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## *Abstract*

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# The Carbon Emission Quantification of the Low Carbon Road Maintenance Technology in China

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**Key words:** Low carbon economy; road maintenance; carbon emission measurement; law

**Abstract.** Low carbon road maintenance( hereinafter referred to as LCRM) technology is an important and essential part of the overall low carbon transportation policy in China. The large amount of carbon emission resulting from road maintenance needs to be determined with definitive methods and data to form a basis of measurement of the carbon emission of the road maintenance process. Various road surface maintenance technologies have different environmental impacts and dissimilar levels of carbon emission. When comparing the merits and drawbacks of the various maintenance technologies, not only factors such as the maintenance outcome, road surface quality, serviceable lifespan, costs and the impact on traffic and environment should be evaluated, but also other factors, such as carbon emission of the material used for the maintenance process, carbon emission of the machinery deployed and other amounts released during construction, have to be assessed and measured. This paper will allow for a comprehensive analysis that will help to choose the right road surface maintenance technology that produces the best road surface quality, the optimal economic benefit and the most favourable social and environmental outcome. LCRM protocol should be regulated and promoted by government legislation and through which adoption of the best practices would be encouraged.

## Analysis on the necessity of LCRM

Transportation is a major source of air pollution due to the large amounts of fossil fuel consumption involved. Sulphur dioxide emission and other greenhouse gas emission are the major contributors[1] . Different modes of transportation could result in great differences in the amount of carbon emission. Statistics show that for the same transport load volume, the energy consumption ratio between rail, highway, and air transportation is 1.9:3:18.6[2] .Hence, highway and air both have high fuel consumption while rail consumes the least. Many scholars have proposed the establishment of a comprehensive policy that governs a sustainable transportation network, and such policy should also address the issue of rapidly escalating greenhouse gas emission from vehicle exhaust[3].

Presently in China, the average highway energy consumption is 5 to 10 times of rail consumption, while in the United States it is 3 times[4]. The impact on the environment is not simply related to emission per kilometre, but also related to the freight volume and the mode of transportation[5]. The World Bank study on 17 cities in China discovered that the increasing high carbon dioxide emission results mainly from the longer distances traveled, motorization and low loading ratio of vehicles[6]. In August 2004, Dr. M.Y. Fisekci, released a four-year research report which sampled only 37 Chinese national highways, with a total length of about 3,000km, mostly 4 lanes to the China Highway Society. Among those highways, 90% are substandard. Without proper maintenance, the life span of these highway would be shortened by half and the national losses would exceed tens of billions RMB each year, enough money to construct two international-standard airports over a life span of 7 to 8 years[7].

Low carbon transportation addresses a broad and comprehensive subject encompassing all the links in transportation with regard to greenhouse gas emission. In reality, consumption of fossil fuel cannot be reduced until there is a discovery of large scale alternative energy sources. Therefore, the primary focus of development of low carbon transportation is reduction in conventional energy consumption, while alternative energy utilization is secondary. Compared to docks in shipping and airports in air traffic, road maintenance in highway transportation deserves even more attention. Transportation is made up of vehicles and infrastructure facilities. At present, the high-grade roads in China save over 20% petrol than standard roads[8] .

Road construction inevitably consumes energy, resulting in high carbon mission in the process. LCRM is an essential part of low carbon transportation, and therefore an important step to achieve low carbon transportation. The highway maintenance in China consumes 50 million tons of rocks now[9]. During the rehabilitation of the highway, traditional methods will create traffic congestion. The slow traffic will create huge quantities of carbon emission. Adding this to more emission from the refining of asphalt, milling and paving of the road surface, the total carbon dioxide emission from road maintenance is about 1.1 million tons yearly[10].

Strong and accurate technical data are crucial in the quantitative analysis of LCRM technologies, which will help to standardize the industry and allow for control and consolidation through government legislation.

## Measurement of carbon emission in road maintenance

**Scope and Standard**. The testing and research of carbon emission during road construction and road utilization represent a systematic and extensive undertaking. The study involves many facets of the road building process where carbon emission in the procurement of the raw materials, machinery mobilization and construction processes will be tested, calculated and determined, arriving at a final total emission for the entire construction process. Parallel to this research, new environmentally friendly and energy efficient materials, technologies and applications can be assayed and compared in their emission levels.

Utilization of a highway requires regular maintenance of the road surface. Different pavement maintenance systems and techniques affect the environment and carbon emission in different ways. Consequently, the comparison of the merits of pavement maintenance techniques has to take into consideration not only factors such as surface results, surface functionality, effective longevity, impact on traffic and the environment, but also the carbon emission burden of the material used, carbon emission of the construction equipment deployed and the emission during the application process.

As a preliminary assessment of carbon emission in road construction and road maintenance, this paper will study the carbon emission during the construction and operational stages of the various techniques, comparing the currently available preventive asphalt maintenance methods in their impact on the environment (or greenhouse effect).

**Classification of road maintenance technologies**. Pavement preventative maintenance (PPM) for asphalt road surface refers to conservative road surface treatment that is applied before any structural damage to the road occurs. Its effect is to enhance the serviceability and longevity of the pavement and to reduce the cost of the regular service cycle. Actual experience shows that proper PPM is a cost effective and efficient technology that can delay damages and extend the serviceable life of the surface, and postpone major rehabilitation and rebuilding of the highway.

At present, PPM technology can be divided into these main categories: asphalt rejuvenation technology (ART), micro-surfacing technology (MST), hot ultra-thin surface milling and over laying technology (HUT), and fog seal technology (FST). In general:

1. ART is very effective in preventing early damage to the road surface and in reviving the functionality of the asphalt, turning the old asphalt road back to almost new asphalt road without the need to mill and pave.
2. MST is suitable for use in high grade highways as an early stage preventive measure. It can significantly improve the performance and longevity of the surface.
3. The advantages of HUT are high leveling accuracy, anti-skit characteristics and noise reduction features. Again, traffic can flow 1 to 2 hours after process completion.
4. FST is a commonly used PPM technique. It has been popular with high speed highways because of its low cost, quick application and good performance. Highway can be re-opened for traffic very quickly following application.

As this paper focuses on carbon emission quantification, hence it is not the authors will to discuss, compare and evaluate all the foregoing methods in terms of costs, reliability and life span in this paper. For carbon emission evaluation purposes, measurement of carbon dioxide emission during the application process and subsequent operational phase of these four technologies should produce a comparison of the environmental impact of these techniques, allowing for better compliance with the objectives of low carbon emission and environmental compatibility.

Currently there is no established method to measure the carbon emission during highway construction and maintenance. This study draws on the atmospheric carbon dioxide assaying technique to determine the carbon emission during the construction or application process and at various time intervals after resumption of traffic flow. We have chosen carbon dioxide measurement as an indicator of the level of carbon emission of these technologies. The sequential measurement following initial completion of construction or application will show the longer term impact of the different PPM techniques.

**Assaying methodology for carbon emission of pavement preventive maintenance techniques**. Volumetric titration is the method used. The principle is that the carbon dioxide in a sample of air of known volume is absorbed in a barium hydroxide solution of known concentration. The test required the following equipment and reagents were as follows: 1. Instruments: suction tube, air sampler, burette, iodine bottle; 2. Reagent: absorption (barium hydroxide) solution, oxalic acid standard solution, phenolphthalein indicator, butanol, pure nitrogen or air with $CO_2$ removed by soda lime tube.

The test was divided into two parts: laboratory samples and field test samples. The procedure was as follows:

1. In the laboratory, asphalt rutting boards measuring 300mm x 300mm x 50mm (thickness) were fabricated at a moulding temperature of 60 degrees C, and wheel pressure of 0.7MPa. The surface is then treated with either RejuvaSeal (an asphalt rejuvenating agent approved by the Shanghai Authority)[10]or fog seal according to the manufacturers' directions. For micro surfacing and ultra-thin hot wear surface milling and over laying, the surfaces were prepared and then treated with the materials following manufacturer's directions.
2. At the end of the application process, air samples were taken at time intervals of 0 min, 30 min, 1h, 2h, 4h, 6h, 12h, 1d, 5d, 10d, 30d, and 60d.
3. In the field, the sampling sites were spaced out by 20m and their locations marked for future sampling.
4. To collect $CO_2$ gas samples, a suction tube purged with pure nitrogen or de-carbonated air was used. The tube was filled with 50 ml of barium hydroxide solution. The suction tube opening was positioned 10 cm above the surface and 3L of sample air is collected at a flow of 0.3L/min.
5. At the end of collection, the suction tube opening was sealed to prevent contamination. The temperature and atmospheric pressure were recorded during sample collection. Sampling was done

under good weather conditions to minimize fluctuations in temperature, humidity and barometric pressure that may cause inaccuracy in the measurements.

The analytical process involved the following:

1. The sand core tube of the suction tube was removed after sample collection and stopper applied and let standing for 3h. This allowed for complete precipitation of the barium carbonate. 25ml of the supernatant fluid was extracted and placed in the isodiametric bottle. 2 drops of phenolphthalein indictor were added to the solution and standard oxalic acid from the burette was used to titrate against the sample until the pink of phenolphthalein faded.

2. For each batch of samples, a 25ml volume of unused barium hydroxide was titrated using the same reagents to establish a baseline value.

3. The concentration of carbon dioxide in the air was calculated using the following formula:

$$c = \frac{20\,(V_2 - V_1)}{V_0}$$

C - $CO_2$ concentration in the air sample

V2 - volume of oxalic acid used in titration of the test sample

V1 - volume of oxalic acid used in titration of the blank barium hydroxide solution

V0 - volume converted to standard temperature and pressure.

Parallel data were obtained for the four different PPM techniques to allow for scientific comparison.

4. The $CO_2$ concentration of the samples were calculated and compared to the standard $CO_2$ level in the atmosphere.

This analysis formed the basis of the evaluation of the impact of the different PPM technologies had on the environment. The data obtained in the field showed higher values because of vehicular exhaust, and had to be adjusted using the laboratory tests.

**Analysis of PPM carbon emission results**

Tests have been concluded based on the above mentioned methodology on the four pavement preventive maintenance treatments, both in the laboratory setting and in the field where asphalt surface treatment has been performed. The results are also compared to $CO_2$ concentration in air samples over ordinary asphalt pavements. The test results are contained in Table1 and Table2; the $CO_2$ concentrations at different time intervals following different application methods can be seen in Figure 1 and Figure 3, and the comparison of $CO_2$ concentration under different methods is presented in Figure 2 and Figure 4.

| *Lab* | *$CO_2$ Volume, %* | | | | | |
|---|---|---|---|---|---|---|
| *Time* | *Air in Lab* | *ART* | *MST* | *HUT* | *FST* | *NAP* |
| 0min | 0.06 | 3.51 | 4.15 | 5.97 | 4.08 | 5.83 |
| 10min | 0.06 | 2.98 | 3.86 | 5.73 | 3.54 | 5.64 |
| 30min | 0.06 | 2.03 | 3.54 | 4.86 | 3.09 | 4.78 |
| 1h | 0.06 | 1.55 | 3.05 | 3.78 | 2.86 | 3.67 |
| 2h | 0.06 | 0.87 | 2.72 | 2.55 | 2.58 | 2.45 |
| 4h | 0.06 | 0.43 | 2.21 | 1.05 | 2.03 | 0.95 |
| 12h | 0.06 | 0.14 | 0.81 | 0.12 | 1.08 | 0.12 |
| 1d | 0.06 | 0.11 | 0.53 | 0.06 | 0.87 | 0.06 |
| 5d | 0.06 | 0.08 | 0.08 | 0.06 | 0.52 | 0.06 |
| 10d | 0.06 | 0.06 | 0.06 | 0.06 | 0.43 | 0.06 |
| 30d | 0.06 | 0.06 | 0.06 | 0.06 | 0.24 | 0.06 |

*Table 1*: Test results of $CO_2$ concentration of different preventive maintenance technologies in the laboratory where $CO_2$ concentration of the gas sample at a point 10 cm above test surface (percentage by volume)[10].

*Note*: NAP means normal asphalt paving

| *On-Site* | *$CO_2$ Volume, %* | | | | | |
|---|---|---|---|---|---|---|
| *Time* | *On-Site Air* | *ART* | *MST* | *HUT* | *FST* | *NAP* |
| 0min | 0.04 | 3.86 | 4.75 | 6.92 | 4.59 | 6.57 |
| 10min | 0.04 | 2.04 | 4.19 | 6.45 | 4.02 | 6.02 |
| 30min | 0.04 | 0.54 | 3.88 | 5.31 | 3.56 | 5.14 |
| 1h | 0.04 | 0.04 | 3.42 | 3.55 | 2.57 | 3.22 |
| 2h | 0.04 | 0.04 | 3.03 | 2.14 | 2.01 | 1.86 |
| 4h | 0.04 | 0.04 | 2.51 | 0.36 | 0.98 | 0.21 |
| 6h | 0.04 | 0.04 | 1.87 | 0.04 | 0.64 | 0.04 |
| 12h | 0.04 | 0.04 | 0.47 | 0.04 | 0.59 | 0.04 |
| 1d | 0.04 | 0.04 | 0.04 | 0.04 | 0.51 | 0.04 |
| 5d | 0.04 | 0.04 | 0.04 | 0.04 | 0.36 | 0.04 |
| 10d | 0.04 | 0.04 | 0.04 | 0.04 | 0.22 | 0.04 |
| 30d | 0.04 | 0.04 | 0.04 | 0.04 | 0.18 | 0.04 |
| 60d | 0.04 | 0.04 | 0.04 | 0.04 | 0.06 | 0.04 |

*Table 2*: Test results of $CO_2$ concentration of different preventive maintenance technologies on-site where $CO_2$ concentration of the gas sample at a point 10 cm above test surface (percentage by volume)[10].

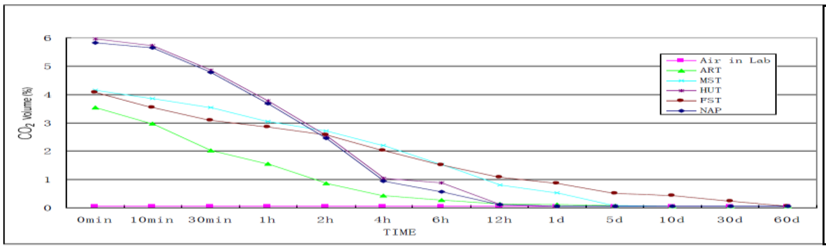


*Fig 1*: Change of the $CO_2$ concentration following time of different PPM in the laboratory[10].

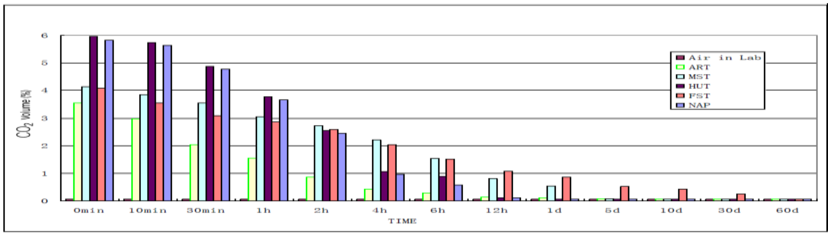


*Fig. 2:* Comparison of $CO_2$ concentration of different PPM in the laboratory[10].

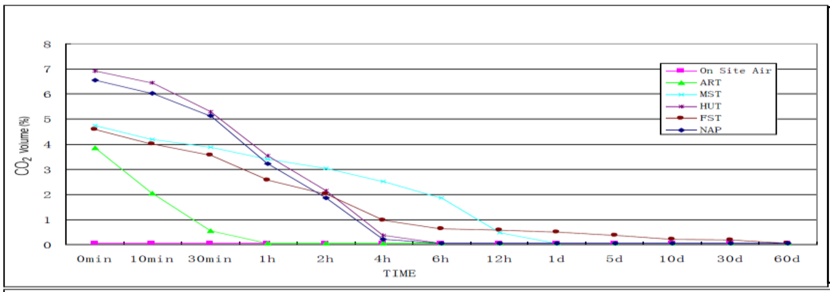


*Fig. 3*: Change of $CO_2$ concentration at different time intervals following PPM application on site[10].

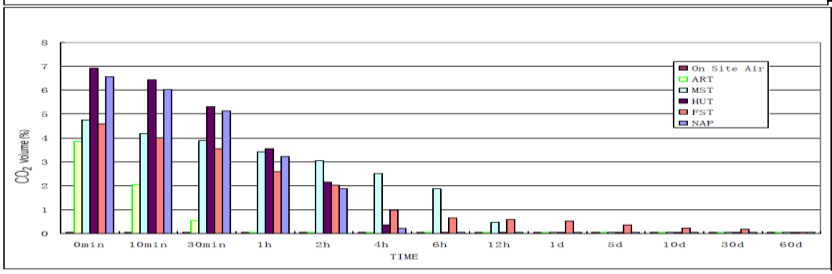


*Fig. 4:* Comparison of $CO_2$ concentration of different PPM on site[10].

**Observations derived from the test results**

The laboratory and field tests reveal the amount of $CO_2$ released during the application process of the different PPM technologies ranked highest for hot ultra-thin surface milling and over layering technology (HUT), followed by the normal asphalt pavement (NAP), micro-surfacing (MST), fog seal (FST) and asphalt rejuvenation technology (ART), all of which result in higher $CO_2$ concentration than ambient air.

Owing to the unique characteristics of the different material used, each PPM technology has its own pattern of change in $CO_2$ release. Mixtures that require heating have the greatest change in $CO_2$ release, such as HUT and NAP, where the $CO_2$ release greatly decreases as the material temperature drops. Usually, within 10min to 4h after application the $CO_2$ concentration drops from 5% - 7% to lower than 1%. As for rejuvenation material of ART, the mixture content is already environmentally friendly and therefore produces the least $CO_2$ emission. During the drying and downward penetration phase of rejuvenation, $CO_2$ concentration declines with time partly because the material does not contain harmful organic solvents. In an enclosed environment, the $CO_2$ level will decrease to below 1% within 2h, while in the open air field site $CO_2$ level can drop to below 0.5% within 30min. As for MST and FST the $CO_2$ emission during application will also decrease with time, but the speed of the decline is less rapid than rejuvenation or hot asphalt, requiring 12h before the concentration drops to 1%. This phenomenon could be due to the fact that both techniques utilize chemically reactive materials. In the drying and emulsion breakdown process chemical reactions may be occurring with the production of new substances and more $CO_2$ release. Laboratory and field tests both showed the same pattern of $CO_2$ changes.

Within the laboratory, ventilation is comparatively restricted and gases take longer to dissipate. For the rejuvenation material of ART, it takes $CO_2$ concentration in the laboratory 4h to drop from 3.55% to 0.43%. In the field where good ventilation is available, the same drop takes only 30min. This difference is even more obvious for heated asphalt mixtures of HUT. In the relatively closed environment of the laboratory, fresh asphalt (NPT) and HUT material need 6h to drop the $CO_2$ level from 6% to 0.6%, while in the well ventilated field condition $CO_2$ level can drop from 7% to 0.3% within 4h. Similar observation applies to MST and FST material, where $CO_2$ concentration takes 1d to 5d to drop down to 0.5% in the laboratory, but only 12h on site.

Fresh air contains 0.03% of carbon dioxide, which is the level compatible with human biological existence. If $CO_2$ concentration is too high because of poor ventilation or burning of fuel indoors, $CO_2$ toxicity could occur. There is no uniform international standard for $CO_2$ concentration in indoor air. Japan sets 0.15% of $CO_2$ concentration as the level where air exchange is required. Table 3 illustrates the effect of increasing $CO_2$ concentration on the human body.

*Table 3*: The effect of $CO_2$ on the human body[10]

| *The content of $CO_2$ in the air/%* | *Symptoms* |
|---|---|
| 2.5 | No symptoms for hours |
| 3.0 | Increased breathing without being aware |
| 4.0 | Signs of agitation |
| 6.0 | Hyperventilation |
| 8.0 | Difficulty in breathing |
| 10.0 | Confusion, leading to death |
| 20.0 | Paralysis within seconds with heart stoppage |

Taking the above Table 3 information as guide, the upper limit of $CO_2$ content during the construction phase could be set at 6%, and the upper limit in the usage phase could be set at 0.5%. The various PPM technologies would evidently have different effects on the human body, and the timing of the re-opening of the road would have to fluctuate according to the speed of decline of $CO_2$ concentration. At the construction site, ART, MST and FST can all meet the upper limit requirement. NAP and HUT layering both require heated mixtures and the $CO_2$ concentration during construction is close to 7%, which may be harmful to the health of the workers. To meet the requirement of 0.5% limit at time of re-opening of the road, ART needs 30min after application, MST needs 12h and FST will require 1d. HUT layering and normal asphalt paving (NAP) both need 4h. From the point of human health considerations, the proper choice would be for a PPM material that produces the least $CO_2$.

This study did not conduct tests and research into the total amount of $CO_2$ produced at the construction and operational stages using different PPM technologies. However, we can make some reasonable estimate from Table 1 and 2, and from Figures 1 to 4. For example, in Figure 3 (Change of $CO_2$ concentration at different time intervals following PPM application on site) the area below the curve can indirectly reflect the total $CO_2$ emissions.

## Preliminary Conclusions

Different pavement preventative maintenance technologies would produce different concentration and different total amount of $CO_2$. Mixture materials that require heating give out higher concentration as well as greater amount of $CO_2$. This is followed by methods that utilize reactive type of material like micro-surfacing (MST) and fog seal (FST). Asphalt rejuvenation technology (ART) gives out the least.

The drop in $CO_2$ concentration is quite fast in well ventilated surroundings, but for road sections within cities where ventilation is more stagnant, a PPM method with low $CO_2$ emission should be chosen to prevent high $CO_2$ accumulation that could be harmful to human health.

From the results of this study, one can deduce that in asphalt pavement preventative maintenance the technology of choice would be one that can be applied in ambient temperature and one that does not involve chemically reactive materials. This avoids the need for heated materials and ensures $CO_2$ level will remain low.

## Ideas for future in depth research

This study is only a preliminary and exploratory study of $CO_2$ emissions from different preventative maintenance technologies currently used in highway construction. The $CO_2$ emission testing and evaluation during highway construction and operation involves all kinds of materials and machinery. Different construction techniques and maintenance methods also affect the testing and evaluation, making it a very large and complex undertaking. Further detail study is needed to analyse the various materials, machinery, and construction techniques in the highway construction process and road operating stages to determine the $CO_2$ emission under various conditions and over time. Such study can aid in the standardization of the testing and evaluation of $CO_2$ emission during the different phases of the construction and operation of the road. The main research emphasis in future would be as follows:

1. Include the composition and constitution processes, and calculate the unit $CO_2$ emission of each material.

2. Collect information on the machinery mobilized in the construction and maintenance processes; perform testing and calculate the $CO_2$ emission from each piece of equipment.

3. Collate the total requirement of the material, machinery and manpower needed in the road construction and maintenance processes, and calculate the $CO_2$ emission for each unit of highway construction or maintenance.

4. Develop computer software that calculates the $CO_2$ emission based on different road design and maintenance conditions.

5. Collect from China and overseas new low carbon and environmentally friendly materials, methods and technologies and evaluate their quantitative $CO_2$ emission levels.

6. Taking into consideration the available new materials, methods and technologies, compile a set of basic $CO_2$ emission standards for low carbon roads.

7. Using the $CO_2$ emission standards for low carbon roads, conduct a survey on planned or existing roads to evaluate their carbon emission level to determine if they meet the requirements for low carbon emission.

8. Investigate the factors that lead to noncompliance in road projects and implement improvement measures.

Last but not least, in China, related law must be established and reinforced. The authors will present their legal opinions in their next join paper in the not very distance future.

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