

Comparison of Pavement Network Management Tools and Its Probabilistic of Pavement Engineering for Western Australia

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Abstract

Since the Association of American State Highway Officials (AASHO) road test of 1956-62 at Ottawa in Illinois, enormous efforts have been devoted to improve the methodologies and engineering techniques of pavement performance predication. For instance, the successful implementation of the Network Optimization Systems (NOSs) in the Arizona Department of Transportation (ADOT) in the 1980-82 was one of a tremendous effort that represented advancement in predication methodology and engineering technique by using Markov Chain-Process based to define the transition process of pavement network condition. The main role of this paper is to evaluate and analysis the pavement network performance of Western Australia (WA) and also applied the existing pavement management tools relevant to WA road networks. Two approaches were used to evaluate and analysis the pavement network of WA. First, the current pavement performance data was used to assess the State road networks and then, predict the future from the past and current pavement network data. Second, the Probabilistic network – Markov-Chain Process and Chapman-Kolmogorov method was used to predict the pavement behavior in Western Australia. The results showed that the pavement performance of the predicting model using probabilistic network process (i.e. Linear) perform well in all categories as compared to the past 30 years LRDM data inventory. This study will draw into appropriate and effective pavement engineering management system to account for proper pavement design, preliminary planning, future pavement M & R networks, service life and functionality.

Keywords

Pavement engineering; pavement management; Markov chain-process; pavement network-probabilistic behavior; Western Australia

1. Introduction

Pavements are an important part of highway transportation infrastructure that constitutes an enormous investment of public funds. A tremendous amount of time and money is spent each year on construction of new pavements as well as on maintenance and rehabilitation (M&R) of existing pavement. To maximize benefits and minimize overall costs, a systematic and scientific

approach is needed to manage pavements (Lee et al. 2013). Pavement management systems (PMSs) provide consistent, objective, and systematic procedures to determine priorities, schedule allocating resources and budgeting for pavement M&R (Federal Aviation Administration (FAA) 2006). The management of pavement is a decision making action with uncertainties. Though we had unlimited resources, there is not always agreement on the best approach and time of pavement maintenance and rehabilitation. Since resources are invariably severely constrained, the difficulty of the decision making is almost overwhelming. However, over the last six decades hard and soft technology has emerged which provide us with improved decision making decision making ability such as microcomputers and decision support system (DSS), soft technology, operation research methodologies, artificial intelligence technologies, modeling aids including spreadsheet program and data base systems for the management of information and so forth.

Pavement management was first conceived in the mid-1960s as a result of major work done in the United State and Canada (Hudson and Hudson 1994). The early pavement management concepts focused on the project level, design, rehabilitation, maintenance, and pavement performance modeling. By the mid-1970s pavement management had expanded to primary use at the networks varying-sizes. By the mid-1980s the application of these same system concepts to bridge became evident to engineering community, and a major research project was funded by the National Cooperative Highway Research Program (NCHRP) to develop bridge management systems (Hudson and Hudson 1994). Since then bridge management has become relatively commonplace. Work has been performed by other on building management system, sewage management system and other systems for managing the world's infrastructure. However, pavement management systems based on engineering knowledge are limited.

Pavement engineering management systems uses the systems approach to provide a unified treatment of pavement design, testing, construction, maintenance, evaluation, and restoration (Haas and Hudson 1978). Improving road safety through proper pavement engineering and maintenance should be one of the major objective of pavement management systems (Tighe et al. 2000). When pavement are evaluated in terms of safety, a number of factor related to pavement engineering properties are raised, such as pavement geometric design, pavement materials and mix design, pavement surface properties, shoulders type and pavement color and visibility (Tighe et al. 2000). A good pavement engineering management system requires an accurate and efficient pavement performance (Butt et al. 1987) so that prediction models based on the Pavement Condition Index and the age of the pavement can be developed.

The objective of this study is to evaluate and analysis the pavement network of Western Australia roads using a pavement management data and also predict the likely pavement maintenance and rehabilitation (M&R) performance of the State using probabilistic model.

2. Methods and Techniques

2.1 LRDM Inventory

Pavement management data's are collected from Lao Road Design Manual (LRDM) inventory from seven roads categories on sixty seven locations of Western Australia roads networks. Pavement data are for the past thirty years on traffic roads survey, and it includes: surface type, construction and maintenance and rehabilitation (M&R) year, average daily traffic (ADT), heavy vehicle in road (HV, %), Thornwaite Moisture Index (TMI), and pavement cracking types.

2.2 Pavement Network Management Tools

Linear and non-linear programming models are the two main types of algorithms utilized by researchers in developing pavement management optimization models (Gao et al. 2010). In linear programming models, key assumptions of all functions that includes objective and constrain function are consider as linear. However, in non-linear programming, this assumption does not accumulate at all (Hillier and Lieberman 2010). Pavement condition prediction models are significant component of pavement optimization models. These are two types of prediction models: deterministic models and probabilistic models. According to Butt et al. (1994), the pavement deterioration rates are often “uncertain”, frequently used the probabilistic model based on the Markov process approach to evaluate and analysis the pavement condition (Chen et al. 1996).

2.2.1 Linear Model Algorithm

The linear model for pavement maintenance and rehabilitation optimization is formulated as follows (Gao et al. 2010):

$$\sum_{t=1}^T \sum_{k'=1}^K \sum_{i=1}^5 \sum_{k=0}^K Y_{tk'ik} \cdot C_{tk'ik} \quad (1)$$

$$\sum_{k=0}^K Y_{tk'jk} = \sum_{i=1}^5 \sum_{k=1}^K Y_{(t-1)kik'} \cdot P_{k'ij} + \sum_{i=1}^5 Y_{(t-1)k'io} \cdot DN_{k'ij}$$

for all $t = 2, \dots, T$; $k' = 1, \dots, K$; $j = 1, \dots, I$ and $Y_{tk'k} \geq 0$ for all $t = 1, \dots, T$; $k' = 1, \dots, K$; $I = 1, \dots, I$; $k = 0, \dots, K$ (2)

$$\sum_{t=1}^T \sum_{k'=1}^K \sum_{k=0}^K Y_{tk'jk} = 1 \text{ for all } t = 1, \dots, T; S_{Tj} \leq \varepsilon_{Tj} \text{ for selected } j \leq \varepsilon_{Tj} \text{ for selected } j \quad (3)$$

$$\sum_{t=1}^T \sum_{k'=1}^K \sum_{i=1}^5 \sum_{k=0}^K Y_{tk'ik} \cdot C_{tk'ik} \cdot L \leq \beta_t \text{ for all } t = 1, \dots, T \quad (4)$$

where, $Y_{tk'ik}$ = proportion of pavement in state I with lost treatment k' receiving new treatment k in year t ; $C_{tk'ik}$ = unit cost of applying treatment k in year t to pavement in state I with lost treatment k' ; $P_{k'ij}$ = probability that pavement receiving new treatment k transit from state i to state j ; $DN_{k'ij}$ = probability that pavement with new treatment k' receiving no new treatment (don nothing moves from state i to j); S_{Tj} = proportion of pavement in state j at year at final T ; ε_{it} = upper limit of proportion of pavement in condition I in year t ; L = total length of entire pavement network; β_t = maximum available budget in year t ; T = number of analysis years; and K = number of repair treatment types.

3. Comparison of Pavement Performance Predicting Models

Modeling of payment performance is absolutely essential to pavement management on all levels: project level to national network level. Performance, it its broadest sense, is predicted by

deterministic and probabilistic models (Lytton 1987). The deterministic models include those for predicting primary response, structural, functional and damage performance of pavements, whereas the probabilistic models include such as survivor curves, Markov and Semi-Markov transition process (Lytton 1987). Damage models are particularly important because they are impact load equivalence, cost allocation, and a variety of the other tax related subjects. A cumulative damage model based upon a Markov process has been proposed by Bogdanoff and Kozin (1985) and has been successfully used to investigate crack propagation and fatigue. The Markov process seems superior to the curve-fitting approaches mentioned above because it introduces a rational structure for interpreting road condition data. It can also be used to predict future pavement condition in a probabilistic manner (Carnahan et al. 1987).

Lytton (1987) underlined the concepts of pavement performance prediction and modeling including the limitation and the use of the models. Project level models are different from and more detailed than network level models for they are used in the analysis and design of pavements of life-cycle cost analysis of alternative designs and other related purposes. While Network level models are necessary less detailed but used in the selection of optimal maintenance and rehabilitation strategies, size and weight and cost allocation studies, and network level trade-off analysis between pavement damage, maintenance, and other user costs. Well-developed performance models, resting on the twin pillars of statistics (i.e. experimental design) and mechanics can satisfy both technical and economical requirements for managing pavement based on engineering (Lytton 1987). The development of better performance models should be a continuing task and much remains to be done.

Markow (1986) suggested that load equivalent factors should be calculated based upon a marginal damage concept, marking the range from 0 to 1 between any two pre-determined levels of distress or serviceability index (Lytton 1987). The load equivalent factors for the same vehicle will change as the pavement becomes more distressed, and will also depend upon the presence of other types of distress and upon timely maintenance action. The objection may be made that this will make the calculations of load equivalence factors more difficult and pavement design for mixed traffic more complicated but the reply is that it will also make it more realistic.

4. Pavement Management Tools and Pavement Rehabilitation

The most important and priority decisions that can be made is to rehabilitation of the existing road rather than the selection of new roads to be built. Pavement management includes all planning, design, construction, maintenance, and rehabilitation of pavement part of a public work program. Whereas, a pavement management system is a set of methods which support the decision makers in arriving at the optimal strategies for the construction and maintenance of traffic roads in serviceable condition for a given period of time (Hudson et al. 1979). A pavement management is nothing more than a decision support system in the terminology of operation research (Hugo et al. 1989).

Several pavement management systems have been described in the literature. For example, some use integer goal programming (Cook 1984), linear goal programming (Benjamin 1985), linear programming (Karan and Haas 1976), linear integer programming (Garcia-Diaz and Liebman 1980; Lytton et al. 1982) and others. However, all these approaches fail when the special circumstances surrounding the problem and discussion are taken into account. Integral and integer goal programming problems cannot be solved on a microcomputer (i.e. problems of

practical size), while the linear and goal programming problems cannot handle the constraint on the duration such as of any project, because no project may stretch over more than two years but only two consecutive years (Hugo et al. 1989).

4.1 Existing pavement management systems

The existing pavement management systems are: the Arizona Department of Transportation (Kulkarni et al. 1982) ; the Washington State Department of Transportation (LeClerc and Nelson 1982); the U.S.A. Army Engineering Cooperatives (Shanin and Kohn 1982); Urban Pavement Improvement (Karan and Haas 1976); and the Texas Transportation Institute (Lytton et al. 1982).

4.2 Current and the shortcoming of the previous system

The current pavement management system is computerized and has procedures for gathering data, a data base, procedures for the validation of data, procedures for analysis and reporting of data, and procedures for the identification and prioritization of rehabilitation. Previous pavement management system can be compare with the present condition of pavement (systematically and objectively). However, it does not take the future behavior of pavement into account, and it is significant to do so because each pavement deteriorates has a unique action, and deformation is also dependent among others. For instance, the structure materials in the pavement and traffic loading is expected to carry environmental condition such as temperature and moisture (Hugo et al. 1989). It is necessary to consider a characteristic of different roads into account in order to obtained a better schedule for maintenance and rehabilitation in particular, models for forecasting the behavior of pavement such as model for ride comfort, cracking forming, user costs and routine maintenance as described by (Hugo et al. 1989).

4.3 Overview of pavement management systems

A pavement management system (PMS) is a decision support system which is designed to be used by pavement personnel to help make cost-effective decisions concerning the maintenance and rehabilitation of the pavements for which they are responsible pavement management provides a means to organize the massive amount of data that develops with a pavement network. Pavement management is generally described and developed at two levels, network and project level. The difference between network-level and project level include the level for which the decisions are being made and the amount and type of data required (Smith 1991).

The basic elements of a network-pavement management system include: an inventory, condition assessment, identification of project when fund are constrained and a method to determine the impact of funding decisions on future condition. Project-level pavement management is basically the engineering analysis and design required to develop the most cost-effective maintenance or rehabilitation treatment for a specific section of pavement that was hopefully selected for repair by the network- level system (Smith 1991). Pavement analysis and design are complex engineering problems requiring a systematic approach to quantify and analysis the many variables which influence identification and selection of appropriate maintenance and rehabilitation techniques.

5. Results and Analysis

A summary of average daily traffic (ADT) and a pavement rehabilitation year over the past 30 years (1970 – 2002) are shown in Figure 1. From the data presented, it can be seen that the ADT has been increasing by about 53.8% since 1994 in Western Australia (WA). This showed that the

use of full depth asphalt pavement to construct and rehabilitate heavily loaded urban roads has rapidly grown in WA over the past nearly 10 years and the costs for Pavement M & R have also been increasing from year to year. For example, the average daily traffic in 1984, 1990 and 1994 was 5971, 6860 and 7850, respectively. However, very good correlation ($R^2=1$) between construction and rehabilitation years as function of traffic flow on the sixty seven road locations. Guyer (2009) evaluated the pavement thickness that must be design to withstand the anticipated traffic roads, categorized by type and weight of vehicles, and measured by average daily volume (ADV) of each type for the design life of pavement. Author stated increasing the gross weight by as little 10 percent can be equivalent to increasing the volume of traffic by as much as 300 to 400 percent and imposed largely a fatigue effect on the flexible pavement as rapidly increased number of loads repetition per vehicle operation.

A summary of pavement crack distributions (i.e. crack 1, crack 2 and crack 3) is shown in Figure 2. As it can be seen from the results, the crack distribution for type 1 and 3 in 1984 – 1986 were above 85% all over the area. In addition, the crack types 3 were above 50% even in 1999. This showed that the stress and strain of the flexible asphalt pavement as the result of traffic loading and environmental factors (i.e. Temperature, ages and healing) might have deteriorate and damage the asphalt pavement on these particular years. Besides, the pavement construction and rehabilitation performance might not have also been as such effective and efficient. Although, similar pattern and good correlation ($R^2=1$) between crack type 1, crack type 2 and crack type 3 in terms of the size distribution. The Federal Highway Administration (FHWA) of the U.S. Department of Transportation (Stubstad et al. 2012) developed an approach for incorporating techniques used to interpret and evaluate deflection data for network- level pavement management system (PMS). According the FHWA guide fatigue cracking should not exceeding 25 percent of the total area within the first 15 years' service (Stubstad et al. 2012).

The Thornwaite Moisture Index (TMI) versus pavement crack of the seven roads categories is shown in Figure 3. The analyses indicated that the TMI for the seal granular pavement were low in percent (i.e. about 50%) during the past 20 years (1970-1990) and then, rapidly drop below zero after 1990 onward. This indicated that the roughness, rutting and cracking of sealed asphalt pavement within the past years were everywhere as the result of environmental factors such as temperature, ages and healing. It is considered that pavement M & R performance actions were not as such effective and sustainable on those periods. Though, similar pattern and very good correlation ($R^2=1$) between crack type 1, crack type 2 and crack type 3 in terms of the size distribution. Austroads has recently developed road deterioration models for roughness, rutting and cracking predicting of seal granular pavement, which represents 85% of sealed pavement in Australia (Ferreira et al. 2012).

An Average daily traffic versus heavy vehicles for seven different types of roads categories from sixty seven locations is shown in Figure 4. From the data presented, it can be seen that the heavy vehicle volume (HVV) on the traffic roads has been increased by 30 to 40% since 1990. This indicated that the wheel load of heavy trucks contribute to several forms of pavement distress. However, very good correlation ($R^2=1$) among the seven different types of roads categories in terms of pavement distress and fatigue as function of the heavily urban town traffic flows. The National Cooperative Highway Research Program in the U.S. (NCHRP1993) studied the effect of heavy-vehicle characteristics on pavement response and performance. The report concluded that the wheel loads of heavy – trucks can contribute to various forms of pavement distress and damage that influence sensitivity of truck wheel load. Fatigue damage varies over a range of 20:1

with typical variations in axle loads and over the same range with typical variations in pavement thickness (NCHRP1993). Similarly, Bonaquist et al. (1989) evaluated the effect of tire pressure on flexible response and performance, and the results showed increased rutting and cracking for section trafficked with the higher tire pressure of heavy-vehicle (HV).

The pavement construction and rehabilitation year for the surface types of asphalt concrete (AC) is shown in Figure 5. From the data demonstrated, it can be seen that the pavement rehabilitation for the cracks is twice in every year since 1990. These indicated that the deterioration of flexible pavement has been increased by 50 percent than 1970s due to traffic loading and environmental factors in the urban cities. While, very good correlation ($R^2=1$) between the construction years and the asphalt concrete rehabilitation years on the sixty seven road location as function of road surfacing. Blankenship et al. (2003) reported that it is common to see cracks reflect through a new hot-mix asphalt overlap in three to five years. The water infinity ration, freeze, thaw cycles and repeated loading cause the asphalt to deteriorate at joint and will eventually cause revelry. The reflecting structural degradation might also occurred as a result of moisture through the cracked pavement and deteriorates the base and loss of support underneath the joint concrete pavement slab.

Slurry Seals (SS) construction and maintenance years for different types of Asphalt Concrete on twenty five locations is shown in Figure 6. As it can be seen from the analyses, The SS construction and rehabilitation years are somehow persistence ($R^2=1$) which is the state of being quality for pavement M & R performance of the flexible pavement ver. Although several different rehabilitation strategies have been used in Western Australia, reflecting crack through joint concrete pavement overlays has been a persistence problems ever since. According to Chen et al. (2006) the performance of cracking has been related to the several premature failures. The small openings in pavement cracking retarding grid and lack of an effective bonds can causes the layer to great separation and then, cause to failures of the pavement structure.

6. Conclusion

The use of full depth of asphalt pavement to construct and rehabilitate heavily loaded urban roads has rapidly growth in Western Australia. The average daily traffic (ADT) has been increased by 53.8% since 1994. Similarly, the costs for pavement M & R have also been increasing from year to year. The pavement crack distribution (i.e. crack type 1, type 2 and type 3) were above 50% all over the area since 1999 although the crack distribution for type 1 and 3 in 1984-1986 were above 85%. The deteriorate and damage of the flexible asphalt pavement might have occurred due to the increased of the traffic loading in the urban roads and environmental factor (i.e. temperature, ages and healing) on these particular years. According to FHWA guide fatigue cracking should not exceeding 25% of the total area within the first 15 years' service (Stubstad et al. 2012).

The Thomwaite Moisture Index (TMI) for the seal granular pavement were low (about 50%) during the past 20 years (1970-1990) and then, rapidly drop below zero after 1990 onward. This indicated that the roughness, rutting, and cracking of seal asphalt pavement within the past years were everywhere as the result of temperature. However, Austroads has recently developed road deterioration models for roughness, rutting, and cracking predicting of seal granular pavement which represent 85% of sealed pavement in Australia (Ferreira et al. 2012).

The pavement construction and rehabilitation for the pavement cracks are twice in year since 1990 and the deterioration of flexible pavement has been increased by 50% than 1970. Blankenship et al. (2003) reported that it is common to see crack reflected through a new hot-mix asphalt overlap in three to five years. Although several different rehabilitation strategies have been used in Western Australia, reflecting crack through joint concrete pavement overlay has been a persistence problems ever since. According, to Chen et al. (2006) the performance of cracking has been related to the several premature failures and lack of an effective bonds between aggregate can causes the layer to separation and then, cause to failure of the pavement structure.

The pavement performance of the predicting model using probabilistic roads network of pavement engineering perform well in all categories and it is recommended to do the pavement work using the probabilistic network models.

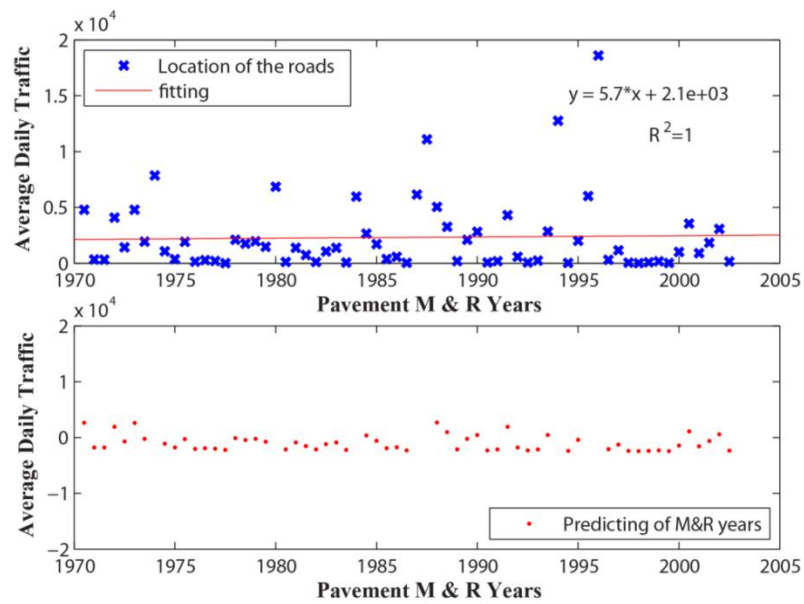


Figure 1: Average daily traffic versus pavement maintenance and rehabilitation years of seven roads categories on sixty seven locations

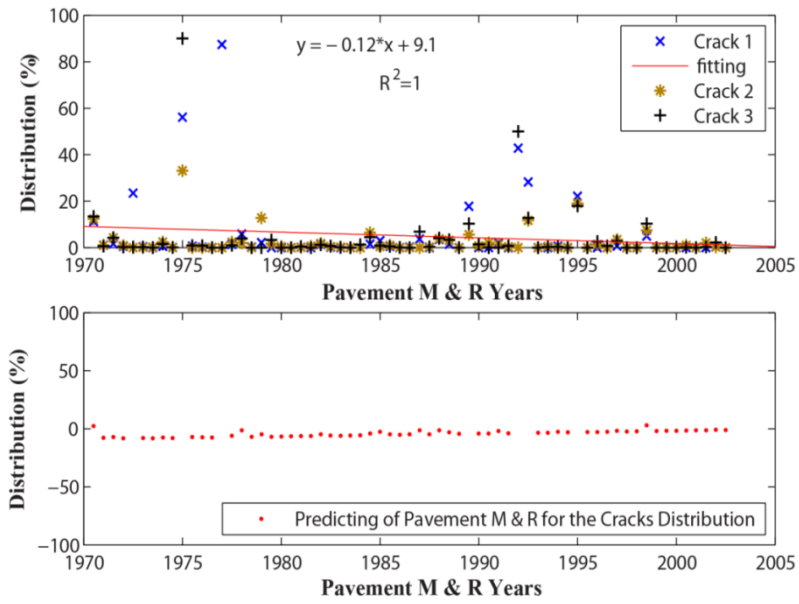


Figure 2: Crack distribution versus pavement maintenance and rehabilitation years of seven roads categories on sixty seven locations

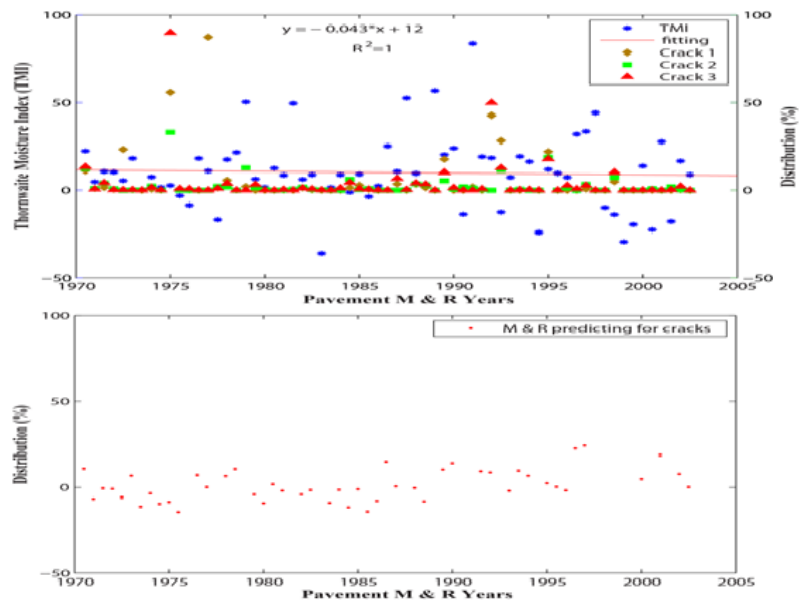


Figure 3: Thornwaite Moisture Index (TMI) versus pavement crack for seven different types of roads categories on sixty seven locations and Predicting of pavement M & R for cracks

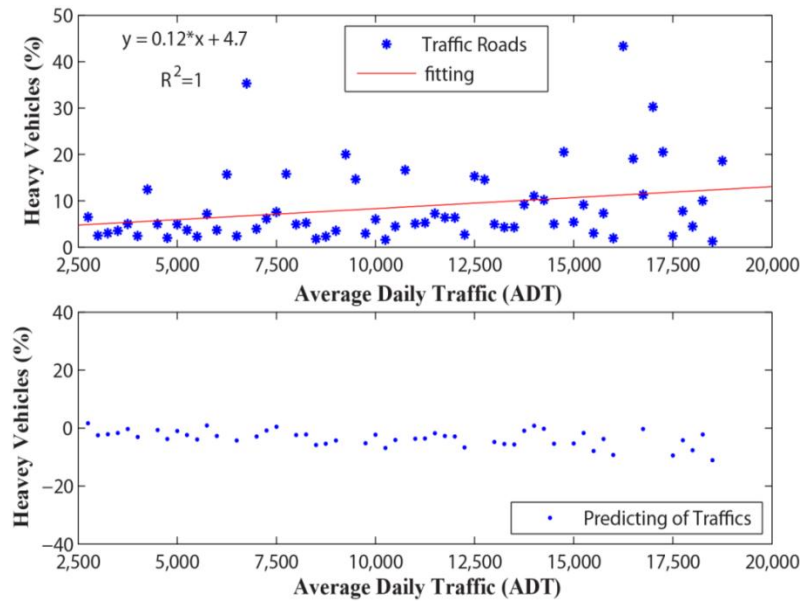


Figure 4: Average daily traffic versus heavy vehicles for seven different types of roads categories from sixty seven locations

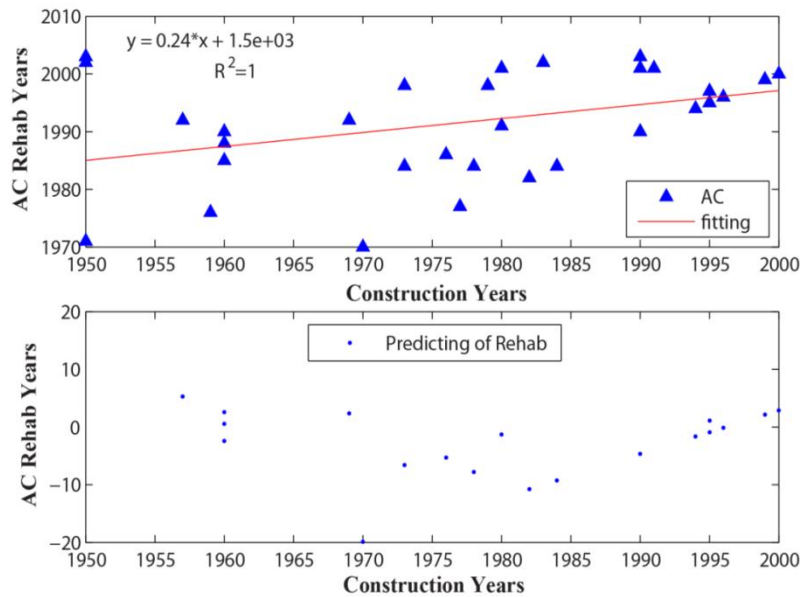


Figure 5: Asphalt Concrete rehabilitation years versus construction years for different types of Asphalt Concrete on thirty six locations

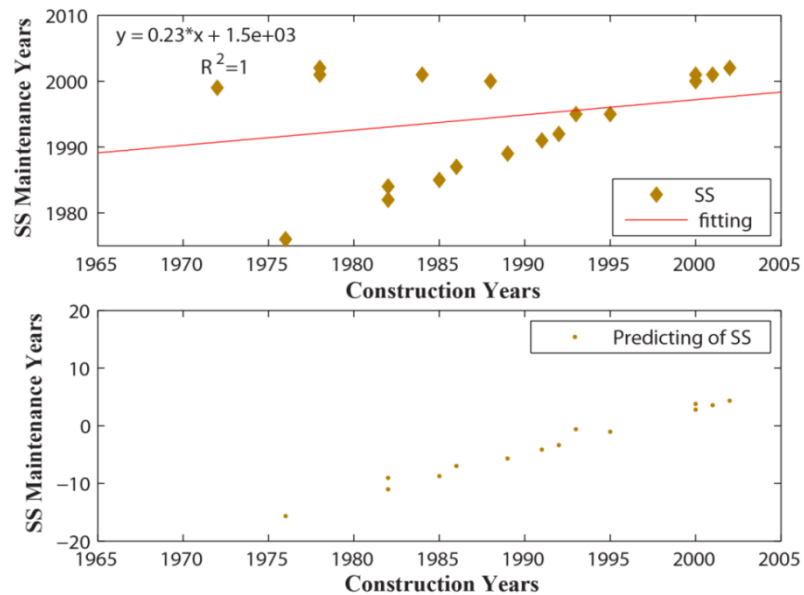


Figure 6: Slurry Seals maintenance years versus construction years for different types of Asphalt Concrete on twenty five locations

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