</td>
<td>20.2</td>
<td>220.0</td>
<td>23.3</td>
</tr>
<tr>
<td>30 - 40</td>
<td>21.9</td>
<td>32.7</td>
<td>169.4</td>
<td>38.2</td>
<td>156.0</td>
<td>39.2</td>
</tr>
<tr>
<td>40 - 50</td>
<td>20.7</td>
<td>47.3</td>
<td>141.8</td>
<td>48.0</td>
<td>140.8</td>
<td>49.2</td>
</tr>
<tr>
<td>50 - 60</td>
<td>11.7</td>
<td>50.1</td>
<td>137.9</td>
<td>50.7</td>
<td>137.4</td>
<td>51.6</td>
</tr>
<tr>
<td>60 -</td>
<td>20.0</td>
<td>60.0</td>
<td>130.0</td>
<td>60.0</td>
<td>130.0</td>
<td>60.0</td>
</tr>
</tbody>
</table>

**TABLE 3: CO2 emissions factors for four wheelers in the various scenarios**

**FIGURE 7: Relationship between average travel speeds for four wheelers (passenger vehicles) and CO2 emissions (National Institute for Land and Infrastructure Management 2003)**
RESULTS OF TRIAL CALCULATION

Baseline CO2 emissions

Baseline CO2 emissions were calculated by multiplying the CO2 emissions factors in the various scenarios, which are shown in Tables 3 and 4, by the vehicle kilometers traveled per year in the various scenarios, which are shown in Figures 6. The CO2 emission factor for the scenario closest to the number of vehicles in each country was used as the baseline CO2 emission factor. For Indonesia, Scenario 4 was closest, and for Japan, Scenario 1 was closest.

CO2 emissions with the conversion from four wheelers to two wheelers

In Indonesia, the CO2 reduction resulting from the conversion from four wheelers to two wheelers was calculated to be approximately 21 million tons by using the baseline as the reference. Meanwhile, the CO2 increase caused by the conversion from two wheelers to four wheelers was calculated to be approximately 46 million tons. In countries that have higher ownership rates of two wheelers compared with four wheelers, it is expected that the conversion from two wheelers to four wheelers lead to a dramatic increase in CO2 emissions, whereas the CO2 reduction effect resulting from the conversion from four wheelers to two wheelers is small (see Figure 9).

In Japan, the CO2 reduction resulting from the conversion from four wheelers to two wheelers was calculated to be approximately 66 million tons by using the baseline as the reference. Meanwhile, the CO2 increase caused by the conversion from two wheelers to four wheelers was calculated to be approximately 1 million tons. In countries that have higher ownership rates of four wheelers compared with two wheelers, it is expected that the conversion from four wheelers to two wheelers lead to a dramatic reduction in CO2 emissions, although the increase in CO2 emissions resulting from the conversion from two wheelers to four wheelers is small (Figure 9). However, the possibility of the conversion to two wheelers ownership in countries that

<table>
<thead>
<tr>
<th>Current travel speed class (km/h)</th>
<th>Vehicle kilometers traveled ratio (%)</th>
<th>Scenario 1 Average travel speed (km/h)</th>
<th>Emissions factor (gCO₂/km)</th>
<th>Scenario 2 Average travel speed (km/h)</th>
<th>Emissions factor (gCO₂/km)</th>
<th>Scenario 3 Average travel speed (km/h)</th>
<th>Emissions factor (gCO₂/km)</th>
<th>Scenario 4 Average travel speed (km/h)</th>
<th>Emissions factor (gCO₂/km)</th>
<th>Scenario 5 Average travel speed (km/h)</th>
<th>Emissions factor (gCO₂/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10</td>
<td>0.1</td>
<td>8.9</td>
<td>109.2</td>
<td>15.6</td>
<td>64.3</td>
<td>22.1</td>
<td>52.1</td>
<td>26.9</td>
<td>47.6</td>
<td>30.1</td>
<td>49.3</td>
</tr>
<tr>
<td>10 - 30</td>
<td>25.5</td>
<td>18.4</td>
<td>56.0</td>
<td>20.2</td>
<td>55.7</td>
<td>23.3</td>
<td>50.7</td>
<td>26.7</td>
<td>47.8</td>
<td>29.0</td>
<td>46.1</td>
</tr>
<tr>
<td>30 - 40</td>
<td>21.9</td>
<td>32.7</td>
<td>42.5</td>
<td>38.2</td>
<td>42.7</td>
<td>39.2</td>
<td>42.2</td>
<td>40.2</td>
<td>41.6</td>
<td>40.9</td>
<td>42.1</td>
</tr>
<tr>
<td>40 - 50</td>
<td>20.7</td>
<td>47.3</td>
<td>38.7</td>
<td>48.0</td>
<td>38.2</td>
<td>49.2</td>
<td>37.8</td>
<td>50.3</td>
<td>37.4</td>
<td>51.1</td>
<td>37.1</td>
</tr>
<tr>
<td>50 - 60</td>
<td>11.7</td>
<td>50.1</td>
<td>36.5</td>
<td>50.7</td>
<td>37.2</td>
<td>51.6</td>
<td>36.9</td>
<td>52.5</td>
<td>36.5</td>
<td>53.1</td>
<td>36.4</td>
</tr>
<tr>
<td>60 -</td>
<td>20.0</td>
<td>60.0</td>
<td>34.9</td>
<td>60.0</td>
<td>34.9</td>
<td>60.0</td>
<td>34.9</td>
<td>60.0</td>
<td>34.9</td>
<td>60.0</td>
<td>34.9</td>
</tr>
<tr>
<td>Weighted average</td>
<td>-</td>
<td>43.0</td>
<td>-</td>
<td>42.9</td>
<td>-</td>
<td>41.4</td>
<td>-</td>
<td>40.4</td>
<td>-</td>
<td>39.8</td>
<td>-</td>
</tr>
</tbody>
</table>
have higher ownership rates of four wheelers compared with two wheelers is low; thus, it is considered that conversion to next generation four wheelers will be more effective in CO2 reduction in these countries.

**FIGURE 9: Results of trial calculations**

CONCLUSION

In this study, trial calculations were conducted on CO2 emissions with the conversion of road traffic modes from four wheelers to two wheelers in Asia in order to verify that two wheelers have advantages over four wheelers in road traffic and that road traffic composed of two wheelers is friendly to the global environment. The findings from the results of these trial calculations are summarized below:

- In countries that have higher ownership rates of two wheelers compared with four wheelers, it is expected that the conversion from two wheelers to four wheelers leads to a dramatic increase in CO2 emissions, whereas the CO2 reduction effect resulting from the conversion from four wheelers to two wheelers is small.

- In countries that have higher ownership rates of four wheelers compared with two wheelers, it is expected that the conversion from four wheelers to two wheelers lead to a dramatic reduction in CO2 emissions, although the increase in CO2 emissions resulting from the conversion from two wheelers to four wheelers is small. However, the possibility of the conversion to two wheelers ownership in countries that have higher ownership rates of four wheelers compared with two wheelers is low; thus, it is considered that conversion to next generation four wheelers will be more effective in CO2 reduction in these countries.

It is indicated that road traffic composed of two wheelers is friendly to the global environment. However, two wheelers are not suited to inner city transportation such as logistics, though they are suited to relatively short trips such as commuting within a city. Therefore, it is necessary to examine for what kinds of trip the conversion from two wheelers to four wheelers should be controlled. Because two wheelers pose a higher risk of traffic accidents than do four wheelers, it is necessary to examine road safety measures, which are done in Indonesia now, and two wheeler safety measures will be able to contribute CO2 reduction in the future.
REFERENCES

1. Japan Automobile Manufacturers Association Inc. (2009). Environmental design using motorcycles -toward social efficient transportation, Tokyo

2. International Road Federation. (2010). World Road Statistics 2010


8. National Institute for Land and Infrastructure Management. (2003). Calculation of emission factor of CO2, NOx and SPM to use for the calculation of the quantitative index, Tsukuba

HIGHWAY ENVIRONMENTAL POLLUTION INDEX (HEPI)

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ABSTRACT
Controlling air pollution during the project planning stage is more cost effective than establishing control mechanisms during project execution. This paper presents a model to estimate pollution resulting from highway construction. This model focuses on emissions resulting from flexible pavement roads construction projects. These emissions are divided into four main categories: dust, gases, noise, and waste removal. The proposed environmental model is utilized as an assessment tool for emissions associated with highway construction projects. The environmental model is developed to calculate the value of pollutants associated with each activity in highway construction projects, especially flexible pavement roads. The model calculates the accumulated amount of pollution emitted during a projects construction phase. This model is defined as Highway Environmental Pollution Index (HEPI).

INTRODUCTION
Air pollution has been and continues to be viewed as a serious problem that affects human health and welfare. Improvements in environmental quality reduce the magnitude of these adverse effects (1). Investigation of the quantitative significance of these effects is an integral part of the formulation and implementation of environmental policies that aim at improving quality of life. Construction industry poses a major potential threat to the environment. One reason for the lack of progress in improving environmental performance in construction is the perception that pollution generated from construction activities incidents has little impact. This is mainly due to the shortage of the effective pollution assessment tools.

The construction industry has various impacts on the environment. Highway construction is considered a large sector of the construction industry. It represents 50.46%, and flexible pavement roads represent 23.75% from construction industry in Egypt during the last decade according to Egyptian Central Agency for Public Mobilization and Statistics records (2). This paper focuses on emissions resulting from flexible pavement road construction projects. The proposed environmental model aims at estimating the amount of pollution generated from construction activities. This model mitigates construction pollution by calculating the pollutants released from each project activity, further it calculates the overall project pollution index. Integrated environment protection at the project planning stage ensures that measures to avoid and minimize pollution can be built into the project design and work schedule. To minimize the pollutants generated, construction engineers and planners need to analyze and optimize their resource utilization decisions and selections. For each activity in the project, these decisions include: a) selecting construction methods and raw materials, and b) identifying equipments and labors crews’ configurations and size. For example, using more
productive equipment or hiring more workers may save time, but it often increases air pollution. Similarly, other resource utilization decisions have a direct impact on project pollution index. The Environmental Management Systems (EMS) are intended to formalize procedures for managing and reducing environmental impacts (3).

Considerable research efforts have been made in the context of environmental issues. However, most of these studies discussed challenges from a qualitative point of view while others calculate the emissions of pollutant separately. Chen et al. 2000 proposed an approach for quantitative assessment during the planning phase; this approach is based on the calculation of a “Pollution Index” for each of the construction activities. The index is simply a multiplication of the impact magnitude by the duration of the activity (4). Soderman 2006 discussed the environmental management in the construction industry. The study concluded that the quantitative risk analysis provides an assessment of environmental safety, the link between quantitative risk analysis and environmental management is crucial for minimizing environmental impact (5). Madany 2009 proposed a quantitative tool based on calculating the amount of air pollution generated from construction activities. Total pollution is calculated by normalizing the amount of dust, harmful gases, and noise emissions can be summed, adopting multi-attribute utility theory (MAUT) (1).

ESTIMATING HIGHWAY CONSTRUCTION POLUTION INDEX

This model is dedicated to assess the pollution generated from flexible pavement road activities. Figure 1 illustrates the procedures followed to calculate the Highway Environmental Pollution Index (HEPI). The proposed environmental model is divided into four sub-modules; dust, gases, noise, and waste removal. The waste removal is neglected in calculating the HEPI because: a) the amount of waste released from flexible pavement road projects is negligible compared with building, industrial, and utilities projects, and b) the recycling of demolition material in pavement application as base or sub base layers can represent a sustainable alternative as they save natural resources and reduce the amount of materials to be disposed in landfills. These procedures are summarized as follows:

- Literature has been reviewed for air pollution related issues through different sources, especially the United States Environmental Protection Agency
- Quantifying the amount of pollutant emissions generated from each highway construction activities. These pollutant emissions should be measured according to the previously identified sub-modules
- Calculating the Relative Danger Weight (RDW) for each pollutant according to the maximum threshold limit of pollutant based on environmental regulations applied in Egypt, especially Law No. 4 (1994)
- Calculating the HEPI
- Formulating the developed model into prototype software to facilitate its use

![Figure 1: Highway Environmental Pollution Index “HEPI” Methodology](image)

**Estimating Dust Sub-Module**

Dust arises from mechanical disturbance of granular material exposed to the air. It is termed fugitive because it isn’t discharged to the atmosphere in confined flow stream (6). In highway construction sites, the common sources of fugitive dust are; ground excavation, drilling, land clearing, cut and fill, and construction operations. In order to estimate the quantity of dust emitted from certain activity, the activity should be broken down into component operations. As such, all the possible sources of fugitive dust will be considered. The main sources of fugitive dust in highway construction are: a) grading (7), b) bulldozing (7), c) materials handling (8), and d) traffic on paved and unpaved roads (9). Figure 2 shows the flowchart for dust sources and factors affecting each one.
**Estimating Gas Sub-Module**

Construction vehicles and plant machinery are the main sources of harmful gaseous emissions. Most of the pollutants from combustion engines are emitted through the exhaust. The most major primary pollutants emitted from combustion engines are: a) Carbon monoxide (CO), b) Total organic carbon (TOC), c) Oxides of nitrogen (NOX), d) Oxides of sulfur (SOX), e) Particulate matter less than 10µm in aerodynamic diameter (PM10), and f) Other pollutants are also emitted in trace amounts as products of incomplete combustion, these pollutants are neglected in this study due to their low effects on health. There are two methods used in estimating the amount of gas emissions. These methods are emission factor method and material balance method. In this research, the material balance method isn’t be used due to its difficulty in application (9). Emission factor method is used to estimate pollutant emissions from construction equipment. There are three ways shown in Figure 3 to calculate gas pollutant emissions according to available data, these ways are: fuel consumption, engine power, and distance traveled (10).

**TABLE 1: Emission Factor from Typical HMA Facility (kg/ton)**

<table>
<thead>
<tr>
<th>Pollutant (i)</th>
<th>Batch Mix Oil Fired</th>
<th>Gas Fired</th>
<th>Drum Mix Oil Fired</th>
<th>Gas Fired</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.0485</td>
<td>0.0485</td>
<td>0.0703</td>
<td>0.0703</td>
</tr>
<tr>
<td>TOC</td>
<td>0.0068</td>
<td>0.0068</td>
<td>0.0227</td>
<td>0.0227</td>
</tr>
<tr>
<td>SOx</td>
<td>0.1860</td>
<td>0.1860</td>
<td>0.0635</td>
<td>0.0635</td>
</tr>
<tr>
<td>NOx</td>
<td>0.3992</td>
<td>0.0022</td>
<td>0.0056</td>
<td>0.0016</td>
</tr>
<tr>
<td>PM</td>
<td>0.0562</td>
<td>0.0132</td>
<td>0.0272</td>
<td>0.0132</td>
</tr>
</tbody>
</table>

**Estimating Noise Sub-Module**

The main source of noise in highway construction projects is construction equipment. Extensive noise studies have been carried out by different agencies such as the Federal Highway Administration (12) and the Environmental Protection Agency (13). Noise is measured with a sound level meter and usually in terms of Decibels (dB). The potential noise effects of the project on adjacent areas can be separated into short term and long term impacts. Short term impacts would result from noise generated by equipment during the construction phase. Long term impacts would be associated with future project related traffic noise. In this study only short term impacts were considered.
Construction noise represents a short-term impact on ambient noise levels on and around the sites over the entire period of project construction. Noise generated by construction equipment, including earthmovers, material handlers; and… etc. can reach high levels. Table 2 lists noise levels generated by typical construction equipment at a distance of 50 feet and the suggested sound levels for analysis according to Federal Transit Administration (14-15). When two or more pieces of construction equipment are producing sound simultaneously, the total sound level isn’t the summation of sound produced from each equipment. Because Decibels are geometric values, they can’t be added or multiplied directly, they must first be converted to energy units. In order to calculate the total sound level, first decibels are converted to arithmetic value, which are in turn averaged and converted back to decible value. This can be accomplished by calculating the equivalent sound level (Leq) from Equation (1) (16).

\[
Leq = 10 \log \left( \frac{\sum_{i=1}^{N} 10^{\frac{L_i}{10}}}{N} \right)
\]

Where;

\(L_{eq}\): Equivalent sound level.
\(L_i\): Sound level for source \(i\).
\(N\): Total number of sources.

<table>
<thead>
<tr>
<th>Type of Equipment</th>
<th>Noise Level (dB) at work site</th>
<th>Ranges of sound level</th>
<th>Suggested sound level for analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Roller</td>
<td>74-86</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>Pneumatic Roller</td>
<td>78-88</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Asphalt Paver</td>
<td>84-94</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>Dozer</td>
<td>85-92</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Front-end Loader</td>
<td>86-90</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>Hydraulic Backhoes</td>
<td>81-90</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Hydraulic Excavator</td>
<td>81-90</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Grader</td>
<td>79-89</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Trucks</td>
<td>81-92</td>
<td>88</td>
<td></td>
</tr>
<tr>
<td>Tractors</td>
<td>77-82</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Scraper</td>
<td>85-95</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>HMA Plants</td>
<td>84-96</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>Concrete Mixer</td>
<td>75-88</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Concrete Pump</td>
<td>78-85</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>Concrete Vibrator</td>
<td>74-78</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Air Compressor</td>
<td>76-86</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td>68-80</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Cranes</td>
<td>70-84</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>Saws</td>
<td>80-98</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Pile Driver</td>
<td>81-96</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>Rock Drill</td>
<td>83-99</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>Jack Hammer</td>
<td>75 - 85</td>
<td>82</td>
<td></td>
</tr>
</tbody>
</table>

**HIGHWAY ENVIRONMENTAL POLLUTION INDEX**

The Highway Environmental Pollution Index model is developed to calculate the amount of air pollution generated from each activity in flexible pavement road project. Further, it calculates the overall pollution of project. The HEPI consists of three main components; dust, harmful gas, and noise. The model is able to calculate the impact of these main categories for each activity. The pollutants generated from dust and gas are in the same unit, this unit is kilograms as described previously. Table 3 shows the maximum threshold limit of pollutant according to environmental regulations applied in Egypt, especially Law No. 4 (1994) (17). It is noticeable that the Egyptian standards describe the concentration of pollutants units in weight per volume. In addition, it is obvious that the emission values resulted from pollution module are in rate units (i.e. weight per time units). Therefore the pollution module values can not be compared with the standards. The pollutant which has minimum threshold limit is danger than the higher one. Thus, the maximum threshold limit is considered danger or a fatal pollution limit.

The maximum threshold limit is considered danger or a fatal pollution limit. It is noticeable that the emission values resulted from pollution module are in rate units (i.e. weight per time units). In addition, it is obvious that the Egyptian standards describe the concentration of pollutants units in weight per volume. Therefore the pollutant emission values can not be compared with the standards because their units are different. After reading the environmental regulations Law No. 4 (1994) applied in Egypt, its noticed that one cubic meter of air contains in maximum limits 150 µg from NO2 and 10 mg (10000 µg) from dust. This means, the dangers occur due to generation of one gram from NO2 is greater than the dangers occur due to generation of one gram from dust. So, the pollutant which has minimum threshold limit is danger than the higher one.

The Danger Weight (DW) for each pollutant is described as the reverse of its Maximum threshold Limit (ML) of this pollutant as shown in Equation (2). As the gas and dust emissions are measured in one index. So, the Relative Danger Weight (RDW) for each gas and dust pollutant emissions is calculated relative to the remaining pollutant as shown in Equation 3. The RDW for gas and dust emissions were calculated together as their concentration of pollutants have the same dimensions units in weight per volume (µg/m3) but noise emission is separated because its dimension unit (dB) is different from gas and dust emissions. The calculation of DW and RDW for each pollutant is illustrated in Table 3 as a first step to calculate HEPI.
\[ DW_e = \frac{1}{ML_e} \]

\[ RDW_e = \frac{DW_e}{\sum_{e=1}^{g} DW_e} \]

Where;
ML_e: Maximum threshold Limit of pollutant emission (e).
DW_e: Danger Weight for pollutant emission (e).

**TABLE 3: Maximum Threshold Limits According to Egyptian Standards and RDW for Each Pollutant (i)**

<table>
<thead>
<tr>
<th>Pollutant (i)</th>
<th>Harmful Gases</th>
<th>Dust</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO</td>
<td>NO2</td>
<td>PM10</td>
</tr>
<tr>
<td>Maximum Limits</td>
<td>10</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Units</td>
<td>mg/m3</td>
<td>µg/m3</td>
<td>µg/m3</td>
</tr>
<tr>
<td>Maximum Limits (ML)</td>
<td>10000 (µg/m3)</td>
<td>150 (µg/m3)</td>
<td>150 (µg/m3)</td>
</tr>
<tr>
<td>Danger Weight (DW) (DW=1/ML)</td>
<td>0.0001</td>
<td>0.0067</td>
<td>0.0067</td>
</tr>
<tr>
<td>Relative Danger Weight (RDW) (RDW= DW/\sum_{i=1}^{g} DW_i)</td>
<td>0.0041</td>
<td>0.2716</td>
<td>0.2716</td>
</tr>
<tr>
<td>RDW_i = \frac{L_{eq}}{80}</td>
<td>1.0400</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The HEPI is calculated in two measures as shown in Equation 4. The first term, calculates the dust and gases index and the second term calculate the noise index. The dust and the gases index is in kilograms and the noise index is dimensionless. The HEPI is calculated by multiplying the sum of the dust and the gases indices by the noise index. The HEPI is an index quantifying the pollution generated from each resource utilization plan in kilograms to select an optimal one. The construction method which has minimum HEPI is the most sustainable and optimal method

\[ HEPI = \sum_{i=1}^{g} \left[ RDW_d (E_{dust}) + \sum_{g=1}^{g} RDW_g (E_{gas}) \times \left( \frac{L_{eq}}{80} \right) \right] \] (4.13)

Where;
HEPI: Highway Environmental Pollution Index for project activities (I) in kilograms.
RDW_d: Relative danger weight for dust.

**IMPLEMENTATION OF THE PROPOSED HEPI MODEL**

The developed HEPI model is coded and implemented using Microsoft Visual Basic 6.0. Friendly user interface are designed to facilitate entering data, sorting data, calculating the HEPI, and generating output reports. Therefore, the user enters each activity involved in the project. The user starts by defining the activity and specifying their description. In addition, the user can add or remove activities. This interface is called activity user interface. The resources such as equipment and materials required for each activity can be added or removed from “Edit” button. The gas, dust, and noise emissions are defined for each resource which required for an activity. After entering the parameter required for each emission the results will appear in the activity user interface automatically.

**SUMMARY AND CONCLUSIONS**

Air pollution has been and continues to be viewed as a serious problem that affects human health. This paper presented a pollution module that aims at assessing the air pollution generated from highway construction projects during the planning and execution phases. Emissions resulting from highway construction projects can be divided into three main categories: dust, harmful gases, and noise. The Highway Environmental Pollution Index accounts for the three main categories by calculating their impacts individually. Further it calculates the overall project pollution index. Microsoft Visual Basic 6.0 is used to facilitate data entry and to perform interim calculations of the designed HEPI. Highway construction authorities and environmental bodies can utilize this research to assure that the total pollution of highway construction projects is within the permissible threshold. Also, construction contractors can utilize the model to follow the environmental regulations.
REFERENCES


Environmental impact assessment has become one of the most important aspects involved in corridor selection and road design processes. As part of environmental impact, visual impact assessment has to be taken into account, which has been done mostly in a qualitative way and so far it has been related to landscape fragility and vulnerability. Some methodologies, such as the United States Federal Highway Administration's (FHWA) Visual Impact Assessment (VIA), have introduced the evaluation of visual changes into the visual impact assessment task, improving the visual quality for both of nearby road observers and road users. VIA works at different scales and allows project monitoring at different phases. It combines geospatial data with information obtained from visual analysis with aesthetic criteria. The tool greatly facilitates the information management, reducing the cost and standardizing the results, making them more quantitative, repeatable and expert independent.

INTRODUCTION

Nowadays the development of transport infrastructures such as roads and railways raises various issues in their relationship to the landscape that affects their design, management and evaluation, both quantitatively and...
qualitatively. These infrastructures are part of the landscape, both to be contemplated and to enable new insights and experiences, such as journeys themselves in vehicles and trains or even shaping the landscape character. Currently, it is assumed that an environmental impact assessment is needed to predict and control the effects that the creation or modification of an infrastructure can impart upon the environment and the landscape character. The visual impact assessment, despite being one of the aspects to be evaluated in the environmental impact assessment, does not have a clear and precise methodology for being carried out. Certainly, there are laws protecting the natural environment, but aesthetic and visual issues are not factored into the assessment.

In the 9th Workshop of the Council of Europe for the implementation of the Landscape European Convention (1) there was a clear need for improvement, both in project drafting and management. Andalusian government, funder of this project, joined this convention as responsible administration. Previous works, such as the catalogue of scenic roads of Andalusia, and various practices in completed projects, for example (2), delve into this line and provide new perspectives in project definition and management.

Nowadays, visual impact assessment is not generally developed, and when it is, it is with a strong subjective component. One of our main objectives is to develop a methodology that will lead to an ontology for visual impact assessment. Simply put, landscape assessment will take into account geographical criteria (viewshed, landscape units, affected population, cultural singularities, etc.), whose information is obtained from geographic information systems (GIS) available in Andalusia, and aesthetic criteria (visual elements, visual patterns, visual quality, etc.) from photographs and 3D simulations analysis inspired by the VIA methodology (3).

In Europe, there are different methodologies for visual impact analysis (4,5,6,7), but none of them offers clear and precise criteria to be automatically implanted. The Landscape Character Assessment (LCA) methodology (4) is being developed in England and Scotland through practical experience, integrating different points of view of the landscape analysis and its conservation. It is well established in both two agencies, the Scottish Natural Heritage and The Countryside Agency. The methodology is rather procedural and it is structured in various stages with continuous feedbacks. The way it is applied depends on the particular case, which makes it very flexible and easy to adapt to any environment. That is why the Center for Landscape and Territory belonging to the Regional government of Andalusia uses this methodology (8). However it does not include very specific descriptions on what to study and how, that is, it works as a guide for structuring information but the specific elements are not developed in detail. Therefore, it is not feasible from this perspective to develop the ontology to automate some of the processes. Moreover, this methodology is developed to characterize landscape units, not to deal with the relationship between landscape and infrastructure.

The two main components of the LVIA are: landscape effects assessment, which deals with changes in the landscape as a resource and visual effects assessment, which identifies individuals and population groups that may be particularly affected by changes in the landscape. In this sense, the methodology is divided into several very specific phases related to identify the effects and propose mitigation measures thereof. The underlying approach is that the effects (changes in the landscape) are “negative” and need to be mitigated; therefore, it has a spirit of correction rather than improvement. This line, which is inherited from the EIA, is a protectionist perspective on the landscape.

SYSTEM OVERVIEW

The system details, such as design and used technologies are described in this section. Because the final aim is to develop a highly scalable and usable system, a distributed Service Oriented Architecture has been chosen to implement the system. This architecture allows splitting the functionality in various independent Web Services, improving its scalability, interoperability and computation capacity.

The system has to support three main (distributed) functionalities: Cartographic operations, Geospatial Processing and intelligent behaviour to automate some of the processes and to guide users according to their particular user profile. Figure 1 shows the main components of the system, which are accessible independently. A Knowledge Driven System has been chosen due to the large amount of different domains involved in the VIA process. Using Semantic technologies the system able to relate concepts from many different domains, such as topography, hydrology, infrastructures, etc. To keep the distributed design, the Knowledge module is what we have called the Web Ontology Service (WOS).

Geographic processing

Open Geospatial Consortium’s (OGC) (11) OWS standards are a great mean to generate and share geographic information sources, both mapping information and algorithmic processes. We use Web Map Service (WMS) (12) and Web Feature Service (WFS) (13) interfaces to store and deliver cartographic resources, which can be consumed for visualization purposes or as data input for geographic processes. We chose Geosolution GeoServer
for its wide adoption, Open Source implementation and active development.

The Web Processing Service (WPS) (14) standard interface provides rules for standardizing both inputs and outputs for geospatial processing services. This standard allows specifying how a client can make requests and how the output would be handled. The core component of the geospatial calculations in the assessment process is the geospatial data interpretation and it is exposed as a WPS process, specifying the set of input data layers and output options. The chosen WPS implementation is 52North WPS (15) for its Open Source implementation, GRASS GIS (16) and Sextante integration and its flexible custom process framework, which simplifies the implementation and integration of our algorithms with the server.

**System Web Service**

The whole system is designed as a Web Service, decoupling the computation needs from the visualization. This service exposes implemented operations simplifying and gathering the various needed requests (WMS, WPS and WOS) into one request. Because nowadays is easy to acquire mobile devices with localization capabilities, this approach is especially suitable for fieldwork tasks which need to collect geospatial data. It is possible to develop mobile client applications to obtain the information at the place and upload to the system in real time, saving the time spent in information collecting and office work to update the system.

**Web Ontology Service**

As said before, there are many different domains involved in the VIA process. Many algorithms need to relate concepts as “road” with others like “tree coverture”. Due to the large amount of concepts, explicit and hidden relations between them, the best approach is to build an ontological Knowledge Model.

At this time, there are 5 ontologies developed or reused from other works like GeoLinkedData (17): methology, covertures, fragility, hydrology and infrastructures. These ontologies are implemented in OWL (18) ontology language. Figure 2 shows a relational diagram of an excerpt from the methodology ontology. Boxes in purple indicate concepts inherited from other ontology sources.

Instead of using “data oriented” standards, such as a SPARQL (19) endpoint, we have encapsulated extensible specific queries and reasoning processes as a service, i.e. Web Ontology Service (WO). The advantage is twofold: 1) maintaining the distributed nature of the system and 2) exposing the ontology and reasoner to any other system. This way there is no need to “hardcode” queries inside our processes, but just make requests for this service.

**Client Web Application**

Since the system distributes the processing, it is possible to build lightweight clients, which exploits the services. To illustrate the system we are developing a Web Client Application using Rich Internet Application (RIA) technologies to assure a good user experience and easy interaction with the tool.

The Graphical User Interface is being designed and developed using Vaadin Framework (20). This library allows designing very complete Web UIs without the need of AJAX programming, which have reduced the development time greatly. For the map and cartographic displaying we have used Openlayers (21) javascript library.

Using these technologies, we have built a friendly and powerful client application, avoiding the need for a heavy desktop Geographic Information Systems (GIS) application.

**CASE STUDY**

One of the developed case studies has addressed the analysis of an in-service infrastructure. The purpose of
this analysis was to carry out an improvement proposal and assessing its resulting visual impact. Figure 3 shows an example of the application interface in a stage of Visual Impact Assessment at a particular point of view. It consists of a header with the main menu of the application and a body that shows useful information from the active section. During the Visual Impact Assessment, the application body is divided into three columns. In the first column we have access to different project views and their respective points of view, thus having an overview and a quick access menu. Once you select a particular point of view, the second column shows the photograph or photographs taken from that point. Together with them, we have a descriptive map of the location and orientation of the photograph, as well as a map of fragility of the landscape. And at the top of this column, a representative diagram of the work process followed in the methodology that is used as access menu to the different steps. The third column shows the information regarding the selected assessment step, an editor with which to work with the various components and the resulting assessment. At the bottom of this column, a graphical system shows an overview of the visual impact assessment being conducted.

FIGURE 3: Screenshot detail of the initial situation.

Medina-Sidonia by-pass, in the province of Cádiz (Spain) was commissioned in the year 2008, easing the access to A-391 Jerez-Los Barrios highway, from A-393 highway. The surrounding landscape is characterized by its farming development with some wild forest, wild olives and Mediterranean meadow, where it is possible to observe the soft lines from the landform.

The visual analysis of the current situation (fig. 3) is focused on obtaining the visual character (elements and patterns) and the visual quality. This analysis was performed using the tool, which helps the expert to determine which intervention needs to be developed at the evaluated landscape restoration point in the infrastructure surroundings. The following conclusions are derived from this analysis:

- Visual pattern elements analysis: it consists on the analysis of visual resources (landform, vegetation and structures) over the visual elements (line, form, colour and texture). The image shows a high degree of irregular lines and monochrome grey-tone colours because of the infrastructure itself. Color element is balanced by wild olive mass and a slight sinuous landform. More geometric and symmetric forms
play a greater role from this point of view.

- Visual pattern character analysis. The aesthetic relationships are the following: Dominance is balanced between elements; scale is human with a low value; continuity has a low value; and, finally, diversity is more homogeneous because the first line elements, road and embankments, cover most of the view.

From this analysis we conclude that both colour and texture should be intervened because line and form elements are associated to the infrastructure and are hardly modifiable, forcing to intervene on the landform, which in this case are the embankments (see Fig. 3). Colour and texture, which are associated to vegetation, are also related with a specific landscape fragility element: the wild olive forest, which is disposed in small groups over the territory (elements 2 and 3 from the fragility map). The system is able to state this relation in two ways: 1) by explicit user input and 2) by using geo-referenced data from the photographs and looking out for the coverture and fragility concepts specified for the given location.

In this methodology we have introduced the concept of fragility weight, which rates the contribution of the special landscape resources such as forests, rivers, buildings, etc. to the visual resources assessment. That is, fragility weight takes into account the contribution of these special resources to the visual pattern elements of landform, vegetation, water and structures and to its visual components (line, form, colour and texture). In this way, the formal features that characterize a particular landscape from its singular elements are determined, regardless its formal structure, giving the chance to introduce and maximize cultural, social and historical values from visual elements. The fragility weight is calculated using the associated fragility value from the fragility map to a given landscape/coverture concept. If the system has not enough data, a default fragility weight is used. The fragility values from the fragility map and the coverture information comes from the corresponding layers stored in the WMS/WFS service. The process is stored and executed in the WPS service, which in turn queries the WOS service for knowledge information. Therefore, the computational complexity of the process can be distributed in different machines.

Next, a solution can be proposed for generating an infographic with this type of vegetation inserted in this view. We can observe how the introduction of wild olives in the characteristic formation of the area increases the fragility weight over the vegetal component and the colour and texture elements. In these cases a positive change is obtained, increasing the scale scoring and therefore getting a small improvement. Figure 4 reflects the new situation.
CONCLUSIONS

In this paper we have demonstrated that the proposed tool has helped to perform the analysis and to assess the visual impact of the infrastructure, knowing which landscape elements, both formal and structural, are being modified. In this sense both the methodology and the tool support project drafting and project design tasks, which in turn facilitate subsequent tasks of evaluation and analysis.

This ontology-based tool works at different scales and allows project monitoring at different phases. It combines geospatial data with information obtained from visual analysis with aesthetic criteria. The tool greatly facilitates the information management, reducing the cost and standardizing the results, making them more quantitative, repeatable and expert independent.

The tool has been built in a modular way: geospatial related processes (mapping and algorithms) are deployed adopting OGC OWS (OpenGis Web Services) standards to improve system scalability and computation capabilities. Semantic Web technologies have been used for the core Knowledge Model allowing process inference to automate many of the assessment steps and to publish project information as Linked Open Data.

REFERENCES


2. Ramajo, L., 2007: Carreteras verdes y vías paisajísticas. 1º Congreso de Paisaje e Infraestructuras. Libro de actas. ED. Consejería de Obras Públicas y Transportes. Junta de Andalucía, Sevilla


THE ROAD SUSTAINABILITY INITIATIVES IN
ABU DHABI

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ABSTRACT
Established in 1962, The Abu Dhabi City Municipality (ADM) today provides essential services to more than 1.2 million citizens through delivering and maintaining the community infrastructure such as roads, structures, community recreational parks, landscape, lighting and public realm, and other initiatives to empower the city. ADM is committed to developing services and building sustainable infrastructure. Through this commitment, ADM has developed several “Green” initiatives that contribute to the wider Government’s vision towards the Abu Dhabi Sustainable Development. The paper presents four sustainable road initiatives that ADM has developed in the last couple of years showing their anticipated impact and anticipated benefits.

INTRODUCTION
In 2009, the Government of Abu Dhabi set “The Abu Dhabi Economic Vision 2030” identifying two key priorities for economic development in Abu Dhabi: building a sustainable economy and ensuring a balanced social and regional economic development approach; “The Coordination between policies related to infrastructure and environmental policies is a part of the full commitment of the Government of Abu Dhabi in order to achieve economic and social development in a sustainable manner and to ensure the highest standards of safety for society and the protection of the natural environment”. Adapted from the Policy Agenda of the Emirate of Abu Dhabi 2007-2008.
ADM STEPS INTO SUSTAINABLE INFRASTRUCTURE

Following the government directives, The ADM affirmed its commitment to introduce and develop sustainability practices in its infrastructure projects by first establishing in 2010 the Infrastructure Sustainability Team (IST), which was formed of professionals and experts from various fields (planners, transport systems, environmental, geotechnical, structural, material, irrigation, etc.). The IST was authorized to receive proposals, analyze, assess, test and recommend sustainability practices, material, technology initiatives after conducting methodical and scientific studies proving their economic, environmental, social validity. In fact, the IST developed procedures shown in Figure 1 necessary to ascertain that proposed initiatives meet sustainability criteria.

In the past three years, the IST has initiated and evaluated many proposals aiming at saving energy and water, recycling material, decreasing the usage of raw materials improving safety and reducing noise and pollution. Four (4) sustainability initiatives will be presented in this paper pertaining to road design elements, namely pavement and lighting.

ROAD SUSTAINABILITY INITIATIVES

The Sustainable Public Lighting Strategy

The lighting intensity level on Abu Dhabi roads is one of the highest in the world especially on highways and arterial roads. In some cases it is more than twice the international practices leading to light pollution especially in urban areas. In September 2009, a committee chaired by ADM was formed to review the public lighting practices. Five months later the committee recommended the need to revise the lighting levels and the introduction of new energy saving lighting technology as an optional alternative to the conventional power consuming lamps. Based on those recommendations, ADM assigned a team of consultants to work together with its experts to develop what is called the “Sustainable Public Lighting Strategy”. ADM is implementing progressively this strategy that was officially approved and adopted by the Abu Dhabi Executive Council in 2011. The Department of Municipal Affairs DMA, the regulator body for municipalities, issued the new lighting intensity levels and the LED specifications officially in April 2012.

ADM compiled data of the entire Emirate’s current lighting assets and analyzed the current design standards, establishing how and where they were followed both for both roads and public realm. A technical, economic and environmental impact analysis was conducted to evaluate the economic and environmental implications of the new strategy. The economic analysis considered the long-term 20-year life cycle economic costs, cash flows and value of time, knowing that the financial value (through subsidies) billed for 1 kWh is 15 fils, i.e. 0.15 AED (Arab Emirates Dirham), whereas the real economic cost is about 35 fils per kWh.

The Study showed the following benefits:

- Green lighting technologies
- 90% less maintenance cost and 80% less operation cost
- $1.1 billion AED savings over 20 years
- 63% CO2 emission reduction
- Elimination of light pollution
- Reduction of equivalent operation hours
- Standardized lighting guidelines
- Higher lighting quality

Cold In-situ Asphalt Pavement Recycling

Recycling is defined as “The reuse, usually after some processing, of a material that already has served its first-intended purpose”. Pavement Recycling is the re-utilization of existing asphalt pavement material with some additives to increase its structural capacity in order to rehabilitate the road and improve the performance of pavement as a major maintenance process.

Pavement structural rehabilitation is applied either by replacing part of the pavement structure, or by removing and reconstructing the whole pavement structure. Pavement recycling is one of pavement rehabilitation options. Rehabilitation is normally required when a road approaches a terminal condition due to deterioration of a pavement structure or when a pavement requires upgrading to accommodate increased traffic volumes.

All types of asphalt pavements can be recycled; low, medium and high traffic volume highways, rural roads, city streets, airport taxiways, and parking lots. Recycling is applied to old asphalt pavement showing severe cracking and disintegration, such as potholes. There are several approaches to recycle pavement. Therefore every rehabilitation case considered must be evaluated carefully in order to determine the most appropriate method for recycling.

The main factors to be studied should include:

- Existing pavement conditions
- Existing pavement material types and thickness
- The structural requirements of future recycled pavement and
- Availability of recycling technique and additives
There are 4 methods to recycle pavement, as Figure 2 illustrates:

- Cold In – Place Pavement Recycling
- Hot In – Place Pavement Recycling
- Cold Central Plant Pavement Recycling
- Hot Central Plant Pavement Recycling

Many countries in the world use the recycling process with success as a tool to help maintain the integrity of their roads infrastructure. However, when pavement recycling is considered as an option to rehabilitate pavement, technical, financial and environmental factors should be analyzed in studying several rehabilitation design options.

**Cold in-place recycling**

In cold in-place recycling process, the pavement material is scarified and crushed to the required gradation. Then the required amount of binder in cold form (emulsion or cutback) is added (see Figure 3). The recycled material mix is laid, compacted and left for aeration. During this process additives like, cement, quick lime, fly ash may be used. The lane needs to be closed for certain time so that sufficient time is available for curing of freshly laid course. Moisture content (when bitumen emulsion is used) needs to be given attention as it influences the gradation control, mixing and workability of recycled mix to a large extent.

**Anticipated Benefits of Cold Recycling**

The Federal Highway Administration (FHWA) developed policy guidance on the use of recycled materials on 2002. It was concluded that cold recycling and full depth reclamation of asphalt pavements provide many environmental and other advantages summarized as follows:
• Pavement recycling improves serviceability of aged, deteriorated pavements
• Reflective cracking can be controlled
• Pavement crown and cross slope can be improved or restored
• Significant saving in construction time, minimize closures time and user delays
• Reduce pavement construction cost
• Environmentally, pavement materials disposal is greatly reduced or eliminated.
• Energy savings
• Recycled pavement can be recycled

ADM Cold-in Place Pavement recycling Pilot Project
The ADM conducted a pilot project on Road Number (31/16)- Shahama area in 2011. The main objective was to study the implementation of Asphalt Pavement Cold In-Place Recycling as a new sustainable technology in road maintenance aiming at increasing pavement service life, saving natural resources and reducing costs, in comparison with the conventional pavement rehabilitation method.

A 3-piece “train” was utilized, consisting of a cold milling machine, a screening/crushing/ mixing unit, and conventional laydown and rolling equipment. The existing pavement layers were removed to a depth up to 25 cm. The material removed was crushed, sized, and mixed a recycling agent; an asphalt emulsion consisting of foamed-bitumen and cement, then the material is placed and compacted. A 5-cm wearing course was applied above the 20-cm recycled base course (Figures 4).

FIGURES 4: The Pavement Recycling Train

Technical Benefits
Cold In-Place recycling resulted in Increasing Rigidity of Stabilized Road Base Course, as a result of aged and hardened bitumen, mixed with 1.5% of normal cement in addition to 2.5% of foamed bitumen. Increasing layer hardness Facilitates Spreading of wheel loads and stresses to the road sub-base and subgrade soil.

Increasing the stiffness of stabilized road base course provides stronger support to asphalt wearing layer, leading to minimize (or elimination) of structural rutting and fatigue cracking. In addition, the recycled stabilized layer is expected to reduce moisture susceptibility of ground water to asphalt.

Since cold recycling increasing stiffness of recycled road base course, this was obviously recognized in the increase of layer coefficient in pavement design from 0.05/cm to 0.11/cm. this increase in layer coefficient can lead to more sustainable pavement design by decreasing the required thickness of road base course, (and / or) increasing pavement service life with the same layer thickness.

Financial Benefits
The comparison between conventional rehabilitation method by removing and reconstructing pavement structure, and the cold in-place recycling method showed a reduction of 20% in construction cost.

Also the comparison showed additional reduction in construction time and energy consumption of 70% and 40% respectively. This significant reduction is referred to reduction of base course raw material production, hauling and construction with recycling production rate of about 300 m2/hour.

Environmental Benefits
Cold in-place recycling process resulted in several benefits for Abu Dhabi environment as follows:
• 100% of the existing road materials can be re-utilized
• Reduction of the use of virgin materials
• No need for material to be hauled away
• The re-use of binder asphalt
• Savings energy
• Reducing air pollution
• Less traffic delays
• Less disturbance to local community life

Using the Recycled Crushed Aggregates in Roads Construction
The Statistics Center in Abu Dhabi reported that the construction and demolition waste in 2010 exceeded 7.4 million tons. The Waste Management Center (WMC) in Al Dhafra Area is the entity responsible for processing and stockpiling the construction and demolition rubble/waste such as concrete from building and rock from construction site excavations.
The technical guidelines for using the Recycled Crushed Aggregates (RCA) were first prepared by the Center for Waste Management and THIESS Middle East. ADM reviewed and customized specifications to meet Municipalities requirements for roads building. The Recycled Crushed Aggregate Specifications for base and sub base courses were issued officially by the Chairman of the Department of Municipal Affairs on January 30, 2011.

ADM introduced to the official final version of the RCA specifications the following requirements:

- For some projects, at which the road pavement may be subjected to ground water or chemical contamination, (or other circumstances) the use of RCA should be restricted.
- In some cases, the use of isolation materials to prevent contact between underground saline water and the recycled crushed aggregate shall be considered in road design and construction.
- The specs should include measures for confirmation of inertness of the material (i.e. does not dissolve, burn, react adversely, no environmental pollution or harm to human health).

In addition, ADM requested the WMC as part of the HSE Management plan to establish procedures to identify hazardous substances and asbestos that could be found in the construction waste. All materials delivered and processed at the Al Dhafra Recycling Facility are controlled and monitored in accordance with the QA Process Flowchart.

The Procedures require also the following:

- All demolition projects are required to establish and maintain a register of hazardous substances used and processes for the safe use, storage and disposal.
- All chemicals used will be of a non-hazardous or biodegradable nature.
- Chemical registers are to be forwarded to Corporate HSE quarterly for entry into the ChemWatch database, which provides risk assessments, treatment and inventory processes.
- The Facility is not licensed to accept asbestos materials. However, there is a 4-part process for the inspections of loads arriving at the facility. The first two are visual inspections before and after the load is dumped.
- If asbestos material is detected at the 1st or 2nd inspection, the load is rejected. If the load is dumped, the work method statement (WMS) for the handling of asbestos materials is applied.
- Part 4 is a quality system incorporated into the site as a proactive system in checking load physically and recording this information with Management leadership, weighbridge and Operators inclusion.

The Use of Geo-grid in Pavement Design of ADM Projects

Geo-grid is one of several types of Geo-Synthetics fabrics family, manufactured from Plastic / Poly – Propylene Material; manufactured for different purposes in road projects including technical solutions for weak soils, soil stabilization, earth slope stability, bridge & tunnel retaining structures.

The main objective of utilizing geo-grid in pavement is to achieve more sustainable pavement design by extending pavement service life (and/or) reducing pavement layers thickness, as well as enhancing pavement performance under different service conditions.

The mechanism of mechanical stabilization that characterized the Geo-grid stems from the concept of Lateral Confinement of aggregate particles, which leads to increasing load carrying capacity and improving pavement structural performance. Increased Load Spreading over a wider area is the key mechanism for pavement reinforcement (Figure 5).

FIGURE 5: Lateral Confinement and Load Spreading Concepts

The Use of Geo-grid in Pavement Design of ADM
Projects
The Reference Standards that ADM is utilizing are:

- ADM Pavement Design Guideline Requirements, January, 2012,
- AASHTO R-50 (2009) is a Standard Reference for Geo-synthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures

In order to standardize ADM requirements of introducing Geo-grid in granular pavement layers, ADM developed and issued The 1st Edition of Approval Process and Acceptance Criteria (Figure 6), which requires:

- Selection of Suitable, Previously Experienced Geo-grid for Each Specific Case Study,
- Technical Review of Material Properties and Previous Implementation cases,
- Verification of Material Properties by Certified Labs,
- Review of Pavement Design Criteria (Referring to AASHTO-R50-09),
- Review of Design Factors, Expressing Contribution of Geo-grid Material in overall Pavement Structural Number,
- Verify Pavement Design analysis, Using Different Calculation Tool,
- Consider Conflict with Existing and Future Utility Lines,
- Consider future maintenance requirement of road and infrastructures in presence of Geo-grids,
- Evaluate Design Options (Technically, Financially and Environmentally), and
- Selection of Suitable Design Option based on (Life Cycle Cost Analysis) LCCA.

Benefits of Geo-grid System in Pavement Design
Abu Dhabi Municipality has conducted studies for the implementation and use of Geosynthetics in road projects; in particular, the use of the Geo-grids to strengthen road pavement layers and reduce the use of soil raw material. It was concluded from those studies that the use of Geo-grid within road pavement layers would yield several benefits, as follow:

- Provide effective solutions to poor soil conditions
- Increase the design life of the pavement
- Reduce pavement thickness
- Reduce stress on the asphalt
- Reduce the cost of setting up of asphalt
- Reduces the risks related to the establishment of quality pavement.
- Shorten the duration of pavement construction
- Save raw materials and reduce energy demand
CONCLUSIONS

ADM has successfully developed and implemented so far four (4) road sustainability initiatives aiming at improving the quality of road projects delivered in conjunction with reducing the social and environmental cost of building and maintaining those roads. The decision to adopt these initiatives was built on solid scientific procedures of investigation, analysis and testing that proved the soundness of implementation and the robustness of the benefits generated considering the technical and environmental conditions in Abu Dhabi.

Finally, ADM believes that those four road sustainability initiatives, and other initiatives underway, would eventually serve the ultimate purpose of building “Abu Dhabi Green Roads”, whose elements and rating system are now under development and expected to reveal by the first quarter of 2015.

REFERENCES

IRF EXECUTIVE COMMITTEE

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The INTERNATIONAL ROAD FEDERATION is a full-service membership organization founded in Washington, D.C. in 1948. The IRF is a non-governmental, not-for-profit organization with the mission to encourage and promote development and maintenance of better, safer and more sustainable roads and road networks around the world. Working together with its members and associates, the IRF promotes social and economic benefits that flow from well-planned and environmentally sound road transport networks and advocates for technological solutions and management practices that provide maximum economic and social returns from national road investments.