Research on development of road engineering automated index detection equipment importing the circular economy strategies

（循環経済戦略を取り入れた道路工学自動指標検出装置の開発に関する研究）

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Abstract

This research focuses on an analysis of the environmental impact and benefits assessment, combines energy-saving and reduces carbon emissions with new different construction methods and technologies for asphalt concrete, circular economy materials applied in Taiwan's forward-looking infrastructure including oxidizing slag and incineration ash pellets, and research on the development of automated equipment for paving damage identification to improve road inspection efficiency.

On the development of automated equipment for paving damage identification, the identification process introduces AI technology and integrated system development, to accelerate the overall road inspection efficiency.

Manual paving damage identification operation takes about 10 days, now it only takes less than 1 day identified in real-time by artificial intelligence, capturing all PCI damage impact factors such as pits, cracks, and patches, including the length, width, and area of damage.

In the environmental impact assessment section, this study uses game theory to find the most suitable manufacturers to reduce the impact of their carbon emissions on the overall environment, and build a lean management system for impact factor identification and systematic presentation.

Keyword : energy-saving, carbon emissions, asphalt concrete, lean management, game theory

Chapter 1. Introduction

1.1 Motive and Background of study

The motivation of this research is conducted to help the important actors in the pavement management are divided into three levels, namely leader in real-time visualized management, while the pavement engineer to improve management, and user in develope the travel quality. This research focuses on the roads throughout Taiwan. Containing National freeway, highway, and the urban roads related the people.

1.2 Purpose of Study

The purpose of the research is divided into two, namely to improve management performance and to reduce dissatisfaction cases. To improve performance management, it starts in introducing artificial intelligence identification technology to pavement image as development and construction of automation equipment and automatically identifying damage such as potholes or cracks. Then establish a pavement maintenance management strategy, and explore and analyze static and dynamic maintenance application strategies through the relationship between different pavement engineering indicators. Finally, the concept of energy saving and carbon reduction and the technology of system development are introduced into fully intelligent management technology and information application

1.3 Research scope

This study uses roads throughout Taiwan as the scope of the study and investigates the paving temperature in Hiroshima as an evaluation reference for the impact factors of energy conservation and carbon reduction.

The main contents are national highways, (including National Highway No. 1 to National Highway No. 10), expressways and urban road. (Based on data from the three cities, Taipei, Taoyuan, and New Taipei City). The reason for the selection was that the national highways were the highest-grade paving, from outsourcing model, materials, construction methods, technology, etc., and discuss the causes of its damage.

The expressways connect cities between Taiwan, the introduction of automated equipment technology for inspection and application will be a reference for improving the efficiency of the overall application. Capital Taipei, its application on urban roads will effectively serve as a criterion for the overall goodness of urban roads. The relevant roads coming down from Taoyuan International Airport will directly affect Taoyuan City. New Taipei City, the municipality with the largest population can be closest to the consideration of public satisfaction.

1.4 Research flow chart

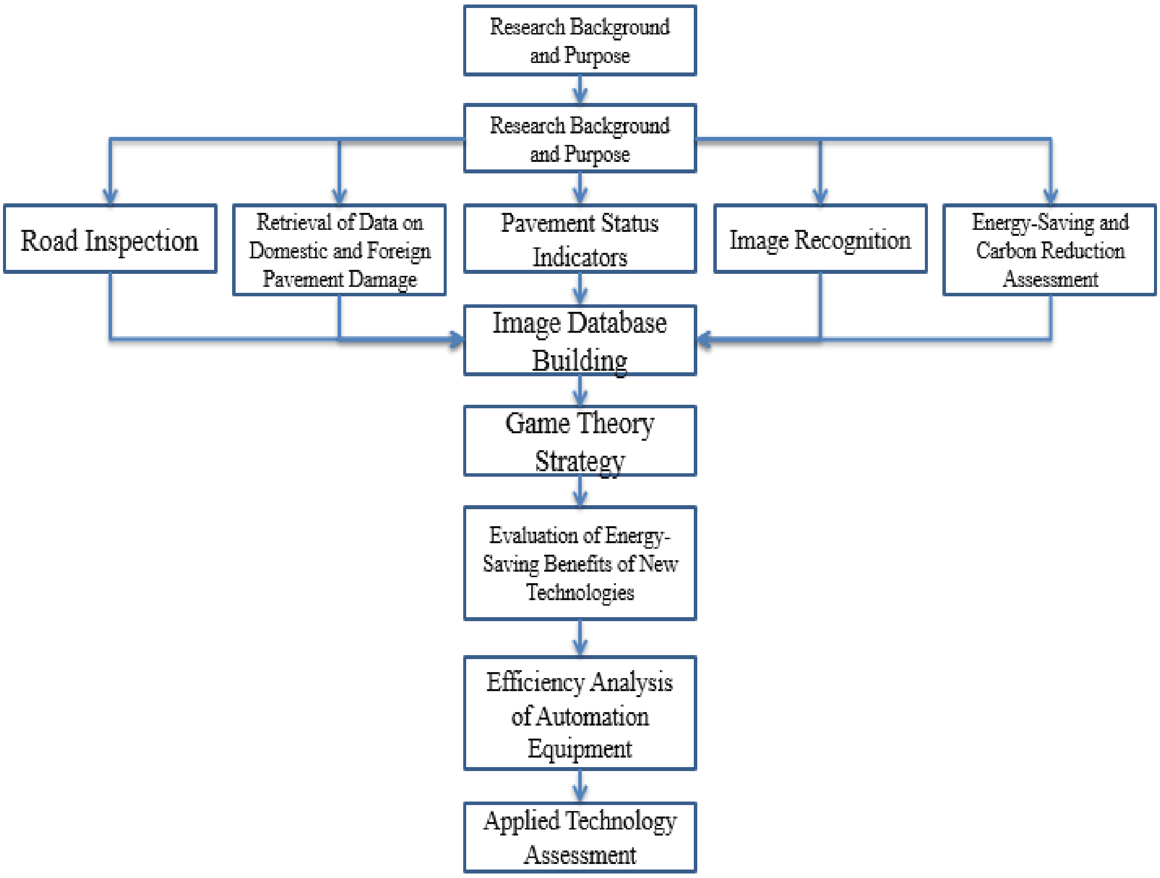


Fig. 1-1 flow chart

Chapter 2. Literature Review

2.1 Pavement Inspection Indicators

In the maintenance and management of national highway pavement, local testing data are collected and related testing indicators classified into categories. Local testing equipment needs to have the characteristics of quick detection and fast movement, without the need for a traffic maintenance plan.

The high-low detector, skid resistance tester, and flexometer from Freeway Bureau have the above characteristics. The road is inspected every year, but the pavement damage should be included in the project due to the high level of service and safety required of the national highway when the pavement is damaged, it will be repaired by the maintenance staff of each engineering section. The relevant literature review was conducted for the paving detection indicators.

2.1.1. International Roughness Index

For the evaluation of the national highway surface, we first understand the definition of flatness [2]. The flatness is mainly divided into three types of deformation section:

Longitudinal deformation, transverse deformation, and horizontal deformation. The deformation of the surface generally affects the lateral and vertical acceleration of the vehicle. The vertical acceleration has a great influence on the comfort of the user on a deformed surface. Lateral acceleration affects the rolling or shaking of the vehicle [3].

The cause of rolling comes from the deformation of the road parallel to the direction of the vehicle. The cause of shaking comes from the deformation of the vertical axis. The rolling of the vehicle is explained differently, in some cases, it greatly affects the unpleasantness of longitudinal acceleration. The common flatness indicators foreign and domestic: International Roughness Index, Profiler Index, Ride Number, Maysmeter Index, Root Mean Square Vertical Acceleration. Subjective flatness indicators: Present Serviceability Index, Present Serviceability Rating, Standard deviation of flatness and 3m straight edge.

The indicators that have been cited internationally as the actual evaluation acceptance criteria today are the International Roughness Index and Profiler Index, the domestic is the Standard deviation of flatness. Various instruments of flatness indicators have been developed internationally, different flatness indicators output different results. The application differs base on road grade. It is not easy when the indicators of different applications need to be converted, and difficult to use properly in the maintenance and management.

Therefore, the World Bank conducted the International Road Roughness Experiment (IRRE) in Brazil, 1982, to try to derive an internationally common roughness index to establish a common language between countries. This flatness index is It is the international roughness index IRI.

1. International Roughness Index(IRI):

Different types of instruments and methods tested at 49 different sections on four different forms of paving conducting the International Road Roughness Experiment: Asphalt concrete, surface treatment, gravel, and dirt. Manual operation methods included: cross-section profiler, inertial profiler, react profiler, subjective ratings, etc. The International Roughness Index is built in a mathematical model and calculated through a quarter car model. A quarter car is one of the four wheels on a car equipped with a special mechanical system device to simulate a ride response. Accumulation of vibration caused by road bumpiness and divided by the distance traveled, units include meters/km or inches/miles. According to the National Cooperative Highway Research Program report 228, because the quarter car is a calibration reference, there is another name for this system, called the Golden Car, as shown in Figure 2-1. Its system is mainly divided into two parts, the spring axle mass, and non-spring axle mass. The spring axle mass main structure is a body mass, composed of damper and suspension spring. The non-spring axle mass is the axle mass and the vertical spring. The reaction between the two is to record the vehicle body and road surface response and calculate its IRI value. The establishment of IRI from the World Bank report established five goals:

(1) Temporality: Time will not affect its measurement.

(2) Validity: Any device can be calculated by the formula of IRI, no difference in IRI, despite instrument errors.

(3) Indicative: Any road grade or road of different materials can be evaluated using this indicator.

(4) Simplicity: It can simply indicate the current paving situation, and direct response to the user the cost, quality, or safety.

(5) Popularity: It has been widely used in related institutions, giving the public correct pavement information.

The International Roughness Index has become an internationally used flatness index after being supported by the theory of the quarter car, many analytical methods are widely used in profile indicators. It has the same definition and nature as the real profile and can be used for any profile measurement.

The analytical equations have been developed and tested with minimal impact on measurement properties such as sample intervals. Examples of computer programs have been published by the World Bank and have been used for profiling and other experimental new software calculations using IRI. The wave number of the IRI quarter car filtering reaction is shown in Figure 2-2. The increase in the sine wave output value is due to the increase in the input value. The result is shown as multiple gains in the graph. The gain is a loss of dimension in the graph. However, if the input value is a sine wave with a slope increase, the output value is amplified and its value appears at the peak point.

The flatness IRI is a linear representation, all the elevation values measured for the profile are increased by a certain percentage, the IRI also increases. It means that the section is very flat when IRI calculation is 0. There is no theoretical limit on the upper limit of flatness. However, when the IRI of the paving exceeds 8m / km, its accumulated value will have an adverse effect on the comfort of driving.

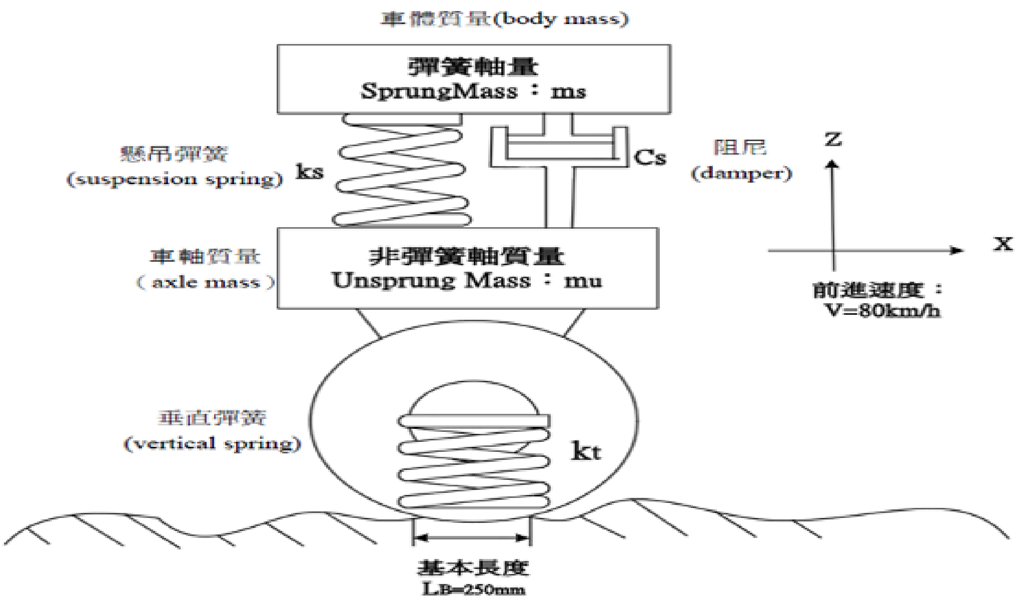


Figure 2-1 Concept of the golden quarter car model

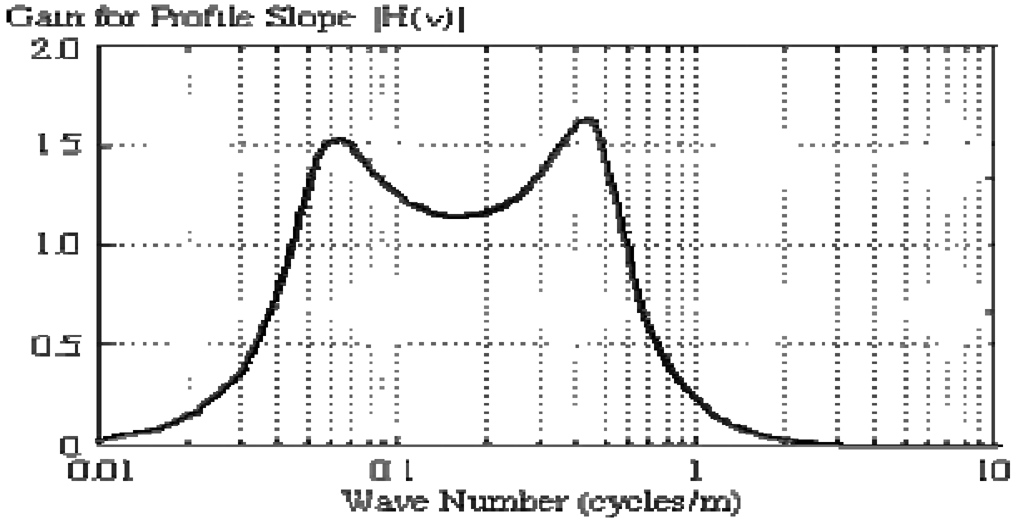


Figure 2-2 IRI Spectrum distribution

2.1.2. Pavement Structural Number

The cause of the traffic accident is closely related to the driver, vehicle performance, traffic engineering facilities, weather, and road conditions, and the slip resistance of the paving is extremely important for driving safety. One of the important functions of the paving is to provide good friction and driving quality, but if the surface layer loses its friction or transverse deformation, it is easy to cause the vehicle to spin or slip and lose control. Surface friction properties are mainly related to surface friction, vehicle speed, transverse deformation, and aquaplaning, the conditions of poor friction properties are:

1. Bleeding asphalt reduces the friction of the interface between the tire and the pavement in a humid climate.

2. The water in the rut cause aquaplaning.

3. Poor wearability of the paving aggregate making the surface too smooth, and reduce the friction of the pavement on rainy days.

4. Improper cross slope of the paving increases water residence time, reduces the friction of the pavement and increases the potential water slip.

In recent years, Arash Rezaei and Eyad Masad (2012) developed anti-skid models, a deterioration equation of anti-skid performance considering the factors in anti-skid quality, surface characteristics of asphalt mixtures (Friction, texture and slip resistance), and traffic level. Based on laboratory and field measurements and analysis, aggregate gradation is described as a Weibull distribution [5].

The formula is as follows:

Wei-Ying, Huang (2000) carried out anti-slip testing operations on flexible pavements in different wet states to explore the influence of the wet state on the anti-sliding ability of the open grade surface layer of domestic expressways, and initially constructed a regression prediction model:

$$y = 0.7349 - 0.0427 \ln(x)$$

y is the anti-slip value of the friction coefficient,

x is the thickness of the water film (mm).

From the above formula, the anti-sliding value of the open grading surface layer decreases naturally with the increase of the thickness of the water film, and the regression coefficient (R2) of the model is 0.9756. When the water film thickness reaches the critical value of 0.25 mm, the anti-sliding performance of the paving will obviously change.

S. Owusu-Ababio (1995) collected the pavement age, speed limit, traffic volume and location of flexible paving in Connecticut, USA, from 1984 to 1989, and builds a model for anti-skid value prediction with regression analysis and neural network.

The regression model is as follows:

SN = anti-skid value

PLC = traffic location (-1 for river valley, 0 for hill, 1 for coast)

MADT = average daily traffic

P.W. Jayawickrama and B. Thomas (1998) studied the anti-skid value of roads with different flexible paved roads and climatic zones in Texas, it was found the temperature and rainfall in the climatic factors were the main factors affecting the anti-skid value of the road surface. The prediction model is as follows:

SN64 = Anti-slip value at 64 KPH

TEMP5 = average daily temperature for the 5 days before the test

RF5 = Cumulative rainfall 5 days before the test

JD = vids date

Ir = Pavement location, r = 1 ~ 5

2.1.3. Pavement Structural indicators (Falling Weight Deflectometer)

Pavement degradation means that the characteristics of various pavement performance will decay overtime or by other variables, the mode of degradation is to explain the attenuation variables of various pavement performance characteristics in mathematical, also known as the pavement performance prediction model. According to the needs of the national highway surface, the performance indicators are defined as flatness, deflection, anti-skid, and pavement conditions.

The degradation modes in the paving system are generally divided into three types:

1. Mechanistic method

The mechanistic method uses the viscoelastic, elastic or finite element method to find the relationship between traffic load, stress, and strain. This method is widely used in structural capacity prediction or material properties of paving projects. Shook (1982) used the strain to predict the development of cracks in flexible paving, this method is imported to the design process by the Asphalt Institute, it is a causal analysis method for quantitative analysis according to its concept.

2. Mechanistic-Empirical method

The mechanistic-empirical method uses the basis of mechanistic and links with pavement service performance locally measured. The AASHTO 1986 design guidelines rebound modulus replaced the soil support factors and other empirical parameters, 1972 edition.

3. Empirical method

The empirical method uses local data or expert judgment to make performance predictions, its significance lies in interpreting the data obtained from local tests or inspections with a suitable mathematical model, modern forecasting method for example. Modern forecasting can be classified as quantitative analysis and qualitative analysis. Quantitative analysis can be classified as causal analysis method, time series method, artificial intelligence method, and four more others.

The most common method is the causal analysis, and its most common one is multivariate regression, also called the multiple regression. This method assumes that a single quantified index is derived from multiple independent variables. Another quantitative analysis method is called the time series method, its definition is a sequence of a single variable arranged in chronological order, a program or called a simulation system, constructs a model to match the results, take the output of the system as the new input, the output number of the next time sequence is the predicted value we want to know. The time series generally uses the self-regression method, the moving average method, exponential smoothing, autoregressive moving average process, self-regressing moving average integration model, or the self-regressive heterogeneous fluctuation model by Robert F. Engle, 1982 (Nobel Memorial Prize in Economic Sciences Winner, 2003).

The artificial intelligence method takes advantage of the characteristics of fast computer computing, simulate human thinking patterns as the basis for implementing prediction methods, it is generally represented by expert systems, neural networks, and genetic algorithms. Other methods include the probability analysis model, Bayes' theorem, Markov chains or semi-Markov chains. From the foregoing, it can be seen that the pavement degradation mode is an application of modern predictive methods, the mechanistic method and the mechanistic-empirical method can be regarded as the multiple regression method in the causal analysis method. The empirical method can use all modern predictive models such as multiple regression, single variable regression, (semi-) Markov chain, neural network method to predict the performance of the pavement.

Unfortunately, the relationship of temperature, load, and strain to flatness, anti-skid, damage, the performance of flexible pavement viscoelastic material is not very obvious, instead, the empirical method or mechanistic-empirical method for single failure items such as cracks is widely used. The impact load of the deflectometer is transmitted to the pavement through a round load plate, the impact load will cause a temporary discoid deformation on the pavement, also known as the deflection basin (Figure 2-3).

According to the load applied to the paving and the deformation of the paving surface (deflectometer), various strengths of paving can be analyzed and calculated. In addition, falling weight deflectometer on rigid paving is also used to detect the interlock between adjacent sections on rigid paving, also known as the Load Transfer Efficiency. The purpose of non-destructive deflection testing is mainly to evaluate the strength of the pavement structure.

According to ASTM D4695, the general road deflection measurement guidelines, pavement deflection values provide structural analysis information for pavement systems, continuously measured deflection data can be used to determine the overall stiffness of the pavement system and the elastic modulus of each layer of material, etc. The test location and number of tests are determined according to the level requirements.

In the field of deflection detection, the vertical velocity duration curve of each layer of the road surface is usually measured with a speed gauge. The deflection duration curve is obtained by one integration along the time axis, from which the peak deflection value of each receiver can be read, the peak deflection value of each receiver can be connected and form a deflection bowl. Its common unit is mil (= 10-3 inch) or μm (= micron = 10-6 m). In order to facilitate future comparisons of deflection values, the deflection bowl is often divided by the peak value of the dynamic load as the normalized deflection bowl.

The deflection data obtained by the falling weight deflectometer simulating the load on the paving surface can indicate the bearing capacity of the paving surface, common paving deflection analysis indicators are as follows:

*Impact Stiffness Modulus

The definition of paving stiffness is: The dynamic load applied is divided by the pavement deformation measured under the load pan, this definition applies to both impact and vibration measurement methods, the only difference is the name: Impulse Stiffness Modulus, and Dynamic Stiffness Modulus. Its calculation formula is as follows:

I (D) SM = impact (dynamic) stiffness modulus

L = load applied

d0 = maximum deflection measured under load plate

From the above definition, the pavement impact stiffness modulus can be regarded as the overall pavement strength of the pavement under this load situation. Therefore, a section with uniform paving structure strength should have a uniform impact stiffness modulus value. Since the deflection calculation is based on the iterative analysis of multilayer elasticity theory, the local deflection bowl measured does not perfectly consistent with elastic theoretical models, the inverse calculation suitability from the deflection data should be determined first.

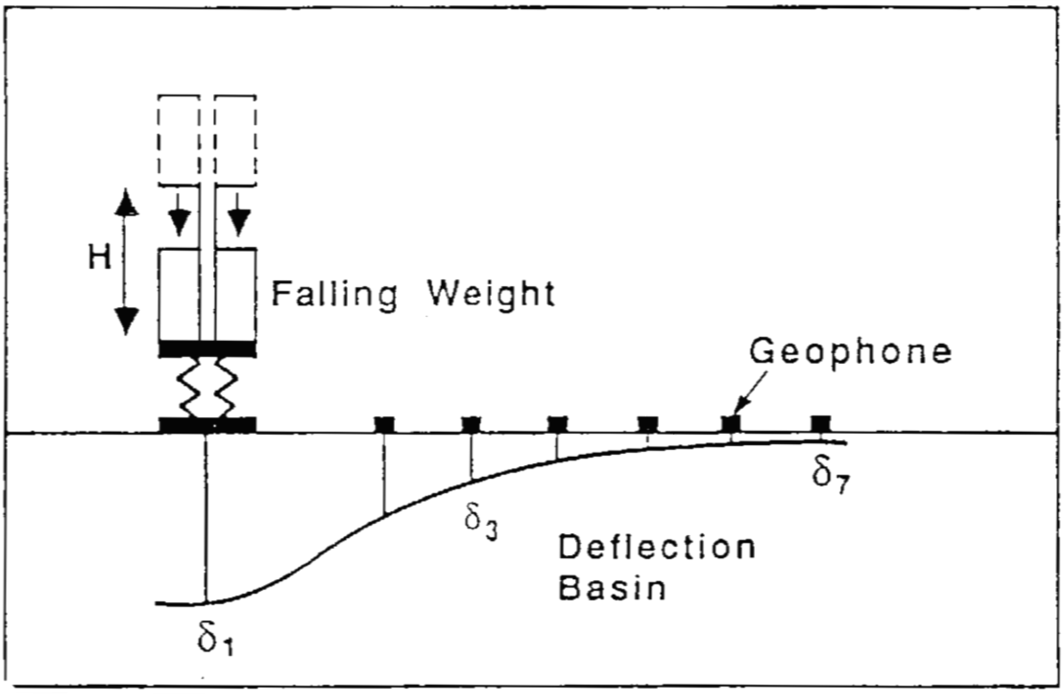


Figure 2-3 How the Falling Weight Deflectometer works

2.1.4. Pavement Condition Index

The surface damage of the pavement is a group of damage forms, from the earliest rut, crack, repair area, to the later transverse cracking, longitudinal crack, block cracking, stripping, etc. The Pavement Condition Index is developed by Darter and Shahin in the late 1970s to the early 1980s, after 20 years of development, the American Society for Testing and Materials formulated ASTM D 6433-99 applicable to roads and parking lots, and ASTM D 5340-98 applicable to airport paving. According to the specification, PCI is a numerical indicator that evaluates the overall condition of the pavement based on the results of the pavement current measurement and the observation of the pavement damage. It mainly investigates the structural integrity of the pavement and the driving conditions of the surface layer.

The PCI cannot measure structural capacity nor provide data of anti-skid or roughness. It provides an objective and rational basis for determining maintenance and repair needs and priorities. Continuous monitoring of PCI can establish the overall degradation mode of the paving, based on the current paving design, maintenance program verification and paving performance improvement, the maintenance feedback data can be used as the basis for determining the renovation needs of the paving. The rating range of PCI can be shown in Table 2-1:

Tab. 2-1 PCI Rating Ranges

PCI value	Chart	Rating
85 ~ 100		Excellent
70 ~ 85		Very good
55 ~ 70		Good
40 ~ 55		Fair
25 ~ 40		Poor
10 ~ 25		Very poor
0 ~ 10		Failed

According to ASTM D 6433-11 [4], there are 19 defined damage type,crocodile cracking, bleeding, block cracking, raised/recessed, wrinkle/wave, depression, shoulder elevation, longitudinal/transverse cracking, patch, smooth aggregate, pothole, rail crossing, rutting, pushing, slide cracking, bulging, weathering/stripping.

For easy classification, it is divided into four categories in the following table 2-2, crocodile cracking, block cracking, and slide cracking are measured by area, edge cracking, reflection cracking, longitudinal and transverse cracking are measured by length, then they are subdivided into two types based on the different measurement methods.

Tab. 2-2 19 Types of Damage of the PCI Definition

Type	No.	Name
Cracking (area)	01	Crocodile cracking
	03	Block cracking
	17	Slide cracking
Cracking (length)	07	Edge cracking

	08	Reflection cracking
	10	Longitudinal and transverse cracking
Surface damage	11	Patch
	13	Pothole
	19	Weathering and stripping
Surface deformation	04	Raised/Recessed
	05	Wave
	06	Depression
	15	Rutting
	16	Pushing
	18	Bulging
Other	02	Bleeding
	09	Shoulder elevation
	12	Smooth aggregate
	14	Rail crossing

The Pavement Condition Rating developed by the Ohio Department of Transportation, the calculation formula of PCR can refer to the following formula, and the scoring scale can refer to table 2-3:

N is the number of breaks present, Deduct(i) is the product value of weight, severity, and range of the broken item (i).

Tab. 2-3 PCR rating intervals

PCR value	**Chart**	**Condition**
90 ~ 100		Very good
75 ~ 90		Good
65 ~ 75		Fair
55 ~ 65		Fair to Poor
40 ~ 55		Poor
0 ~ 40		Very poor

2.2 Big Data & Multivariate analysis

Big data [6] is composed of huge data sets, the size of these data sets often exceeds the ability of humans to collect, apply, manage, and process them at an acceptable time. The size of data often changes, in 2012, the size of a single data set ranges from terabytes (TB) to tens of trillions of bytes (PB) [7].

In a 2001 study and related lecture, Doug Laney, an analyst at META Group (now Gartner), pointed out that the challenges and opportunities for data growth have three directions: Volume (data size), velocity (speed of data input and output), and variety (diversity) referred to as "3V" or "3Vs".Gartner and most companies in the big data industry continue to use 3V to describe big data [8]. Gartner modified the definition of big data in 2012: "Big data is a large, high-speed, and/or changeable information asset. It requires new processing methods to promote stronger decision-making capabilities, insight, and optimization.

In addition, some organizations define the fourth V in addition to the 3V: Veracity, as the fourth characteristic. Data mining are methods used to explore and analyze big data and also known as multivariate statistical analysis when in conjunction with Multivariate Statistical Analysis. For efficient system integration and analysis, this methodology is often used in management science, social science, and life sciences. Multivariate analysis is mainly used to analyze data with multiple variables, explore the correlation between data or clarify the structure of the data, and is different from the parameter estimation and hypothesis testing emphasized by traditional statistical methods. Because multivariate analysis methods require complex and large amounts of calculations, computers are often used for calculations. Commonly used statistical software are SAS, SPSS, and Statisticala. Common analysis methods include Principal Component Analysis, Factor Analysis, Discriminant Analysis, Cluster Analysis, Canonical Correlation Analysis, and Structural Equation Model (Structural Equation Model, Linear Structure Relation.

2.2.1. Big data and Open data

Examples of applications of big data include big science, RFID, network of sensing devices, astronomy, atmospheric science, transportation, genomics, biology, analysis of big social data, Internet file processing, indexing of Internet search engines, Communication details, military investigations, social networks, commute time predictions, medical records, photo images, and video archives, large-scale e-commerce, etc.

With 150 million sensors in the Large Hadron Collider, it transmits data 40 million times per second. Nearly 600 million collisions occurred every second in the experiment. After filtering out 99.999% of the collision data, about 100 effective collision data were obtained. Only 0.001% of useful data was recorded after filtering the result data. The data volume of all four colliders produced 25 petabytes per year before copying, and 200 petabytes after copying. If all the data in all experiments are recorded without filtering, the amount of data will become excessively large and extremely difficult to handle. The amount of data each year will reach 150 million petabytes before copying, which is equivalent to nearly 500 exabytes of data per day. This number indicates that daily experiments will produce data equivalent to 50 zettabytes, which is 200 times the sum of all data sources worldwide.

Hans Roslin, professor of international health, uses the "Trendalyzer" software to present demographic data of humans worldwide for more than two hundred years, and cross-comparison with other data, such as income, religion, and energy use. At present, government departments in developed countries have begun to promote the application of big data.

In 2012, the Obama administration invested nearly 200 million U.S. dollars to launch the "Big Data Research and Development Plan". This program involves multiple federal agencies and agencies, including the U.S. Department of Defense, U.S. Health and Public Services. It is intended to speed up the development of science and engineering and improve national security by improving the ability to extract knowledge from large and complex data.

At the time of 2005, Amazon was one of the three largest Linux-based databases in the world. Wal-Mart can handle the consumption processing of more than one million customers in one hour, that's 167 times the intelligence of books in the Library of Congress. Facebook handles 50 billion user photos. The background of big data is inseparable from the rise of social networks such as Facebook and Weibo, people use social networks to spread information or communicate daily, the information is recorded on the Internet, and sociologists can analyze human behavior patterns and communication methods on the basis of this information.

Examples of applications of big data include big science, RFID, network of sensing devices, astronomy, atmospheric science, transportation, genomics, biology, analysis of big social data, Internet file processing, indexing of Internet search engines, Communication details, military investigations, social networks, commute time predictions, medical records, photo images, and video archives, large-scale e-commerce, etc.

The Durkheim Project in the United States is to analyze suicidal tendencies based on personal data on social networks. The program selects subjects from retired US soldiers, collect data through Facebook ’s mobile app, and send user activity data to a medical database. The collected data will be analyzed by artificial intelligence systems, and then predictive programs will be used for real-time monitoring whether the subject has harmful behavior. The emergence of big data has increased the demand for information management experts, Software AG, Oracle, IBM, Microsoft, SAP, EMC, Hewlett-Packard, and Dell have spent more than $ 15 billion on data management analytics companies.

In 2010, the market value of the data management and analysis industry exceeded 100 billion U.S. dollars and grew at a rate of nearly 10% per year, which is twice the growth rate of the entire software industry. Economic development has promoted the use of intensive data technology. There are approximately 4.6 billion mobile phone users worldwide and between 1 and 2 billion people connect to the Internet. From 1990 to 2005, more than 1 billion people around the world entered the middle class. The increase in income has led to an increase in literacy rates, which in turn has led to the growth of information volume.

The world's capacity for exchanging information through telecommunication networks was 281 petabytes in 1986, 471 petabytes in 1993, 2.2 exabytes in 2000, and 65 exabytes in 2007. Because of the hardest thing to get in the open data of transportation is the real-time driving speed [13], currently known the Google Map navigation function [14], you can use the user ’s mobile speed to estimate each section the speed of movement and the estimated time required to drive, government departments use VD and real-time traffic photography, infer the situation of real-time road use as a reference for the driving route [15].

At present, in order to overcome the problem of insufficient data volume, the public needs to collect real-time traffic data in the website Opentraffic, install driving apps to share driving information, and import them into the database for back-end developers as applications. GPS ... etc., to show more results. The amount of data provided by ETC reaches 14 million daily data, and the accumulated data has reached 9 billion so far. Not only has the information provided by the above-mentioned collection methods been fully provided, but the obtained information is also more comprehensive and more accurate. If there is no privacy issue, it is more capable Obtain the eTag of each vehicle and analyze the complete trend, but in the current data, we can get the traffic flow between each mast, the model time, and estimate the correlation. With high-frequency and multi-year records, this study can also use annual comparative analysis to find the factors affecting the traffic flow on weekdays, holidays, and holidays, and even more sophisticated analysis based on the construction information, based on the history of previous years. Data exploration to provide a more accurate basis for future forecasts.

According to the TCRP Open Data Opportunities and Challenges of the American Transportation Association In the study of the transportation sector, among the 764 big data applications, the public application statistics, and government department applications and the proportion of different mobile phone systems operations were discussed.

The survey showed that the following software uses open data Highest frequency:

1. GoogleMaps.
2. Google Transit: path planning.
3. HopStop: Urban transportation guidelines include public transportation, taxis, bicycles, walking guides, and maps.
4. OneBusAway: Integrated booking system for airplanes, trains, and buses.
5. Open Trip Planner: Provides passenger traffic information and road network planning.
6. Rome2Rio: The search engine for the tourist transportation route plan, which integrates transportation information of aviation, train, bus, and ferry.
7. RouteShout: Public transit time prediction.
8. WalkScore: Evaluate the value of a house based on economics and transportation convenience.

2.2.2. Principal Component Analysis (PCA)

In multivariate statistical analysis, Principal Components Analysis (PCA) is a technique for analyzing and simplifying data sets [16]. The principal component analysis is often used to reduce the dimensionality of a dataset while maintaining the features in the dataset that contribute the most to the number of variances. This is done by preserving low-order principal components and ignoring higher-order principal components. Low-order components can often retain the most important aspects of the data. However, this is not certain, it depends on the specific application.

Since the principal component analysis relies on the data given, the accuracy of the data has a great impact on the analysis results. The principal component analysis was invented by Carl Pearson in 1901 to analyze data and build mathematical models. The main method is to perform feature decomposition on the covariance matrix to obtain the principal components of the data (ie, feature vectors) and their weights (ie, feature values). PCA is the simplest method to analyze multivariate statistical distributions by feature quantities.

The result can be understood as an explanation of the number of variances in the original data: in which direction is the data value the most influential on the number of variances. In other words, PCA provides an effective way to reduce the data dimension, if the analyst removes the component corresponding to the smallest eigenvalue from the original data, the resulting low-dimensional data must be optimized. The principal component analysis is particularly useful when analyzing complex data, such as face recognition. In general, this kind of operation can be seen as a way to expose the internal structure of the data, so as to better explain the variables of the data. If a multivariate data set can be displayed in a high-dimensional data space coordinate system, then PCA can provide a relatively low-dimensional image, which is a "projection" of the original object at the point with the most information. In this way, a small number of principal components can be used to reduce the dimensionality of the data. PCA is closely related to factor analysis, and there are already many statistical packages that mix the two analyses. The real factor analysis assumes the underlying structure and obtains the eigenvectors of the small difference matrix.

2.2.3. Sensitivity analysis

Research and analysis sensitivity method, how the change of the state or output of a system (or model) changes the system parameters or surrounding conditions[17]. In the optimization method, sensitivity analysis is often used to study the stability of the optimal solution when the original data is inaccurate or changes. Sensitivity analysis can also determine which parameters have a greater impact on the system or model. Therefore, sensitivity analysis is important in almost all operations research methods and when evaluating various schemes.

Sensitivity analysis in linear programming for linear programming problems: Here max means to find the maximum value, S.T. means bound by, X is the objective function and xj is the decision variable.

It is usually assumed that aij, bi and cj are known constants. But these parameters are often some data obtained from estimation or prediction, so there are errors. In the actual process, these parameters will change to varying degrees. For example, in the linear programming problem of product matching, the cj in the objective function is generally related to factors such as market conditions. When market conditions and other factors change, cj will change accordingly. The aij in the constraint conditions changes with factors such as process conditions and the value of bi is related to factors such as the ability of the enterprise. The problem to be solved by sensitivity analysis in linear programming is: how will the optimal solution change when one or more of these data changes? In other words, when these data change over a wide range, the optimal solution will not change. Sensitivity analysis in the input-output method can be used to study how the impact of various major economic policies on various sectors of the national economy. For example, the US government has used input-output tables to study the impact of a 10% increase in employee wages on commodity prices in various sectors of the national economy.

The results of the study show that when the wages of employees increase by 10%, the price of construction products will increase by 7%, the price of agricultural products will increase by 1.3%, and the prices of products in other sectors will increase by 1.3 to 7%, and the cost of living will increase by 3.8. %, the actual benefit for employees is 6.2%.

Sensitivity analysis in scheme evaluation can be used to determine whether the value of the alternative scheme changes or how much it changes when the evaluation conditions change. For example, when using an evaluation table for evaluation, it is necessary to determine the weight coefficient of each sub-objective and the number of scores of each sub-objective. There will be more or less subjective consciousness among the parties, and different people may have completely different values. Therefore, it is necessary to consider how the evaluation result will change when the assigned weighting coefficient or the number of rating changes within a certain range.

In a sensitivity analysis of order batches In the analysis of batch-to-batch interval purchase models, the economic order quantity Q * can be calculated by the following formula: Where

D is the demand per unit time, K is a fixed fee per order, h is the storage fee per unit of unit time. They are generally estimated based on statistical data, which differs from the actual situation and requires sensitivity analysis. Use D1, K1, h1, and Q1 to represent the actual demand, order quantity, storage fee, and adjusted economic order quantity. ΔD, ΔK, Δh, and ΔQ * represent the relative changes in demand, order quantity, storage fee, and economic order quantity: After the calculation, we get: After inserting specific values, the above formula can be used to illustrate the comprehensive impact of ΔD, ΔK, and Δh on the order quantity.

2.2.4. Cluster Analysis (K-means)

Cluster analysis is used to test a certain type of interdependence [18]. In practice, it is often used to further divide customer characteristics into several categories to achieve market segmentation. The calculation method used in the cluster analysis is unsupervised, so when clustering, there are no known categories, and the purpose is to reasonably divide the data into clusters based on some standard. Cluster analysis is grouped together according to the similarity of data, and the meaning after analysis also needs to be explained later to make people understand. Cluster analysis is often used to classify data to facilitate subsequent data mining or modeling Use, such as market segmentation and then different marketing strategies.

The commonly used cluster analysis includes the K-means method, two Steps method, etc. The timing and characteristics of the cluster analysis are slightly different. The K-means algorithm was officially published by MacQueen in 1967. The calculation process is completed according to the following steps and the calculation follows.

1. Randomly select K Initial Cluster Centers

2. Classify each profile into the cluster closest to the cluster center.

3. Calculate the new cluster center

4. When the distances between all cluster centers are the same, the calculation ends, otherwise, go back to step 2.

K-means is one of the widely used cluster analysis techniques, but it depends on the choice of the cluster center of the start to process the data (Tou and Gonzalez 1977) and may ignore its cluster analysis results converging to the local minimum (Selim and Ismail 1984).

Therefore, the number part of clusters is still under research (Kuo, Ho and Hu 2002). The two-stage cluster analysis method can also be called a two-stage clustering algorithm. Its basic concept is to complete the data clustering operation in a two-stage manner. The steps of this algorithm can be divided into the pre-cluster step and cluster step:

1. Pre-Cluster Step

The method used in this step is the BIRCH (Balance Iterative Reducing and Clustering Using Hierarhies (BIRCH)) algorithm for large sample clustering in hierarchical clustering. After loading all the data, the original data is compressed into processed subcluster.

2. Cluster

In this step, the logarithmic function (Log) is used as the formula for distance measurement. The clusters in step 1 are again subjected to cluster analysis, and the sub-cluster is gradually merged into larger clusters. Since no data needs to be loaded again, it is more suitable for When processing large-scale data, it can distinguish the number of clusters automatically or set the number of clusters manually. The two-stage cluster analysis method can process continuous or discrete values at the same time, which means that when performing clustering, data of various scales can be processed, but the data must meet two principles. The first is that there is no multiple between variables. Collinearity, the second is that variables must obey normal analysis (Park and Baik, 2006).

2.2.5. Support Vector Regression Analysis

In addition to the classification problem, the Support Vector Machine can also deal with the problem of data regression analysis [19]. The so-called regression refers to that the label corresponding to each instance is a continuous real number, not a discrete and distinct category (in SVM, it is often expressed as an integer). Supervised learning models in support vector machines and related learning algorithms are used for data classification and regression analysis.

Given a set of training samples, each labeled as belonging to one of the two categories, an SVM training algorithm constructs a new assignment as one of the other categories, making it a non-probabilistic binary linear classification. An example of an SVM model is like all points in the space, mapping the classification of different categories, and dividing it as much as possible through obvious gaps. Then when new samples are put on the same space and prediction basis, they will fall into the category of segmentation plane. When the data is unlabeled, supervised learning is not possible, and an unsupervised learning method is needed, which tries to find the natural classification of the data set, and then the new data is mapped to these formed groups. Cluster classification algorithms that provide improved support vector machines are called support vector clusters and are commonly used in industrial applications. They can also be used when data is not labeled, or when only some data is labeled for classification through preprocessing.

In the analysis of supervised and unsupervised continuous data, the genetic algorithm is divided into four categories, SVM, SVR, clustering, and dimensionality reduction. The classification is shown in Figure 2-4 below:

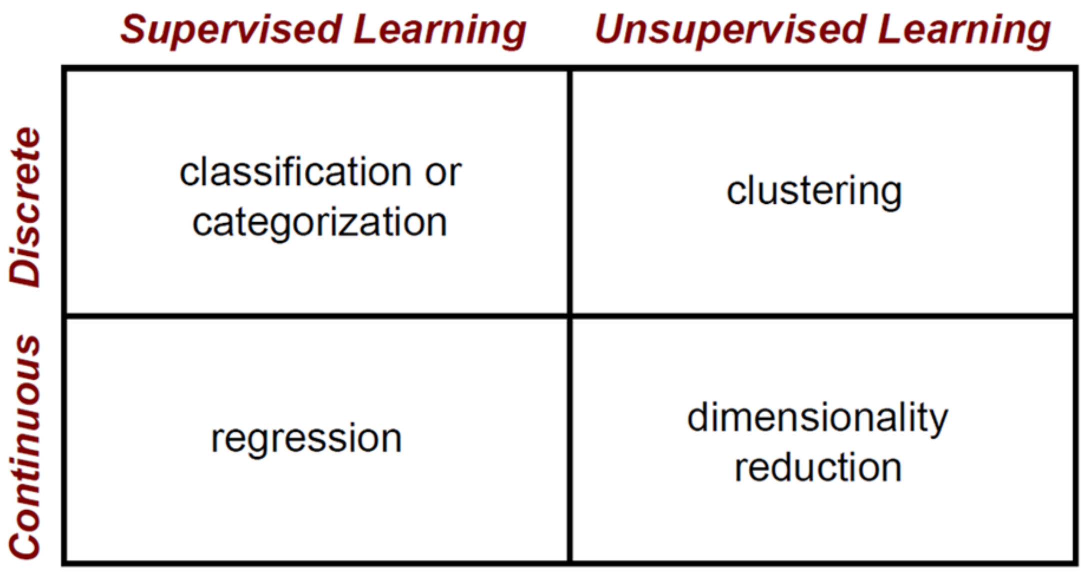


Figure 2-4 Genetic algorithm classification

The classification of SVM is the classification method of supervised training. The goal of SVM is to find the optimal plane (hyperplane) in space, and SVM finds the plane that can divide the data into two. Suppose the training data is expressed as (x1, y1), ..., (xl, yl) ϵRd × R, where x represents the “attributes” of the input, and y represents the regression value corresponding to the feature (equivalent Target class in SVM). The difference between SVR and SVM is that SVM looks for a plane that can divide the data into two, while SVR looks for a plane that can accurately predict the data distribution. Among them, $\varepsilon \geq 0$, which is used to indicate the largest difference between the predicted value of SVR and the actual value, and this algorithm is also called ε-SVR. The predicted class and the actual class must have the same sign (indicating that the prediction is correct), and SVR considers that the difference between the predicted value and the actual value needs to be less than ε. In the case where ε is reasonable (it is unreasonable to give an excessively large ε), if the solution can be obtained from the formula, this situation is called feasible. However, in most applications, because of various factors such as noise and error, it is usually not a feasible situation. Therefore, we need to add additional parameters to allow certain instances to be outside of ε: The biggest difference between SVR and SVM is to find the exclusive kernel function through Fourier transformation and to perform high-dimensional transformation through a kernel function.

Support vector machines and other models use kernel high-dimensional transformation techniques to process a large number of training samples or samples with a large number of features. Therefore, various approximate methods of RBF kernels (or similar other kernels) have been designed. The function used to transform a single vector that is not related to other vectors (such as those in a support vector machine). The kernel function is Fourier transformed by constructing such a z-function method, and then the required function is randomly extracted from it. The dimension conversion plane is shown in Figure 2-5 below:

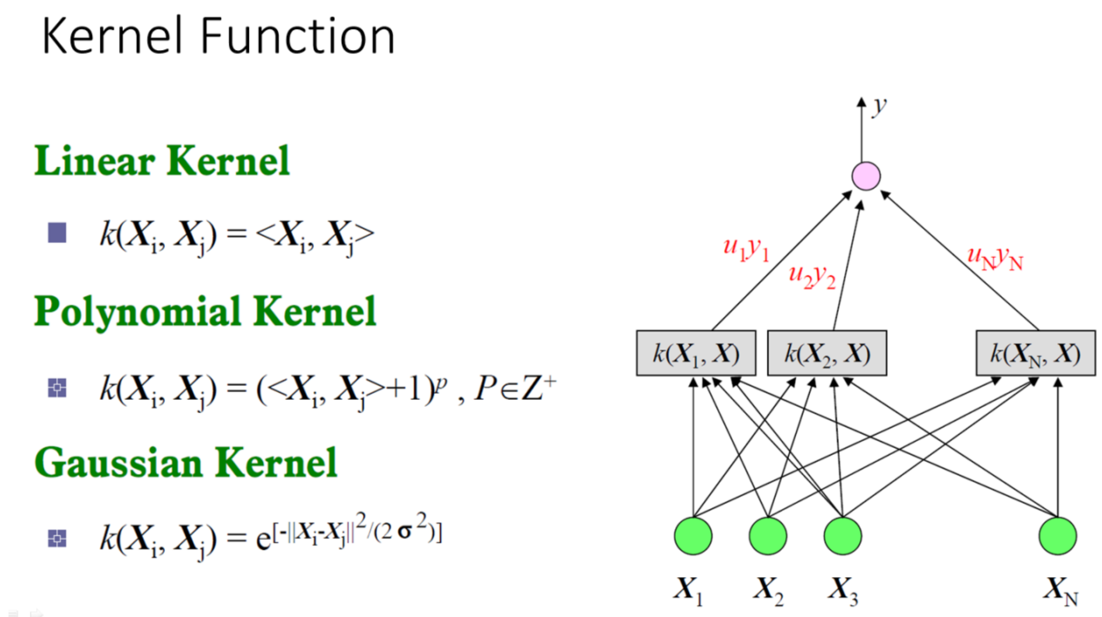


Figure 2-5 High-dimensional Kernel function transformation

2.3 Strategy Management Theory

In the past 50 years, due to advances in transportation and communication technology, the distance between time and space has gradually decreased, and tariff barriers between countries have gradually disappeared. These factors have reduced the barriers to trade between countries and promoted the globalization of industrial competition. The structure of the global communication network enables transactions to be completed 24 hours a day, seven days a week, companies may face competitors from all over the world. Therefore, this study conducts an integrated strategic analysis, each unit must understand its own capabilities and understand the competition among companies, industries, and countries.

Seven different theoretical perspectives on global strategic analysis [20].

1. The Resource-Based View,

2.Core Competence,

3.Competitive Advantage of Nations,

4.Strategic Group

5. Cognitive Communities,

6. Interorganizational Networks in Cooperation and Competition,

7.Strategic Vision and Competing in the Future

2.3.1 Location Economies

The location refers to the economic growth zone or economic growth point in the geographic category and its radiation range [21]. The location is a region where the capital, technology, and other economic factors are highly accumulated, and it is also a region with rapid economic development. What we usually call the Silicon Valley High-tech Industrial Zone in the United States is an example of location economies. The rise and development of the location economies will greatly drive the economic growth of its surrounding areas.

The economies refer to the economic benefits generated by performing value creation activities in a location most suitable for an activity, no matter where the location is in the world, as long as transportation costs and trade barriers allow it. The effect of value creation activities placed in the most suitable place to reduce the cost of value creation in order to achieve low cost and provide differentiated products to increase sales by charging a premium and using differentiation to maintain low prices. The practical significance of the location economy. For multinational group companies, because of the various trade barriers and transportation costs of transnational operations, and each country has different resource advantages, the location economy always exists in the global market. That is to say, there is always the most suitable production location for the production of a certain product or a link in the value chain, where the cost is the lowest. If the best designers of a product are concentrated in country A, then multinational companies should put their design base in country A; If the cost of producing products using country B labor is relatively low, the factories that manufacture the products should be located in country B; If Country C has broad market demand and access to other markets, then the marketing subsidiary should be located in Country C, etc.

In theory, it is more advantageous to distribute each link in the value chain in the best location than in a single location, on the one hand, it can significantly reduce costs, and on the other, it can provide differentiated products. Multinational group companies aim to obtain location economies by implementing the global operation integration strategy, dividing the value chain activities into different stages around the world, thereby creating a global network of value creation activities.

2.3.2 Game Theory

The first theoretical development of the game theory originated in 1944. The "Theory of Games and Economic Behavior" co-authored by the economist Oskar Morgenstern and the mathematician John von Neumann opened the basic concept of game theory, later, John Nash published the Bargaining theory and Non-cooperative game theory in 1950 and 1951, carry forward the game theory. The game theory is to study that two or more participants are in a state of confrontation under the state of rationality because the goals (or interests) pursued by the parties are inconsistent (or conflicting with each other).

The model simulates the conflict and cooperation between rational participants [22]. Game theory can be sorted by:

(1) Constant-sum game/ non-zero-sum game

Constant-sum game: the sum of the payoffs of all players always adds up to the same constant figure for any particular outcome. Thus, one player's gain must be offset by another one or more players' loss. A zero-sum game is a type of constant sum game. Non-zero-sum game: The interacting parties' aggregate gains and losses can be less than or more than zero.

(2) Number of participants

Two-player game Multiplayer game (more than two participants)

(3) Cooperative game/ non-cooperative game

Cooperative game: Participants can make contracts with each other, each participant must abide by the contract after agreeing. The solution of a cooperative game is generally called a cooperative solution, the goal is to pursue the maximization of group interests. Non-cooperative games: In contrast to cooperative games, participants cannot conclude a contract that restricts each other; The goal of non-cooperative games is to pursue maximization of personal interests. Non-cooperative games can also be classified according to the decision order of the participants and the understanding of information:

Decision order of participants Static game: simultaneous moves; often expressed in matrix form. Dynamic game: There is a sequence of moves. Observe the opponent's actions before deciding on their own decisions; it is often expressed as the number of games. Understanding of information. Complete information: Each participant knows the decision point to make a decision. Incomplete information: Each participant is not completely clear about the decision point nor decision making. Because the different distribution of the game will affect the progress and result of the game, the organized classification chart [28] for game classification is shown in Figure 2-6 below:

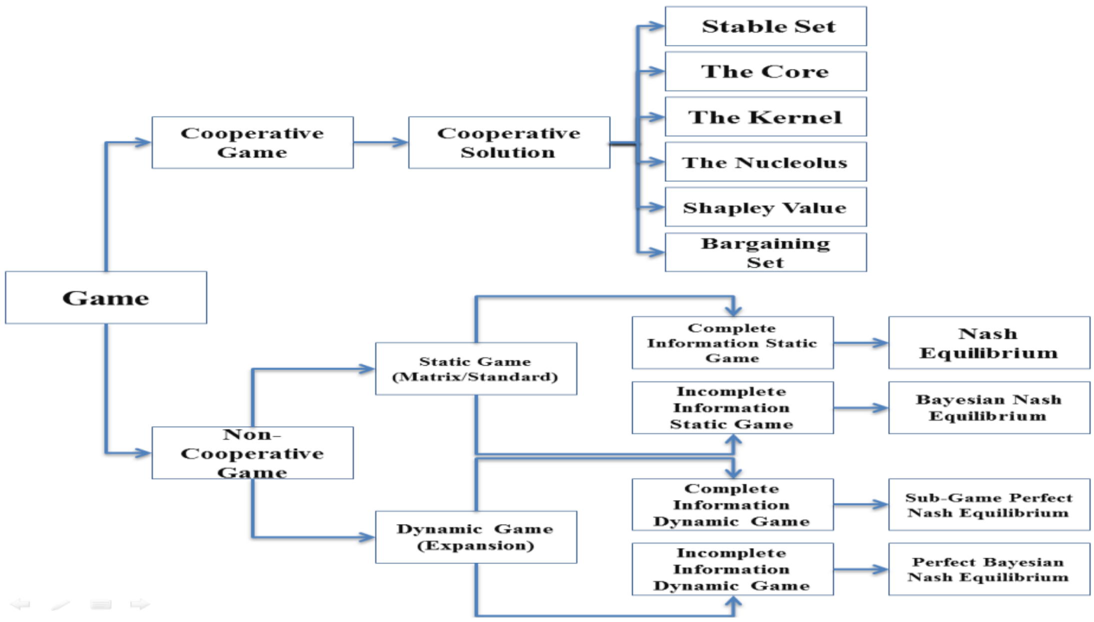


Fig. 2-6 Game classification

2.3.3 Key Performance Indicators Management

Key Performance Indicators, also called the main performance indicator, important performance indicator, or performance evaluation indicator is the most important indicator for measuring the effectiveness of management work. It is a data management tool and must be an objective and measurable performance indicator.

This term is often used for the measurement of financial and general administrative affairs, an indicator of the performance of companies, employees, and affairs in a certain period of time, and can help optimize organizational performance and plan the vision.

Harvard teacher Robert S. Kaplan said: Think of the balanced scorecard as the dials and indicators in an airplane cockpit. For the complex task of navigating and flying an airplane, pilots need detailed information about many aspects of the flight. They need information on fuel, airspeed, altitude, bearing, destination, and other indicators that summarize the current and predicted environment. Reliance on one instrument can be fatal. Similarly, the complexity of managing an organization today requires that managers be able to view performance in several areas simultaneously.

Peter Drucker, a famed management consultant, once said: The key area KPI is a necessary dashboard to guide the development of the enterprise. KPI commonly used methods are fishbone diagram analysis and Mandala chart. According to the company-level KPI, it is gradually decomposed into departments, then decomposed into various positions. The key performance indicators of each department and position are determined in turn by using a layer-by-layer decomposition and mutual support method and determined by quantitative or qualitative indicators.

There is an important SMART principle for determining key performance indicators. [3] SMART is the acronym for 5 English words:

1. Specific:

Specific performance indicators for performance assessment and not general.

2. Measurable:

Performance indicators are quantitative or behavioral, and data or information to verify these performance indicators is available.

3. Attainable:

Performance indicators can be achieved with effort and avoid setting goals that are too high or too low.

4. Relevant:

Performance indicators that are clearly related to superior goals and are ultimately combined with company goals.

5.Time-bound:

Focus on specific deadlines for completing performance indicators. KPI indicators will form targets after specific quantification. Goals should be formulated in accordance with SMART principles, while indicators are not exactly. For example, some girls have always said to find a boyfriend that is tall, rich, and handsome, then tall, rich and handsome is the goal. The indicators that tall, rich, and handsome, is concerned about are height, wealth, and charming. These three indicators do not need to fully comply with the SMART principle. KPI is an indispensable area that must achieve satisfactory results in order to achieve the company's overall goals and is the key to success. A collection of key elements plays a vital role in the organization's mission, vision, and strategic goals.

Peter Drucker believes that companies should focus on 8 key result areas: Market status, innovation, productivity, physical and financial assets, profit, performance and training of managers, employee performance and attitude, and public responsibility. For specific enterprises, their KPIs should be reasonably determined according to their own industry characteristics, development stages, internal conditions, and other factors.

2.4 Pavement management system visualization

Pavement management is to coordinate and adjust all the characteristics and positions related to the pavement, the main purpose is to enable the department or the competent authority of the pavement management to use the resources such as budget, manpower, testing equipment, and pavement materials more efficiently through this management process.

Utilizing the lowest energy consumption and the full life-cycle cost of the paving to enable it to provide and maintain a level of service acceptable to passersby during the service life of the subscription, and provide effective and continuous maintenance operations here, so that highway management agencies such as national, provincial, county, and rural roads can use internet operations to more quickly meet management needs. Through the pavement maintenance management system, historical information of the pavement can be obtained from the beginning, the entire planning, design, and construction of the pavement structure can rely on the pavement maintenance management system to more quickly meet the needs of the management end and the road end.

The use of computer-automated analysis and calculation can further calculate the acceptable service level of the paving and provide a strategy for the planned maintenance and repair, and also conducts periodic surveys and data construction for the current situation of the pavement. For the application of the domestic pavement management system, it is in full swing both at home and abroad, for different road levels and different government organizations, many different management systems and detailed modules will be developed. The following will make simple statements and analyze the similarities and differences for different management systems.

2.4.1 Development of Maintenance Management System for Foreign Pavement

With the increasing urgency of transportation needs, the cost of new road construction is increasing, existing roads are facing management and maintenance issues, the concept of pavement management and pavement maintenance management has emerged.

In recent years, the data of design, construction, monitoring, maintenance, repair, and reconstruction of pavement have been integrated into the pavement management system, improving the quality of road services. The following is a description of the system features and development goals of several sets of foreign pavement management systems.

1. United States

Washington State Pavement Maintenance System in the United States, the system architecture can be divided to:

a. File creation: including geographic information and road maintenance data,

b. Execution procedures include the judgment of current performance,

c. program sequencing,

d. Optimization options (Caldwell, G., 1990.), etc.

The New York City Joint Transportation Management Center (JTMC) is a combination of related transportation units, the New York State Department of Transportation, the New York City Department of Transportation, the New York City Police Department, and the United States Federal Department of Transportation, as shown below.

The center runs the following management systems:

a. Freeway Management System (FMS)

b. Traveler Information System (TIS)

c. Incident Management System (IMS)

d. Integrated Incident Management system (IIMS)

e. Advanced Traffic Management System Map (ATMS MAP)

f. Video Management Platform (VMP)

The center provides round-the-clock express service for road and highway users, there are 3 large TV walls and 24 smaller displays in the center as shown in below. Nearly 500 CCTV cameras (218 at the connection of the bridges and 278 at local streets along New York City) monitor the traffic flow on major roads throughout the city. And through vehicle detection equipment, and by patrolling road events and traffic conditions in real-time, obstacles can be quickly cleared and normal traffic flow can be restored to provide safer road conditions for road users (Chin-Chuan Chen, Jen-Chia Liu, 2009)

2. Japan

Japan's pavement management system for metropolitan expressway, Mitsubishi Road Surface Survey System, mainly inspect the structure and paving conditions of elevated expressways, and establish a maintenance program system:

(1) Establish the damage level for short-term maintenance

(2) Establish the damage level for long-term maintenance

(3) Improvement of maintenance materials and technology

(4) Establishment of the road structure database

(Otsuku et al., 1990).

3. China

Research on pavement management systems in China began in 1984. In 1988, the Ministry of Transport introduced the World Bank's HDM-III highway maintenance standard model in Yunnan, starting China's economic analysis research in the field of highway maintenance. In the early 1990s, China promoted the use of CPMS systems in 14 provinces and cities. Beijing SOGER pavement management system is a road database system established by the second satellite, the architecture is divided into:

(1) Pavement structure information

(2) Maintenance methods

(3) Work item coding system

(4) Pricing of work project units

(5) Calculate the average value of work item funds

(6) Establish a cost-benefit matrix, calculating the maintenance method with the least cost and the most benefit.

4. Singapore

The Singapore pavement management system mainly focuses on surveying the pavement current situation and omits manual visual inspection. This system has a goal of prioritizing road maintenance needs for each road section by instrument surveys, effectively allocate annual maintenance funds, analyze maintenance strategies for each road section, and evaluate the impact of different budget arrangements on the overall performance of road network paving. The pavement survey is based on roughness and rutting. High-Speed Road Monitor (HRM) for flatness (roughness) survey. Deflectograph for a structural survey, collecting the deflection measured. SCRIM for an anti-skid survey, collecting the anti-skid coefficient of the paving (Chia-Pei Chou, Hsu, Tien-Pen, 1993).

5.Canada

Since 2000, the City of Toronto has been using the Toronto Pavement Management System to manage its road network. The PMS software calculates a cost-efficiency factor for every rehabilitation treatment in each analysis year and prioritizes based on the most efficient year to complete the work. Over time, the software designed several enhancements, including linking the system to the City's geographic information system (GIS) and field-based data collection tools and also compiled data from the Greater Toronto area, providing accurate road information.

6.Portugal

The City Council of Lisbon, Portugal, decided to build a pavement management system (PMS) for the vast road network under its administration at the beginning of 1999. A team involving staff from the Lisbon City Council and the University of Coimbra developed a geographical information system (GIS) based PMS. The system consists of three basic modules: a road network database, aquality evaluation tool, a decision-aid tool.

The following Table 2-4 is a summary of the development of the pavement management system in each region.

Tab. 2-4 Summary of Development Pavement Management System by Region

Region	System Architecture	Main Functions
Washington State Pavement Maintenance System in the United States	1. File creation 2. Execution procedures	The content includes the judgment of the current performance in the collection of geographic

	3. program sequencing 4. Optimization options	information data and road maintenance.
New York City Joint Transportation Management Center	1. Freeway Management System 2. Traveler Information System 3. Incident Management System 4. Integrated Incident Management system 5. Advanced Traffic Management System Map 6. Video Management Platform	Integrate New York City's vast and comprehensive road data collection system, including data on paving, road users, traffic conditions, road facilities, and construction information
Mitsubishi Road Surface Survey System	(1) Establish the damage level for short-term maintenance (2) Establish the damage level for long-term maintenance (3) Improvement of maintenance materials and technology (4) Establishment of the road structure database	Expressway pavement and structure inspection, maintenance system
SOGER pavement management system	(1) Pavement structure information (2) Maintenance methods (3) Work item coding system (4) Pricing of work project units (5) Calculate the average value of work item funds (6) Establish a cost-benefit matrix, calculating the maintenance method with	Maintenance system

	the least cost and the most benefit.	
Singapore pavement management system	1. Prioritizing road maintenance needs 2. Effectively allocate annual maintenance funds 3. Analyze maintenance strategies 4. Evaluate the impact of different budget arrangement	Maintenance system
Toronto Pavement Management System	Calculates the cost-efficiency factor providing accurate road information.	data collection, Pavement deterioration, Pavement maintenance, Pavement repair
Portugal pavement management system (PMS)	Road network database Quality evaluation tool Decision-aid tool	The current service indicator (PSI) is used to determine the current service capability of the pavement. The scored data are longitudinal roughness, rutting, cracks, surface looseness and repair data.

2.4.2. Development of Freeway Bureau Maintenance Management System

The function of road pavement is mainly to provide service quality for the comfort and safety of passersby, and it is necessary to implement the correct pavement maintenance behavior when necessary to ensure that the pavement can continuously provide good service quality. Better paving methods can be used at the beginning of pavement to improve the quality, but as the traffic volume increases, the service quality will decrease. When the service performance of road paving decreases to a certain condition, maintenance and repair operations must be performed, but need to be maintained again after years of use to restore the pavement to its original service qualit.

The activities of the pavement management system in the pavement include planning, design, construction, maintenance, maintenance, and evaluation, etc. The pavement manager can use the function of the pavement management system, to correctly and quickly determine the life span, maintenance cost, construction method selection, and life cycle of road pavement, which gives better choices and assessments for maintenance at the most appropriate time to maintain a high level of service quality for its paving and achieve maximum economic benefits at a lower cost. The paving management system is not only for the maintenance and improvement of the paving but also for integrating all the behaviors related to all the paving, as a combination with overall coordination. Therefore, the quality of pavement maintenance services plays a very important role in the pavement management system. Research on the pavement management system in Taiwan started in 1979, the government agencies began to introduce relevant system technology from the Highway Bureau in 1983, however, there is no national integrated pavement management system.

The pavement management system in Taiwan started from the "Taiwan Freeway Pavement Maintenance Management System (Phase 1)" commissioned by Freeway Bureau in 1983. (National Taiwan University Yen Tjing Ling Industrial Research Institute, 1988) The system architecture is divided into eight subsystems: survey system, analysis system, design system, review system, maintenance implementation system, construction system, planning and execution system, research development and personnel training system. The system function, scope, and distribution have met the needs of highway maintenance, however, the development of the system at that time was mainly based on large computer processing systems, it is no longer in line with the current computer environment, and it is not easy to implement the promotion to various public works sections and agency. And because the supporting measures for data surveys were not integrated at the time, the system database did not complete the entire section of the highway, and it was impossible to effectively evaluate the entire highway condition.

Later, in 1996, the Taiwan Construction Research Institute was commissioned to carry out "Computer Practice of Zhongshan Expressway Road Maintenance Management System" (Taiwan University, 1997), continuing previous PMMS research on highways, promoting the maintenance work of the pavement to the personal computer terminals of each engineering department, engineering office and bureau headquarters, to strengthen the computerized function of the pavement management system, connecting each operation system and data storage. Because the PAVMAS framework developed in the early stage could not be compatible with the Freeway Bureau system at that time, the FPMS system was developed, however, the system database did not include complete highway data, and the system still has some errors, so it has not been executed. Later, in 2000, Changtian Engineering Consulting Co., Ltd. was commissioned to correct the system errors, but because the database has not been updated, the system was not executed.

Research on the Ph.D. dissertation "Field Study of High Performance Asphalt Pavement Durability Used in Freeway No.3" by SHUN-HSING CHEN, 2011, the function of the Pavement Maintenance Management System (Freeway PMS) includes "Information Query", "Statistical queries", "Inspection data query", "Predictive Analysis Statistics", "Funding Statistics", "Pavement Selection Criteria", "Knowledge Sharing" and "System Permission Settings". It is an information system mainly used by Engineering Division, the main users are the engineers of the maintenance section of the expressway, including engineering units, sections, other management units, related industries, and academic research institutions initially. And later, the engineering department of the highway management authority, the content of the management system is mainly to cooperate with highway management business projects.

The Freeway PMS [36] concept is based on the results of the investigation, interviewing highway engineering staff, some experts and scholars, and comparison of relevant pavement management systems at home and abroad. The pavement management system also starts with system planning and design in the direction of "convenient", "partition" and "integrity".

Nowadays, the bureau often uses PMS module function to understand and expand the solution, its content is described in the following[35]:

1. Pavement history query:

   At present, the pavement management system provides information on the pavement of road sections, it contains the edit of the station number, annual bid, tonnage. This research will introduce basic data and engineering history analysis modules of national highways, to strengthen the segmentation of various sections of national highways, importing the current data, and the construction of the national road paving information, to complete the overall database. Combined with the engineering resume data module to organize its annual data into a database provides an analysis of related modules, and with the real-time traffic information service, provide the public with information about the pavement condition and the traffic situation of different road sections.

2. Pavement inspection and repair query

This query function currently performs a database query for the location of pavement damage, getting records of the date, area, and depth of the damage inspection.

In this research, the automatic acquisition technology of the pavement image is used to strengthen this query module. The inspection mode developed through the automatic inspection and manual matching APP function over the years will preserve the current damage image. The system calculates the value of the present PCI through the system automatically. Through transmission and database analysis, the degradation of different road sections can be calculated, with the engineering history module and budget preparation module increase the importance of this indicator.

3. Annual contract and pricing inquiry

This query module can query the contract amount with the estimate in different years and has information on the quantity such as OG and DG below. This research will implement through the engineering history module to confirm the sections and budget distribution of maintenance for many years, to make an optimization estimate. With the combination of PCCEE asphalt price, the module can analyze the previous year's budget and optimize budgeting for the next year.

4. Pavement Damage Manual

The contents of this manual are shown in this part, the content displays the description of the types and forms of pavement damage, the information the public needs to understand and as an engineer inspection's reference. This research introduces the PCI automated operation analysis to strengthen the application of this manual.

5. The query of human resources in the road sections

This query function is currently based on the personnel data in each road section of the Freeway Bureau. This study will use the module, combined with the Google Earth base map, to distinguish the inspection data of each road section and systematize the boundaries through the presentation of different colors to understand the pavement condition of different sections in real-time. And design a human resources application to distinguish the personnel from different departments and sections who are in charge, new recruits can build their personal data in the database of this system and quickly understand the staff and position of the unit.

6. Maintenance management authority query

For the maintenance management authority query, the module can query the information and the person in charge of the year. This study targets to format and integrate the content of the tasks that the pavement engineers need to perform daily and the related log forms. Engineers can check the task content and select the road sections on a daily basis to save the data of daily inspections. Daily maintenance list and construction road sections of each section are completed systematically. In order to improve the performance of time allocation and execution of each person, the paving tasks and related basic data performed are uploaded to the paving management system for data collation and application. Introduce asset management for module enhancement.

7. Pavement Condition Index query

This query is currently only for the data of scattered years such as IRI, FWD, SN, with the performance improvement of the national road pavement renovation system case, the inspection data for the year 2013 were imported. In this research will use data query integration to automate the import of relevant indicators of the inspection pavement, then export to the charts.

It can also query different indicators of different road sections, when querying, by inputting different mileage and station numbers, it can achieve the function of dynamic segmentation. Automatically output the proportion of different types of damage in the selected parts of the pavement, the indicators and the photos of the pavement will be compared with the system automation to see if their values are correct. The flatness index will be cluster analyzed through system automation and automatically remove abnormal data when grouping.

Existing functions and advanced functions of the national road pavement management system review, as shown in Table 2-5.

Tab. 2-5 Advanced function of Pavement Management System

Pavement Management System Module	**Existing functions**	**Advanced functions**
Pavement history query	The query of the annual bidding, name, priced and quantity(see Figure 2-11)	Establish information on a national road, engineering resume analysis module, pavement history data with a 3D layer.
Pavement inspection and repair query	Pavement inspection and repair query	Automatic acquisition of paving images, inspection APP development, data transfer, and database construction.
Annual contract and pricing query	Contract amount and estimated amount in different years, with OGAC, DGAC, and other quantity data. (See Figure 2-13)	Systematic construction of engineering history data, analyze repetitive repair sections in different years and estimate the road sections maintenance funds with abnormal.
Pavement Damage Manual	Display the description of the types and forms of damage to the pavement, convenient for engineers to refer to. (See Figure 2-14)	Systematic construction of PCI pavement damage ratio, and strengthened by the development of the inspection APP.
Human Resources Inquiry in Road Sections	Query personnel data in each section. (See Figure 2-15)	KPI performance management system development and performance management, the latest information on the pavement in their road section.
Maintenance management authority query	Information on the person in charge of each year. (See Figure 2-16)	KPI performance management system development and performance management, the latest information on the pavement in their road section.
Pavement condition index query	Data of IRI, FWD, SN each year. (See Figure 2-17)	In this study, the integrated data query is used to import the relevant indicators then

		export to charts automatically. Query different indicators of different road sections with dynamic segmentation.

2.4.3 Visual Management System

The importance of Big Data is increasing, data is collected in the databases of many industries. To turn this complicated data into valuable, more useful, and effective strategy reference, it relies on the appropriate statistical and presentation of the data for managers and the public to understand, that is to say, it is storytelling by looking at the pictures, and the number speaks [37].

Here are 30 well-known data graphing software, simple and practical, can be used without professional coding knowledge or special training.

1. iCharts

iCharts is a platform that connects publishers with research needs, economic and industrial materials, and professional consumers. Tens of thousands of charts covering business, economics, sports and other categories of layer bread scraping, it allows the public to easily understand and keep up with the latest statistics in the world. It provides cloud-based and patented charting tools, easy for everyone to launch a brand, market, and share their profile with charts, and share it with millions of people through the website in order to have a huge amount of data.

2. Fusion Charts Suite XT

Fusion Charts Suite XT is a professional, advanced version of the JavaScript chart library, allowing us to build any kind of chart, using SVG (Scalable Vector Graphics) and supporting more than 90 chart types. Including 3D, Gantt, gauges chart, funnel chart, and the world/states/countries map. Similarly, most charts include 2D and 3D views and are completely customizable, labels, fonts, borders, etc. can be changed.

3. Modest Maps

Modest Maps is a small and extensible free library for designers and developers who want to use interactive maps which provides core features set in a tight, clear package featuring many additional features.

4. Pizza Pie Chart

Pizza Pie Chart is a pie chart based on the Snap SVG structure from Adobe, focus on simple integration with HTML and CSS instead of JavaScript objects, but still can be linked through JavaScript objects.

5. Raw

Raw is a free and open-source web application designed to visualize data flexibly in the simplest way possible.

6. Leaflet

Leaflet is a modern and open-source JavaScript library, a good interactive map optimized for mobile phones.

7. Chartkick

Chartkick is a Ruby gem, it integrated the Highcharts and Google Charts, the two major chart libraries to create beautiful graphics easy and fast.

8. Ember Charts

Ember Charts is a charting library created by Ember.js and D3.js architecture. It contains time series, bar charts, meta-pie charts, and scatter charts, which are easy to modify and extend. The elements of these charts can be seen in the interaction and presentation of the charts, fully expressing their ideas.

9. Springy

Springy is a force-oriented graph layout algorithm, uses real-world physics flexibly to try and understand how to present a nice web-based diagram, designed to be small and simple. It provides an abstract chart operation and calculation layout. The layout and interaction are all by personal preferences.

10. Bonsai

Bonsai is an open-source JavaScript library for charting and animation. The gallery proposes the results of using SVG and a full-featured API. Supports the construction of simple shapes such as rectangles, circles, or ellipses and has specific functions and path functions to customize graphics, color, gradient change rate, and funnel-type screening for different shapes, such as grayscale, transparency and other applications.

11. Google Charts

Google Charts provides a great way to visualize data on the website. From a simple line chart to a very complex hierarchical tree, the Gallery Gallery provides a wide range of chart types. It is a very useful tool for professional visual drawing charts such as geographic maps and dynamic pressure maps and has animation and user interaction control built-in functions.

12. jsDraw2DX

jsDraw2DX is a JavaScript library that is designed to generate interactive graphics in any form using SVG, able to generate any basic graphics such as lines, rectangles, polygons, circles, ellipses, arcs, and also curves, Beziers of any degree, function plots, etc.

13. Cube

Cube is an open-source system for visualizing time series data, built on MongoDB, Node, and D3. If you send Cube timestamped events (with optional structured data), you can easily build realtime visualizations of aggregate metrics for internal dashboards.

14. Gantti

Gantti is an open-source PHP class for generating Gantt charts. The charts created are pure HTML5-CSS3 with no JavaScript involved. The output looks very nice by default but can be customized with ease (with SASS stylesheet).

15. Smoothie Charts

Smoothie Charts is a small chart database, mainly for real-time streaming data. Although there are many graph databases that allow you to dynamically update data content, none of them can truly optimize continuous streaming data. Smoothie Charts currently only works on Chrome and Safari. Compared to other visual databases, Flot, it is not easy to use, however, it must be emphasized that it is really good at displaying streaming data.

16. Envision.js

Envision.js is a JavaScript library that simplifies the creation of fast and interactive HTML5 visual images. It has two different chart types: financial time series data and APIs for developers to create custom charts. It uses a framework-agnostic model and relies on micro-chart libraries.

17. BirdEye

BirdEye is a community project of Declarative Visual Analytics. In order to improve the design and visualization of extensive open-source materials, and to build a visual analysis gallery for Adobe Flex, This chart is based on a narrative database, allowing users to create a multi-data visualization interface to analyze and present information.

18. Arbor.js

Arbor.js is a chart visualization database created by web engineers and jQuery. It provides efficient and force-oriented layout algorithms. Abstract drawing chart organization and filtering the update. It's not limited to the fact that you have to use a specific method for screen painting. Canvas, SVG, and even HTML positioning elements can be used based on the project. Arbor.js helps focus on the chart data and its features, instead of spending a lot of time on mathematical operations to produce the layout.

19. Gephi

Gephi is an interactive visualization and search platform for all types of networks and complex systems, dynamics, and hierarchical diagrams. Visualizers and data seekers based on charts can not only cope with large data sets but also create beautiful charts. They can also filter and clear unnecessary data.

20. HighChartjs

Highcharts JS is a chart database written purely in JavaScript, providing an easy way to increase interactive charts and charts on websites or web applications.It currently supports line, spline, area, area-spline, bar, pie, and scatter charts.

21. Javascript InfoVis Toolkit

The JavaScript InfoVis Toolkit provides interactive data visualizations for creating websites, it has many unique styles and animation editing effects.

22. Axiis

Axiis is an open-source data visualization framework designed for beginners and professional developers. Axiis gives developers a way to define data visualizations in-depth, through a simple and intuitive tagging language and provides pre-built visual content and abstract layout templates, as well as allowing to create unique visual charts.

23. Protovis

Protovis is a visualization toolkit for JavaScript using the canvas element. It takes a graphical approach to data visualization, composing custom views of data with simple graphical primitives like bars and dots. These primitives are called marks, and each mark encodes data visually through dynamic properties such as color and position. Although marks are simple by themselves, you can combine them in interesting ways to make rich, interactive visualizations.

24. HumbleFinance

HumbleFinance is an HTML5 data visualization tool written as a demonstration of interactive graphing in HTML5. It is similar to the Flash tool. The tool itself is written entirely in JavaScript, using the Prototype and Flotr libraries. It can be used to display any two 2-D data sets of real numerical data which share an axis.

25. D3.js

D3.js is a JavaScript library for manipulating documents based on data using HTML, SVG, and CSS. D3's emphasis on web standards and gives the full capabilities of modern browsers without tying to a proprietary framework, combining powerful visualization components and a data-driven approach to DOM manipulation.

26. Dipity

Dipity is a free digital timeline website, organize the web's content by date and time. Users can create, share, embed and collaborate on interactive, visually engaging timelines that integrate video, audio, images, text, links, social media, location and timestamps.

27. Kartograph

Kartograph is a simple and lightweight framework for building interactive map applications without Google Maps or any other mapping service. It was created with the needs of designers and data journalists in mind. Kartograph contains two libraries, one generates beautiful and compact SVG maps, the other helps you to create interactive maps that run across all major browsers.

28. TimeFlow

TimeFlow Analytical Timeline is a visualization tool for temporal data. The current release is “alpha” software—a very early version that may have bugs and glitches. The tool helps you analyze temporal data with five different displays: timeline, calendar, bar, table, list.

29. Paper.js

Paper.js is an open-source vector graphics JavaScript framework built on top of HTML5 canvas and is easy to learn for beginners.

30. Visualize Free

Visualize Free is a free cloud-hosted, zero-client app for data visualization and analytics. It is a derivative of the commercial platform for dashboard, reporting and data mashup developed by InetSoft.

2.5 Summary

This paper reviews the detection indicators of the paving (2.1), include IRI, SN, FWD, PCI, respectively indicate the road comfort, safety, structure, and pavement condition. In the research case of the improvement of the performance of the National Road Surface Renovation System of the Freeway Bureau in 2012, each detection indexes are grouped and classified.

In this research paper, first analyze the principal component factors that caused the damage to the road section, follow-up discussion on clustering and correlation numerical analysis, and finally, each factor is evaluated for the overall management performance of the pavement. After the detection and collection of paving indicators, comprehensive applications of the Open data by the Freeway Bureau, and multivariate analysis in Chapter 4, find out the annual maintenance road sections. In the multivariate analysis, the principal component analysis, sensitivity analysis, cluster analysis, support vector regression analysis, and correlation analysis are selected to find the destruction factor and the threshold of the paving index, Therefore, the literature collection and review of the relevant methodologies were conducted, and the compliance of the maintenance section selection was verified through the bids issued in the subsequent annual bids. The comprehensive application of the management strategy theory in Section 2.3 is mainly aimed at improving the performance of the overall national road pavement management through the management of key indicators.

In Chapter 6, through the theory of location economy, the location economy of North, Central, and South has been found. Through the selection of routes, funds, and strategies to improve the game decision of the national road pavement maintenance outsource. Freeway Bureau can use the system for outsourcing, which select the manufacturer of the road section that is suitable for the bid.

Finally, we reviewed the pavement management system home and abroad, the detailed discussion on the national highway expressway pavement maintenance management system in section 2.4.2, The main purpose is to enhance the existing modules and refine their system functions, let all systems achieve efficient and customized use. Finally, in order to allow the management system to be used flexibly, data is presented in a visual way, and related apps are developed to integrate data.

Chapter 3. Modeling of carbon dioxide measurement and optimization for pavement maintenance

The reduction of the impact of carbon emissions associated with the transport of materials in highway pavement construction projects is addressed. A sparse-coding support-vector methodology is employed to analyze four major indices of highway pavement: the international roughness index (IRI), structural number (SN), pavement condition index (PCI), and equivalent single-axle loads (ESALs). The energy-conservation and carbon-reduction efforts of construction vendors are also evaluated. The proposed model can be further generalized by employing a wider range of traffic data, additional roughness indices, and structural properties of pavement. An optimization scheme is formulated as a mixed-integer linear programming problem based on the time required for asphalt inspection using spatial networks and operating constraints. The ESALs, SN, and PCI based on data obtained employing the sparse-coding support-vector method exhibit a predictably high success rate in the value of the IRI. The proposed approach is shown to lower carbon dioxide emissions by 31.18%. The study further proposes an optimization method capable of increasing the road maintenance that can be completed (11%) for a given level of carbon dioxide emissions.

3.1 SCSV model

The present study employs mathematical programming to estimate carbon dioxide (CO2) emissions associated with pavement repair; i.e., emissions associated with the dispatching of trucks and assignment of materials. The aim is to identify degraded pavement surfaces through the analysis of performance indicators, including the pavement condition index (PCI) and international roughness index (IRI). The PCI is a numerical index ranging between 0 and 100 that indicates the general condition of pavement in civil engineering. This statistical measure requires a manual survey of the pavement in accordance with the standard ASTM D6433-11 for roads and the standard ASTM D5340-11 for airport pavements. The IRI is a roughness index, having the units of slope, obtained from longitudinal road profiles and based on a quarter-car mathematical model. The IRI has become a worldwide standard since its introduction in 1986. A growing need for highway rehabilitation in the face of shrinking resources has prompted researchers to develop a formal approach for the optimization of resource use in highway construction and maintenance through the implementation of pavement management systems (Rada and Witczak 1985) based on pavement analysis (Tavakoli and Ludwig 1992). Soomin and Hwasoo (2016) proposed a framework by which to optimize inspection schedules within a risk boundary defined by the predicted state of pavement based on mechanistic deterioration and traffic flow. Bin and Rui (2015) developed a multi-objective optimization model to optimize asphalt maintenance plans at the project level. Amr and Mohammad (2015) developed a multi-objective optimization problem for pavement maintenance and rehabilitation strategies at the network level, considering minimum action costs and limiting conditions for used road networks. Ashkan and Zakeri (2016) developed methods to reduce the complexity of a system using a hybrid genetic algorithm and particle swarm optimization. Jesus and Denise (2011) developed a simple-yet-useful network-level optimization model employing linear programming to deal with budget constraints on pavement performance goals in terms of total lane-miles for each state of repair. The ability to predict future pavement conditions is essential for the formulation of maintenance budgets and cost-effective rehabilitation strategies (Tavakoli and Ludwig 1992). The continuous monitoring of the IRI allows the evaluation of a variety of parameters that affect the deterioration of pavement, including the materials and structure of pavement and traffic patterns. Material parameters of pavement (Andrii and Aleksandra 2016), such as the asphalt content, gradation type, and percent of fines, affect the progression of the IRI. Road deterioration also depends on traffic loading in terms of the equivalent single-axle loads (ESALs), age, and structural number (SN). The fact that all these parameters affect the deterioration of pavement means that they are ideal input variables for the modeling of pavement performance over time. The present study uses information pertaining to pavement maintenance as an input for an optimization model to reduce overall CO2 emissions. A systematic network model in which the results of asphalt inspection are used to adjust schedules for the transport of asphalt is developed. A time–space network technique that formulates the production of the asphalt manufacturer support is further proposed and a mathematical programming solver is used to solve this optimization model. The efficacy of the proposed model and solution method is demonstrated in a case study. The primary objective of the study is to develop a sparse-coding support-vector (SCSV) methodology for the estimation of the IRI using the PCI, ESALs, and SN as input variables. The concept of the ESALs was developed by the American Association of State Highway Officials, with the ESALs indicating the effects of axles under different loads in terms of road damage. This cumulative traffic load statistic represents a mixed stream of traffic (i.e., different axle loads and configurations) over a given period, which is then converted into an equivalent number of 18,000-lb single-axle loads summed over that period. The SN represents the overall structural requirements for the intended traffic loadings. This number indicates the structural strength of pavement for a given combination of soil support, total traffic, terminal serviceability, and environmental conditions. Road sections requiring repairs are identified using the SCSV IRI prediction model. The study further offers a model for the reduction of CO2 emissions associated with the repair of road sections aimed at minimizing life-cycle costs, such as greenhouse gas (GHG) emissions.

3.1.1 Data

The reliability of IRI prediction models depends on the material, loading, and environmental conditions. It is thus reasonable to consider historical IRI data along with structural characteristics in an effort to improve model efficiency. The present study employs a set of pavement indicator data taken from the Pavement Roughness Maintenance and Repair Project (Ho and Lin 2015) in the development of the prediction model. The dataset includes IRI data as well as PCI, SN, and cumulative ESAL data. Descriptive statistics of the variables are summarized in Table 3-1.

Tab. 3-1 Descriptive statistics of set of PRMR data.

	Variable	Minimum	Maximum	Average	Median	Standard deviation	Range
Predictor	PCI	48.5	100	98.8268	100	6.55	51.5
	SN	31.71	57.45	46.3825	46.35	3.67	25.74
	ESAL (millions)	0.27	7.59	2.3981	1.95	1.75	7.32
Dependent	IRI	0.625	6.09	1.7458	1.64	0.55	5.465

3.1.2 Modeling

The present study investigates a number of methods of partitioning the input space to identify the underlying structure, and further provides an overview of training and testing for IRI modeling, as shown in Fig. 1. Pavement indicators are used to train the dictionary using a least absolute shrinkage and selection operator (LASSO) algorithm. The LASSO method is a regression analysis method used in statistics and machine learning for the selection and regularization of variables. Its purpose is to enhance the accuracy of predictions and interpretability of the resulting statistical model. LASSO was originally formulated for least-squares models. This application indicates a great deal about the behavior of the estimator, including its relationship with ridge regression and best subset selection, as well as the connections between LASSO coefficient estimates and so-called soft thresholding. It also reveals that coefficient estimates need not be unique as long as covariates are collinear, as in standard linear regression. The sparse vector (in sparse coding) is then used to train the support vector regression (SVR) model in predicting the IRI value. The model is based on SVR using MATLAB's LIBSVM, which is a widely cited open-source library for support vector machines (Chang and Lin 2011) that was developed at the National Taiwan University. The model is written in C++ with a C application programming interface. LIBSVM is used to implement the sequential minimal optimization algorithm for kernelized support vector machines, with support for classification and regression. MATLAB is a multi-paradigm numerical computing environment and fourth-generation programming language. The present study develops a proprietary programming language using MathWorks.

Sparse coding is an unsupervised clustering method used to solve an over-complete matrix of recurring patterns in training data. The present paper refers to the matrix as a dictionary and its column vectors as features (Mairal and Sapiro 2010). Within this framework, a data vector can be approximated as a linear combination of features. By imposing constraints on the number of features, approximations can be represented using sparse coefficient vectors with a minimum of nonzero entries. For data with noise or non-Gaussian variations, such as deletions, sparse approximations latch measurements to exemplar patterns, thereby truncating weakly expressed information and restoring missing values. This process improves the tolerance to variation in subsequent statistical analysis.

There are several formulations for dictionary training (Bach and Obozinski 2012). In the present study, dictionaries are learned offline using a large set of pavement data to improve statistical accuracy, employing an optimization method based on LASSO. This method relaxes the constraint of sparse coding on the number of nonzero feature coefficients by penalizing the sum of coefficient magnitudes (Tibshirani 1996). LASSO is effective for offline dictionary learning yet the computational overhead is too high to compute sparse codes in real time during the testing step. Because k is a hard sparsity threshold, the proposed formulation can be solved in a greedy manner employing a matching pursuit (Mallat and Zhang 1993) via a series of inner-product tests, which iteratively select k features to reduce the residual.

SVR differs from methods predicting continuous variables in terms of its generalizability to previously unseen data. The consistency of SVR is enhanced by relying on only a subset of training observations known as support vectors, which are differentiated from the remaining training observations through the use of a discriminating loss function, which does not penalize residuals below a set tolerance ε. Thus, for a given hypothesis and ε, observations related to the hypothesis have no effect on predictions. In accordance with the principle of structural risk minimization, for a given ε, SVR attempts to find a hypothesis with low structural risk and low complexity.

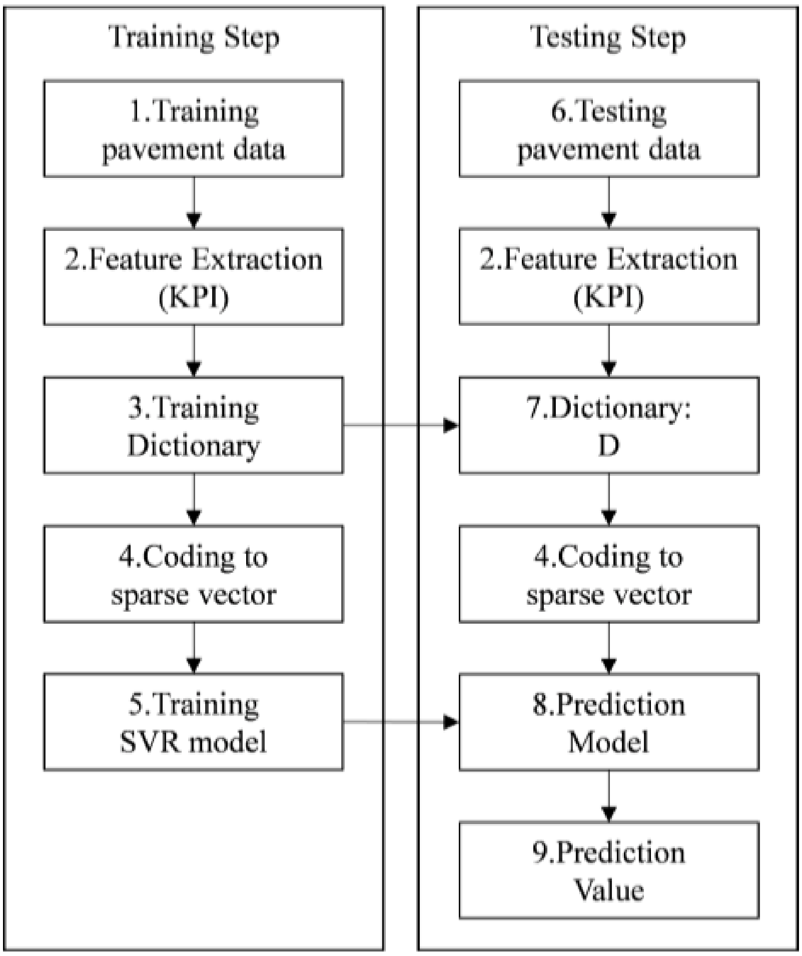


Fig. 3-1 The architecture of IRI prediction using sparse coding and SVR

3.2 CO2 Emission Optimization

3.2.1 Problem description and model assumptions

For the ease of description, the notations used in the model development are listed in Table 3-2.

Tab. 3-3 List of parameters and variables

Symbol	Parameter and Variable Discerption
$\boldsymbol{i}$	Representative indices for an asphalt manufacturer.
$\boldsymbol{j}$	Representative indices for a repair day.
$\boldsymbol{k}$	Representative indices for a construction.
$\boldsymbol{N}$	Index set of asphalt manufacturers.
$\boldsymbol{T_k}$	Index set of repair days for a construction k.
$\boldsymbol{K}$	Index set of constructions.
$\boldsymbol{B}$	Constant whose values should be large enough.
$\boldsymbol{M_k}$	Minimum requirement of asphalt for a construction k.
$\boldsymbol{d_{i,k}}$	Distance from an asphalt manufacturer i to a construction k.
$\boldsymbol{m_{i,j}}$	Maximum volume of asphalt produce for an asphalt manufacturer i on jth repair day.
$\boldsymbol{C_i^{TRA}}$	CO2 emissions of transport from a truck per 1 km for an asphalt manufacturer i.
$\boldsymbol{C_i^{OPE}}$	CO2 emissions of regular produce for an asphalt manufacturer i.
$\boldsymbol{C_i^{PRO}}$	CO2 emissions of asphalt produce per 1 ton for an asphalt manufacturer i.
$\boldsymbol{x_{i,j,k}}$	Decision variable for transport volume of asphalt from an asphalt manufacturer i to a construction k on jth repair day.
$\boldsymbol{y_{i,j,k}}$	Decision variable indicating an asphalt manufacturer i to repair a construction k on jth repair day.
$\boldsymbol{z_{i,j}}$	Decision variable indicating an asphalt manufacturer i does not repair for any constructions on jth repair day.

The present study focuses on the development of a logistical support scheduling model for asphalt transport in Taiwan. The main information and conditions of the pavement repaired following real practices in Taiwan are as follows.

(1) CO2 emissions of asphalt transport from the manufacturer to the construction site

(2) CO2 emissions of the asphalt product from the manufacturer

(3) CO_2 emissions associated with a regular product, which is the operating cost, of the manufacturer

(4) Minimum requirement of asphalt for construction

(5) Only one manufacturer supporting asphalt on a day of construction

(6) Maximum volume of the asphalt product of a manufacturer

Modeling approach

Figure 3-2 presents temporal–spatial networks pertaining to the inspection of asphalt, which were used to formulate the transport of one shipment in logistical support among locations within a construction site within a specified time period.

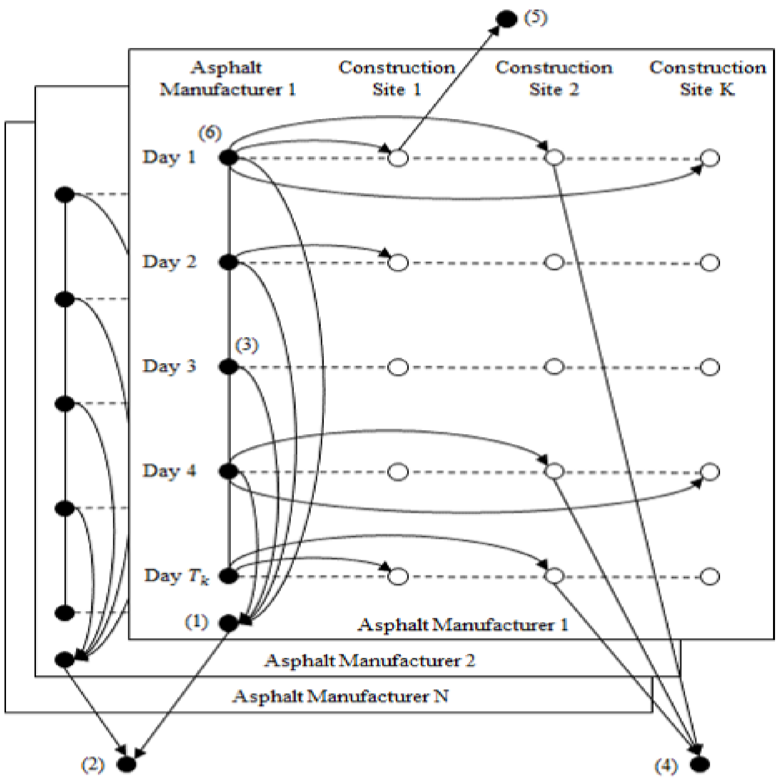


Fig. 3-2 Asphalt material inspection time space networks

◎Model formulation

The model is formulated as a mixed-integer linear programming problem based on operating constraints and the temporal–spatial networks mentioned above. The model is based on the concept of expected optimization as follows.

$$\min \sum_{i \in N} \sum_{j \in T_k} \sum_{k \in K} x_{i,j,k} \cdot y_{i,j,k} \cdot d_{i,k} \cdot C_i^{TRA} + \sum_{i \in N} \sum_{j \in T_k} \sum_{k \in K} x_{i,j,k} \cdot y_{i,j,k} \cdot C_i^{PRO} + \sum_{i \in N} \sum_{j \in T_k} z_{i,j} \cdot C_i^{OPE} \quad (1)$$

$$\sum_{k \in K} y_{i,j,k} + B \cdot z_{i,j} \leq B \cdot (1 - z_{i,j}) + 1, \forall i \in N, \forall j \in T_k \quad (2)$$

$$\sum_{k \in K} y_{i,j,k} + B \cdot z_{i,j} \geq 1 - B \cdot z_{i,j} + 1, \forall i \in N, \forall j \in T_k \quad (3)$$

$$\sum_{i \in N} \sum_{j \in T_k} y_{i,j,k} \cdot x_{i,j,k} \geq M_k, \forall k \in K \quad (4)$$

$$\sum_{i \in N} y_{i,j,k} = 1, \forall j \in T_k, \forall k \in K \quad (5)$$

$$\sum_{k \in K} x_{i,j,k} \leq m_{i,j}, \forall i \in N, \forall j \in T_k \quad (6)$$

$$x_{i,j,k} \geq 0, \forall i \in N, \forall j \in T_k, \forall kinK \quad (7)$$

$$y_{i,j,k} \in 0, 1, \forall i \in N, \forall j \in T_k, \forall kinK \quad (8)$$

$$z_{i,j} \in 0, 1, \forall i \in N, \forall j \in T_k \quad (9)$$

3.2.2 Solution methods

This section discusses the methods used to solve the proposed model and to dynamically adjust plans for the transport of asphalt during construction. To ensure that the findings are relevant to practical situations, the proposed model must provide solutions within a reasonable timeframe. The model is written using C++ in conjunction with CPLEX 11. The CPLEX Optimizer generally refers to the simplex method implemented in C programming; however, it can also be used to support other types of mathematical optimization using interfaces other than C. Nonetheless, it is nearly impossible to obtain optimal solutions for realistically large problems within a limited time. The size of the search space is therefore reduced by fixing a heuristic variable to a capacitated network design problem and temporal–spatial network-based pavement inspection scheduling problem.

3.3 Case Study

3.3.1 Model Tests and Results

The model incorporates the effects of three input parameters (i.e., the ESALs, SN, and PCI), which are used to simulate the international roughness index (IRI). The evolution of the programs toward the best solution is determined by a fitness function; i.e., the root-mean-squared error (RMSE). The general form of the mathematical model proposed for the first set of LTPP data is as follows.

$IRI = f(PCI, SN, ESALs)$…….. (10)

Here, the IRI has the units of 100 m/km and the ESALs has a unit of millions. The training dataset has a reliable correlation coefficient; however, there is weaker correlation between the validation data and predicted IRIs compared with the measured IRI. A hybrid approach was therefore adopted to improve the results of the SVR model by first creating a dataset of sparse vectors for use as the feature values of the SVR model. The input parameters for the sparse coding model were the SN, PCI, and ESALs. These features were encoded into a sparse vector for vocabulary training using a dictionary learning algorithm. Finally, the IRI was predicted through SVR for learning and prediction. For example, first, consider PCI, SN, ESALs as a set of features, and the corresponding IRI is treated as a label, which is the target to be predicted. The feature is encoded into a sparse vector via Sparse Coding, and the sparse vector is trained with the corresponding IRI using SVR.

The performance of the resulting hybrid prediction model is illustrated in Fig. 3-3. The hybrid sparse-coding SVR method appears to be as effective as the IRI prediction model in terms of the RMSE (from SVR model: 0.2966 to sparse-coding SVR: 0.0808). Note that for comparison purposes, all prediction models used the same variables for roughness prediction.

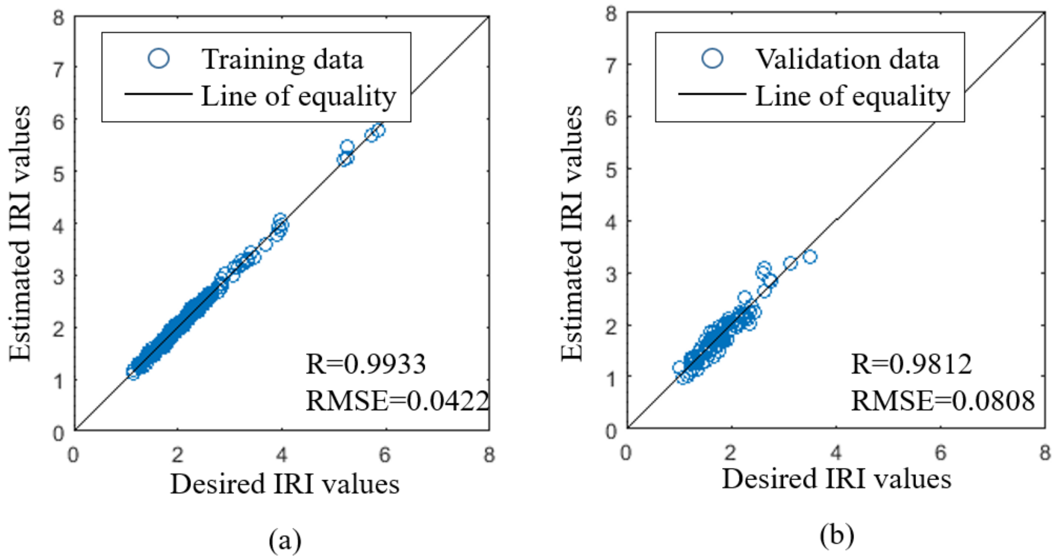


Fig. 3-3 Comparison of predicted and measured IRI values for training and validation data. (a) Performance of Sparse-Coding SVR model for training data. (b) Performance of Sparse-Coding SVR model for validation data.

3.3.2 Scenario Analyses

The efficacy of the proposed model and solution algorithm when applied to real-world problems is evaluated in a case study. The problems are solved using the CPLEX11.0 Callable Library based on the C++6.0 programming language.

Testing is performed on an Intel Core i7-9202.66 CPU with 4 GB RAM running Microsoft Windows 7. The proposed SCSV model is used for the analysis of pavement failure, with the results shown in Fig. 4. State Road 1 is taken as an example. In the figure, the main segments of road repair are located between 130 and 230 km. Table 3 lists the results of analysis and the expected maintenance, showing that six road sections require repair and maintenance. Table 3 gives the segments of Taiwan National Highway No. 1 that require repair, most of which are located in the central region. The longest section is segment 2 (at about 12.5km), which is expected to require 252 days of maintenance and 12,072 tons of material. Most maintenance is required along the Dounan branch, with there being six sections covering a length of approximately 250 km. The amount of material required for road repairs varies according to the length of road to be repaired and the width of the lanes and thickness of the pavement. According to the length of section to be repaired and number of lanes in that section, the amount of material required for maintenance is

$$m = c \times w \times l \times d$$

Where m is the total amount of material (tons) required for the i-th road section, l is the length (m) of the i-th maintenance section, d is the thickness of the pavement in this section (usually 0.05–0.225 m), c is the factor of the unit conversion from a square meter to a ton (2.3), and w is the width of the road (approximately 3.75 m). The amount of required material m is estimated according to the length of each segment requiring repairs and the number of days required for repairs is computed as $t = m/48$. Here, the variable t refers to the estimated maintenance period for service section i, and the total amount of maintenance material is divided by 48, as the amount of material produced by each asphalt plant is approximately 48 metric tons per day. Results obtained using the proposed maintenance forecasting model reveal six road sections requiring repairs.

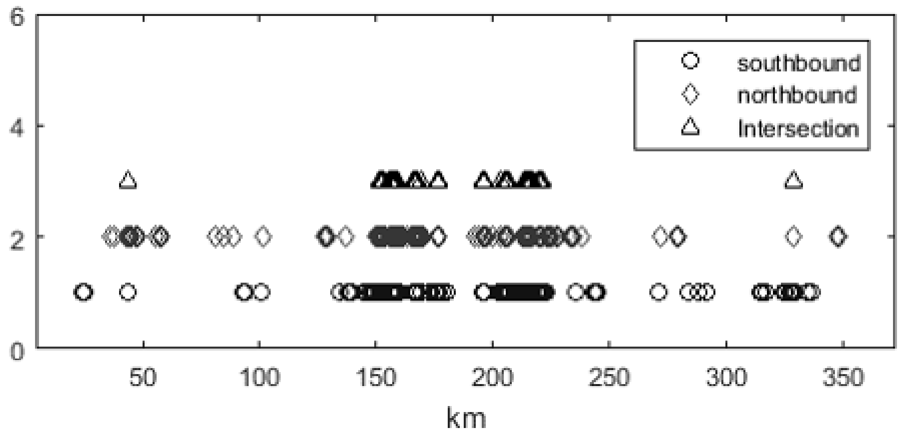


Fig. 3-4 Result of maintenance segment from Sparse-Coding SVR model for National Highway 1.

Tab. 3-4 Maintenance segment of National Highway 1

ID.	Segment (km)	Length (km)	Engineering Office	Branch	Engineering Days	Ton of repair materials

1	42.5-47.8	5.3	Northem region	Zhongli	122	5863
2	147.1-159.6	12.5	Central region	Miaoli	252	12072
3	175.3-180.2	4.9	Central region	Dounan	138	6614
4	202.1-206.4	4.3	Central region	Dounan	163	7808
5	218.4-225.3	6.9	Central region	Dounan	240	11526
6	326.3-329.8	3.5	Sourthem region	Kangshan	75	3609

Tab. 3-5 The pavement index of maintenance segments in National Highway 1

ID.	Segment (km)	Length (km)	Average IRI	Average PCI	Average SN	Average ESAL [millions]
1	42.5-47.8	5.3	3.67	79.88	28.43	11.84
2	147.1-159.6	12.5	3.75	66.78	31.44	12.25
3	175.3-180.2	4.9	3.86	70.45	25.86	10.78
4	202.1-206.4	4.3	4.13	71.98	27.31	9.88
5	218.4-225.3	6.9	3.83	69.48	30.02	11.15
6	326.3-329.8	3.5	4.12	77.42	28.84	13.76

The relevant pavement indicators for the road sections are listed in Table 3-4 in terms of averages. The identification of these sections is based on the pavement indicators, IRI, PCI, and SN, which indicate serious deterioration. Table 3-5 (Ho and Lin, 2015) lists information pertaining to the suppliers of pavement material. The location of hot-mix manufactures is shown in Figure 3-4. The suppliers can be divided into small- and large-scale suppliers. Large-scale manufacturers are able to produce larger quantities of pavement materials in a given period of time; however, they have higher production costs in the form of CO2 emissions. This table lists the maximum amount of material produced by small- and large-scale manufacturers as well as the total CO2 emissions. The proposed optimal maintenance model is then used to derive the optimal maintenance strategy. Figure 5 presents the results, where the red line indicates the conventional maintenance method and the blue line segment is the optimal strategy derived in this study. Note that the conventional maintenance model requires fewer days than the optimal maintenance strategy for the completion of repairs. The optimal maintenance scheme is able to determine the size of the manufacturer that minimizes the emissions of CO2 for a given situation. Although this would extend the time required to complete maintenance, it would reduce CO2 emissions and the costs associated with the production of materials. The GHGs emitted by large-scale manufacturers far exceed those emitted by small-scale manufacturers. The proposed model is able to derive an optimal maintenance strategy based on the specifications of the manufacturer, while considering the release of GHGs within a set timeframe. Figure 3-5 illustrates the effect of maintenance duration on CO2 emissions. The solution conventionally used for maintenance and scheduling is Tra-ED = 64, wherein manufacturers closest to the project are given priority (Ho and Ling, 2015).

Tab. 3-6 Manufacturer parameters for pavement repair material produced

Parameter	Min.	Max.	Average	Med.	Std.	Range
Max ton of material produced for small scale manufacturer	40	60	49.26	49.5	5.64	20
Max ton of material produced for large scale manufacturer	197	246	219.93	219.5	14.18	49
Ton of CO2 emissions for material produced per ton	66.82	99.52	78.16	68.12	13.78	92.7
Ton of CO2 emissions for manufacturer operating per day	26.83	59.52	38.15	28.235	12.77	32.69

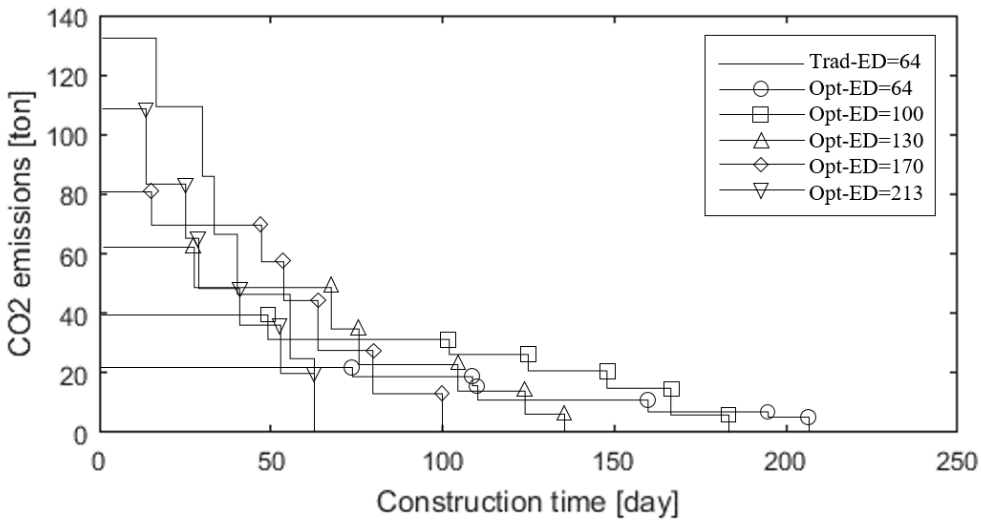


Fig. 3-5 Result of optimal repaired scheduling and general operating for pavement maintenance.

Opt-ED is the best solution for the optimal maintenance scheduling model. CO2 emissions calculated using the proposed optimization model are lower than those calculated using conventional methods, even when using an equivalent timeframe.

A maintenance timeframe of 64 days results in 4417.59 tons of CO2 emissions, which is approximately 7.55% lower than that obtained using the conventional approach. Figure 6 shows that proportion of small manufacturers exceeds that of large manufacturers throughout Taiwan. Highway sections 2 and 5 require more time for maintenance owing to the large amount of materials required from large manufacturers. Each section of the highway requires approximately 4.3 small vendors and 0.7 large vendors to provide the pavement materials required for repairs. An optimized maintenance strategy can reduce emissions yet tends to increase the time required for the completion of repairs, as illustrated in Fig. 7. The maximum time required for maintenance section 5 is approximately 52 days, and the entire project takes approximately 84 days. Using the conventional approach, the maintenance of the six sections would produce 4778.36 tons of CO2, whereas the proposed optimization model would reduce this amount to 3288.56 tons (i.e., a reduction of 31.18%). Figure 8 illustrates the impact of CO2 emissions, as calculated using the optimized scheduling model for various maintenance timeframes. For a maintenance period of 64 days, the proposed model reduces CO2 emissions by 7.55%, relative to taking the conventional approach. Disregard of the maintenance timeframe (i.e., if minimizing CO2 emissions is the only goal) reduces CO2 emissions by 35.67%. There is thus a tradeoff between the maintenance duration and CO2 emissions. Furthermore, in calculating the time assigned for the repair of a given section of road, decision makers must consider a wide range of factors, such as labor costs and inconvenience to the public. Figure 9 illustrates the amount of material that can be used for repair for a given level of CO2 emissions. When using CO2 emissions on par with those of conventional schemes, the introduction of ED constraints increases the length of road that can be repaired by 11.86%. Disregarding the maintenance timeframe extends this percentage to 28.31%. Figure 10 illustrates the CO2 emissions according to the number of lanes for various scheduling methods. CO2 emissions clearly increase with the number of lanes. Note that the effectiveness of the proposed scheme increases with the number of lanes in terms of CO2 emissions. For example, CO2 emissions can be reduced by 7.55% when the proposed scheme is applied to the repair of a single lane, whereas CO2 emissions can be reduced by 31.18% when applied to two lanes.

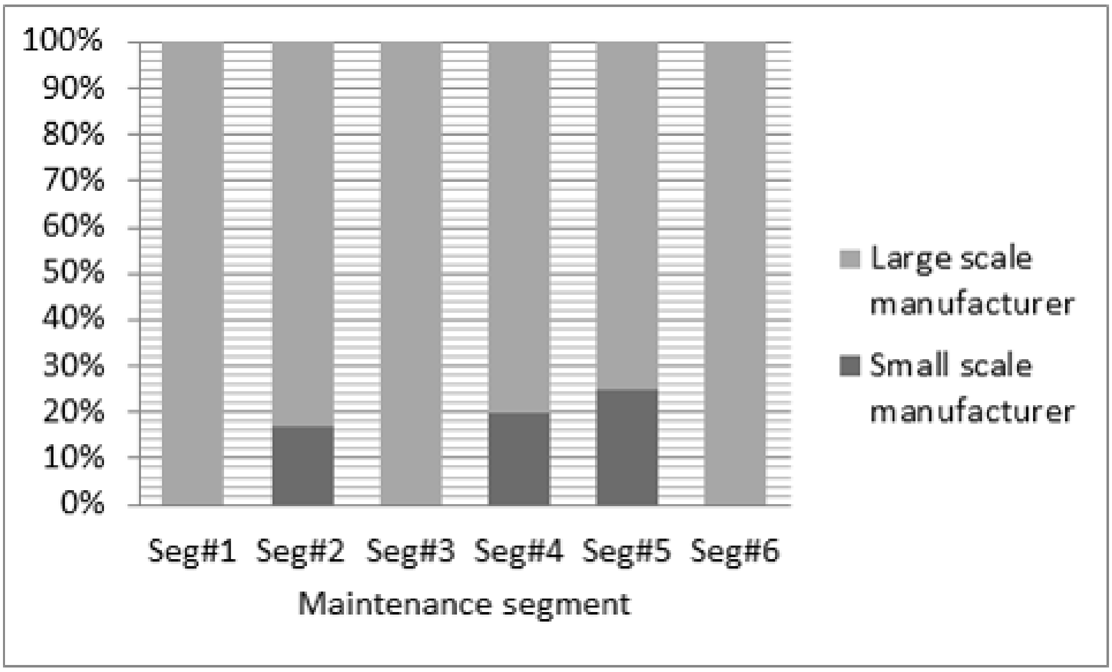


Fig. 3-6 Ratio of large and small scale manufacturer in an optimal repaired scheduling for pavement maintenance.

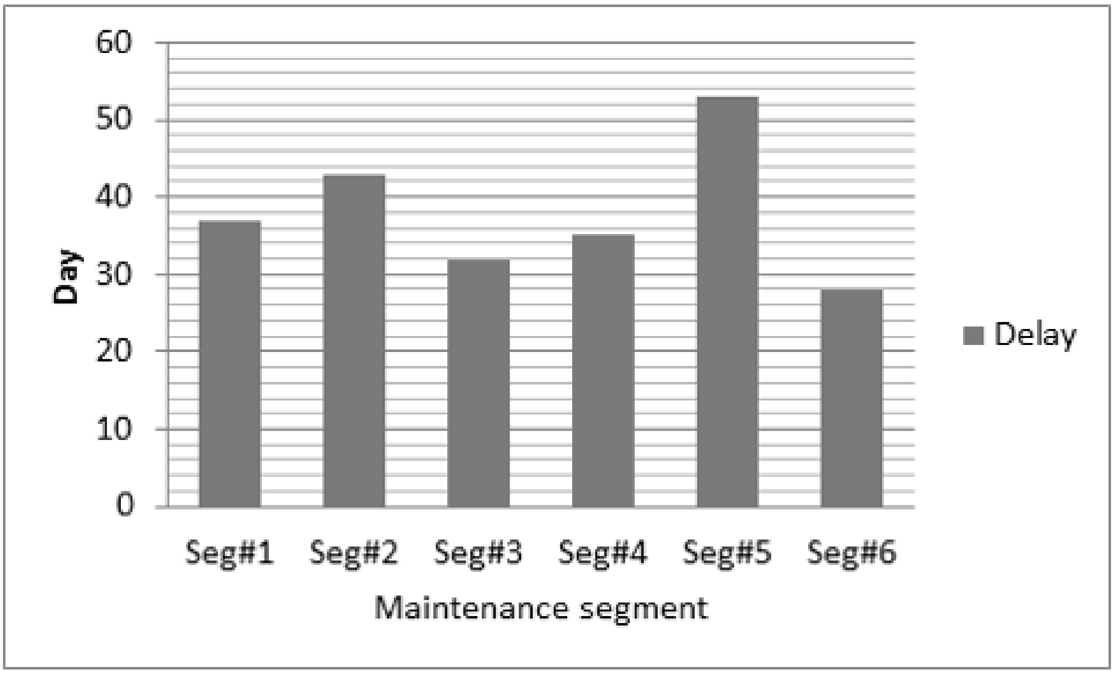


Fig. 3-7 The delays of optimal repaired scheduling over general operating for pavement maintenance.

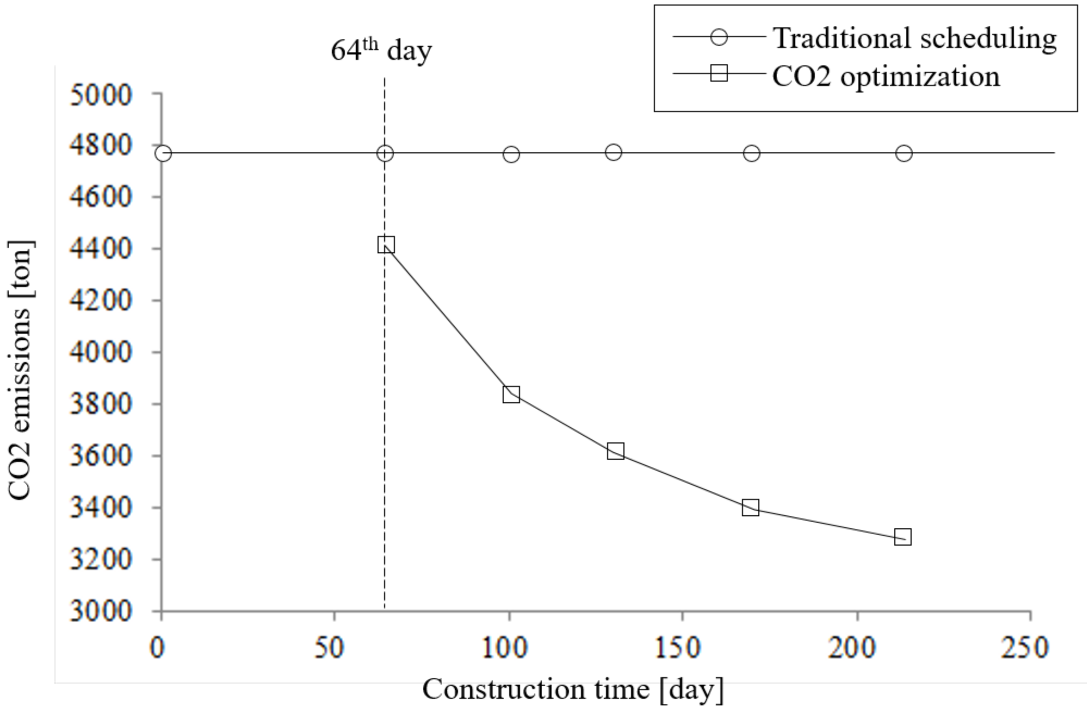


Fig. 3-8 Results of CO2 emissions reduction variation time constraint.

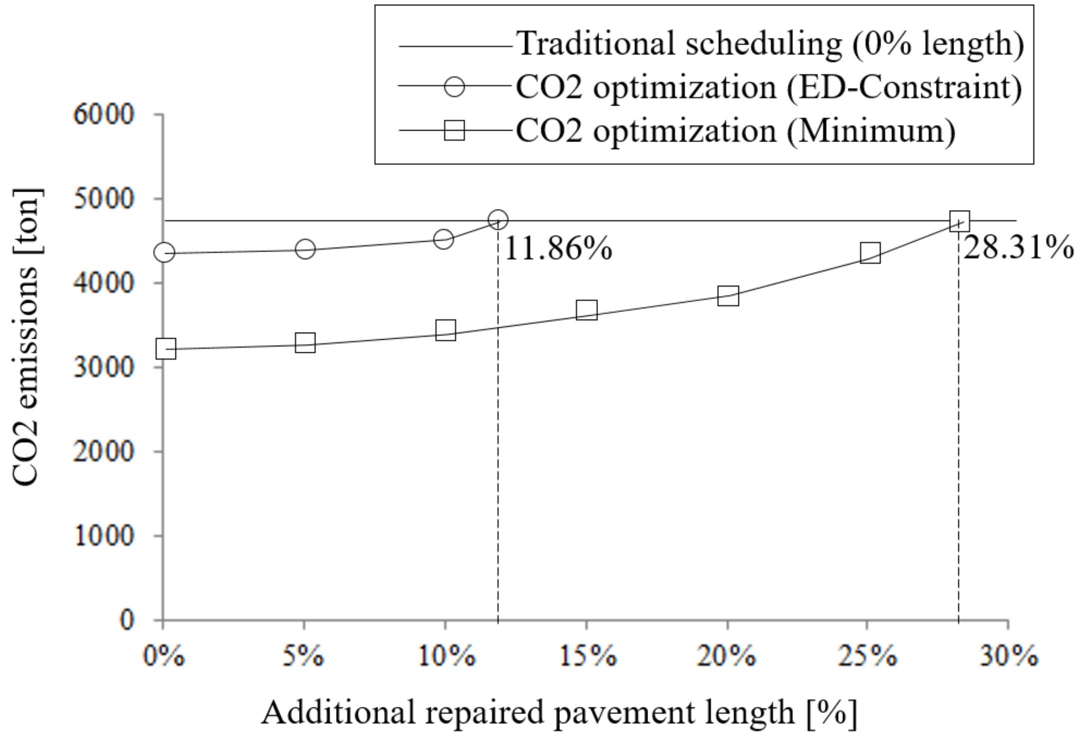


Fig. 3-9 The additional repaired pavement length in the same CO2 emissions from traditional scheduling.

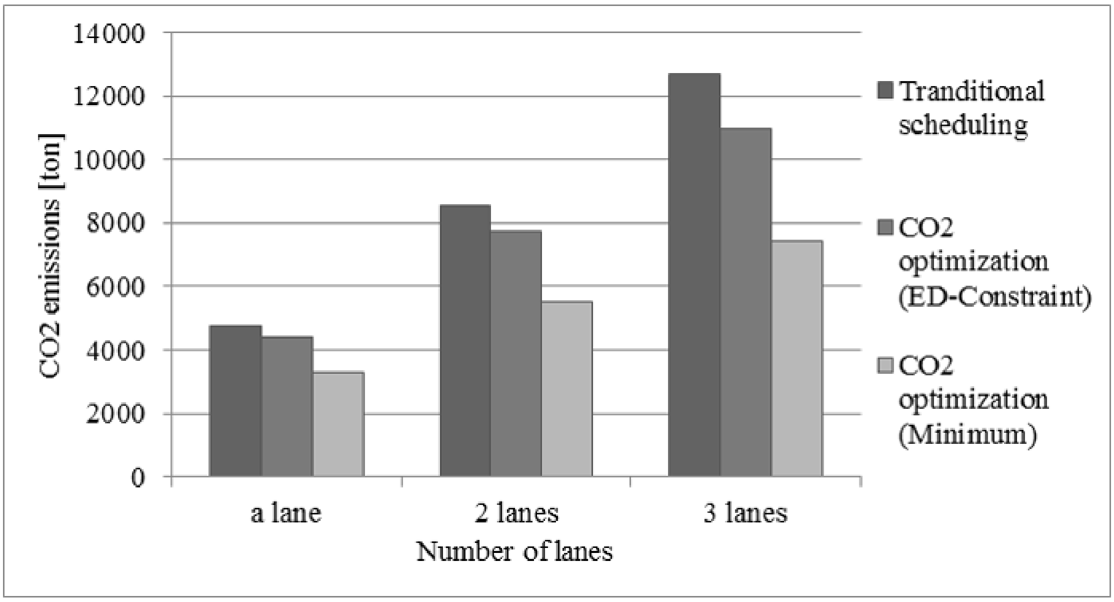


Fig. 3-10 The result of CO2 emissions consider the number of lanes being repaired.

Fig. 3-11 The location of hot-mix manufactures in Taiwan.

3.4 Summary

The present study estimated pavement performance indicators (i.e., the IRI, ESALs, SN, and PCI) employing the SCSV method. Each parameter was entered one by one and brought together using seven different models. This resulted in a predictably high success rate to the value of the IRI. Many highway agencies have the equipment necessary to take IRI readings but are unable to afford the personnel that such readings require. The proposed model allows the state of pavement to be estimated at present and in the near future in assisting scheduling maintenance projects. The proposed scheme is designed to minimize CO2 emissions for a set quantity of repair materials. Likewise, the proposed scheme can be used to extend the length of road that could be repaired for a given amount of CO2 emissions. Decision makers can determine whether to enhance the efficiency of road work or to lower CO2 emissions according to the results of the analysis. The proposed model could be generalized to a wider range of situations by including a wider range of traffic data, pavement structural properties, and roughness indices.

Chapter 4. Circular economy materials used in asphalt concrete and cement concrete

The research is focused on the addition of energy conservation and carbon reduction into precasting concrete plant to improve the level of quality further. Application of the cost efficiency with the introduction of carbon calculator for the “carbon footprint” and lowering carbon emission strategies is further discussiond. During the life cycle of precasting structure, a good structure design incorporates not only the planning and design, but also its materials, equipment, and construction, which make up the important elements in preparing the final products in the precasting concrete plant.

By precasting structure of life cycle, good design in addition to the planning and design of building structures, precast concrete plant factory precasting products, materials, equipment and construction of a building structure unit of the finished product is very important element, and the energy conservation and carbon reduction import precasting concrete plant for further improve quality level, will cost when the subject research of the main shaft, through better understanding of concrete precasting factory, by the import carbon foot machine can statistics and energy cost savings to reduce carbon strategy;As the main direction of research papers.

4.1 Case study

Precast mechanization construction has less environmental impact due to unified construction methods which produces carbon energy saving effect; and contributes to economic investment plan. A minimum of 10 percent of the percentage is applied to the green materials, green or green energy construction method. The short-term objective of the National Energy Conservation Program is to reduce the total carbon footprint in the future 2030 to 2005 emission targets.

Carbon emissions if it does not reduce, the earth, approximately, in 30 years will suffer severe drought - Willey Interdisciplinary Reviews: Climate Change (2010). The latest study warning that unless greenhouse gas emissions reduced, most of the regions on Earth may within 30 years will face a very severe drought. Part of Asia, the US, Southern Europe, and most of the Africa, Latin America and the Middle East region in the coming decades will be affected by serious drought, and the area near Mediterranean region will face an "almost unprecedented" drought damages.

Precast Method (factory cast) first appeared in Europe, its strengths and weaknesses as follows:

Advantages:

1. Site need only base and the combination of work and finish the decoration, without the need for conservation and decrease duration.

2. Components Factory production, quality unified products.

3. The template can be used repeatedly without scaffold and support, only needs assemble workers, low cost savings.

Disadvantages:

1. Crane lifting and transport are more expensive and is restricted and the need to increase welders.

2. Assemble precision high, less changes of building outlook.

The Precast Method in the precast factory from raw material, equipment, construction of carbon footprint section project inventory based on ISO 14064-1 standard calculated statistics pre-MOLTEN products in addition to its own advantages and disadvantages, and provides gas environment and energy savings resulting from the improved efficiency as statistics and identify more favorable to precast materials used in the factory and expand the use of the green sustainable construction and building materials for the purpose. Settings section Carbon Footprint General Objectives:

1. Energy savings objectives: future 8 years (since 2008) Energy efficiency every year more than 2 per cent of the energy density at 2015. More than 20 percent decline; by technology breakthroughs and complementary measures to 2030 declined more than 50%.

2. Carbon reduction target: CO_2 reduction, in 2030 the national carbon dioxide emissions back to 2005 emissions to 2030 national carbon dioxide emissions back to 2000 emissions.

November 3, 2011, the Executive Yuan publicized the “New Energy Policy” is to “ensure nuclear safety, lower dependency of nuclear plants, developing low carbon green environment, and steadily moving forward to non-nuclear power plants homes” as the overall energy development vision and the main driving force for policies of the energy-related objectives of the industry with energy efficient technology research and promotion applications. The current energy in promoting the development of science and technology is to study the development of technology-based industry, while at the same time advance participation and cooperation, technology licensing and other combination of domestic industry and the implementation of the research and development results to authorize the efficient industry production equipment and tools; through the final verification of nuclear energy, energy efficiency standards of control, such as the chapter energy policy instruments to promote efficient product manufacture and application.

4.1.1 Carbon dioxide carbon emission index

1 With regard to CO2 emissions-induced global warming is the most serious global environmental issues and for this reason is to talk about building CO2 emissions LCA assessment. The construction industry CO2 reduction issues, in addition to the general everyday use of energy, the rest of the section from building materials production of CO2 emissions. Building Materials Production of CO2 emissions and local energy structure and energy efficiency have close relations. For example, Norway 99 percent of electricity totally dependent on hydroelectric power, its clean units per ton oil equivalent of energy CO2 emissions (1.36t) only 52.7 percent of Taiwan and the thermal power generation accounted for 59 per cent of Japan, annual average energy emissions of CO2, about 0.533kg is thermal powered accounted for approximately 74 per cent of Taiwan's 81%. A domestic building materials of CO2 emissions in the energy statistics, regulations and statistics section has detailed the Ming and the results show that most of the metal building materials such as high processing, high CO2, high-energy emissions of building materials, in particular import of rough aluminum ingots of CO2 emissions are 8.6 times that of steel is a general cement 18.8 times, follow ISO14067 standards of carbon footprint analysis to prove that the factory is committed to environmental protection.

The building lifecycle LC, can generally be divided into (1) Building materials production, transport, construction works (2) Construction, (3) Day-to-day use, (4) Repair update, (5) Remove the Disposal, (6) Building materials recycling the six stages. The so-called building lifecycle of CO2 emissions is the sixth phase of the total CO2 emissions in this LCCO2 are called. To view LCCO2 assessment, day-to-day energy conservation in the housing CO2 reductions in response to occupy a position of absolute dominance. On the other hand, the same methods of assessing a 10-RC office building, also found in the construction process of building materials production, transport, construction CO2 emissions only accounted for

8.35 per cent of the LCCO2 that 40 years accrued daily consumption CO2 emissions is high on the 86.41 per cent. Day-to-day energy-CO2 emissions higher proportion of course, i.e. after the construction is completed daily consumption of CO2 emissions in the building lifecycle is large proportion of building energy management and maintenance of the building is the most important part of environmental protection.

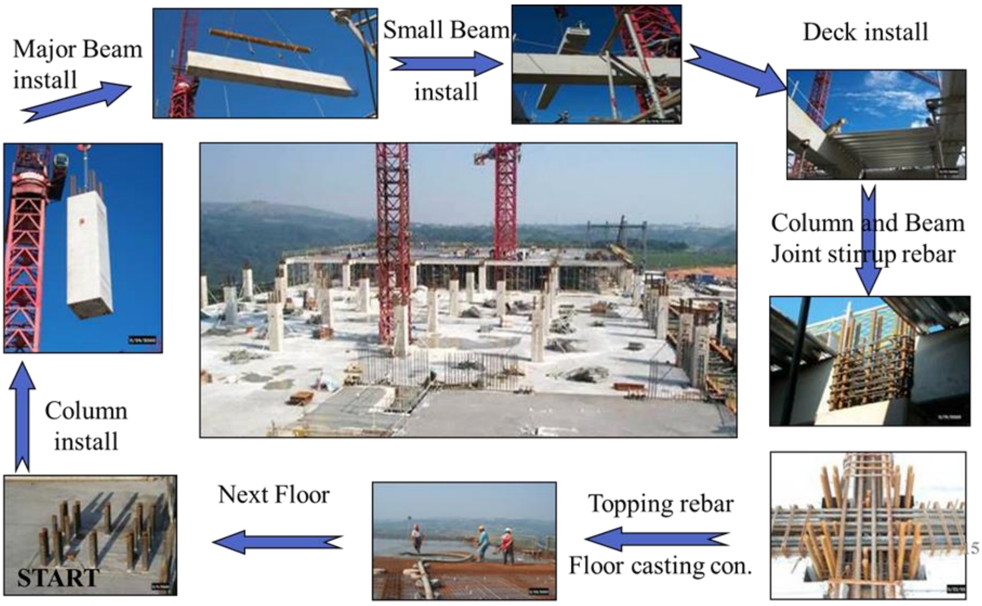


Fig. 4-1 Precast construre one floor to Install in site.(Source from Ruentex Co.,)

4.1.2 Precast Plant Energy Saving and Carbon Reduction Discussion

Public Works schema specification Chapter 3, 03400 chapter precast concrete, precast concrete components (products) of manufacturing, inspection, installation, and their materials and construction of the relevant provisions. 1. Cement concrete materials 2. Equipment Factory of production mold 3. Construction Products, transport and lifting as this section carbon footprint studies Discussion approach. The study mainly assess resource is a concrete and steel; two non-main assessment resources such as water, cement, sand with previous studies of manufacturing energy consumption data and its proportion to the product system add carbon emission calculation.Fllow the Road Map:

Areas of considerations and limit the carbon footprint calculation guidelines is provided in the product evaluation project is a comprehensive general clauses, based on product features with simple desktop life cycle assessment, and discounting is not suitable for evaluation of the project and the elements by itself to select suitable assessment project. The study is limited by the time and manpower to terrorism difficult to various factors of carbon emissions and therefore need to be incorporated into the evaluation will assess the scope of the project to reduce and limit, the following considerations and Limitations section description: its carbon emissions are defined as follows in Table7.

The original value - Scrap Steel recycling of energy efficiency rate = × steel CO2 emission value (blast furnace steel GERM + rebar processing) (blast furnace steel GERM - electric arc furnaces steel GERM) 0.8. The development of precast construction steel cage up to section 43% average carbon footprint in recent years to heritage sites as success rate and therefore are not included in this research.

4.1.3 Material precast concrete Discussion

Tab. 4-1 Amount of concrete cement and water-cement ratio (this research)

	Cement(kg/m3)	W/C+P	Slump	Reduction of cement
Ordinary Portland concrete (OPC)	492.6	0.48	small	-
High Strength concrete (HSC)	390~560	0.3~0.4(Low)	small	5~20%
High Preformance concrete (HPC)	≦450	0.2~0.45	big	50%(Up)
Roller Compacted concrete (RCC)	100	0.42	small	20%(down)

1. Section Carbon Footprint Assessment System Creation: Confirm the boundary, if this is the clear definition of PCR(Product Category Rules) product range.

2. Each phase of the assessment and the methodology for the collection of the entire life cycle of all stages of the material usage, activity and emission factor data.

3. Now the visits of the advanced computing and carbon emissions data validation abroad; computing products carbon footprint.

4. Products carbon emissions; assessment of the carbon footprint analysis of accuracy.

4.1.4 Device - Precast Factory

With the ISO 9001 certification by the industrialization process to mold steel mold and the level of production and concrete indoor Gate Building and conservation to ensure quality precast components. Factory production and environmental stability and insulated from the effects of mechanical equipment manufacturing and operating standards of technical work needs small and human control process with the conservation of the environment, precision steel mold production.

Through standard modular design torque, and automates production processes to streamline management processes and reduce the overall duration of funds derived benefits so that total cost savings. Precast construction costs by traditional RC only limited cost competitive, precast technology can save 30% on deadlines and in early revenue and reduce interest expenses.

4.1.5 Construction - precast concrete products PCR (Product Category Rules)

Building durable design, the most effective way of providing durability (durability, serviceability maintainability), two responses. The first is the durability design" just simply increase structural strength is relatively easy to deal with countermeasures, and most effective design of the life cycle. According to expert estimates, structure should be structural strength by 20 percent, approximately can improve building life.

The second is the maintenance of the design of the building body and the device in the service line. The construction of the maintenance of the body design is simple, easy to clean, pollution of the design, as well as all-weather deep into the door and window design. The device line serviceability design of water, electricity, communication, fire gas pipes, devices such as the design of the "prove", as long as the existing planted many of RC Beams floor version of tubing in spite of, for Building Life Extension is a great help.

4.1.6 Costs - the Difference of Traditional and Precast

All precast structural members, pre-production factory production, site use of mechanized device only for group a pendant and immune to external eagle-painted and decorated synchronized to effectively decrease construction period; structure-wise at least saved 7 days per story; precast structure: 7 days; traditional structure: 14 days inspection report of a precast construction and decoration per story. No Fire-proof prime, no scaffold support, and precast construction can work on decoration and equipment, electrical and mechanical works at the same time.

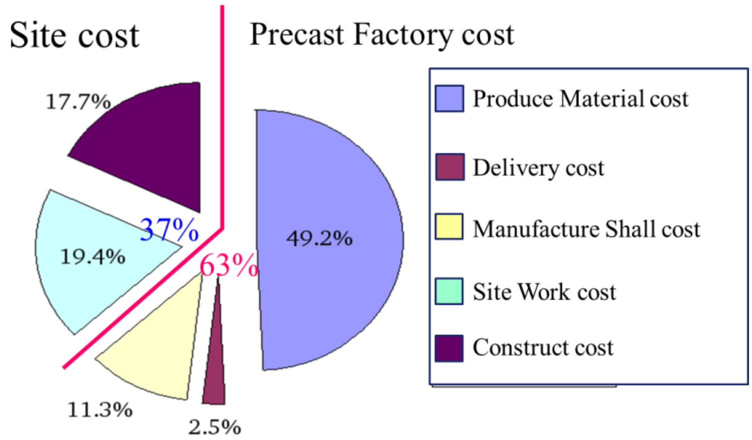


Fig. 4-2 Site and Precast Factory the difference cost

4.1.7 Benefits - progress and quality Discussion

The progress and quality of the differences are as follows:

1. MRS post structure size is small and floor height can be reduced, reduce overall structural steel, cement usage, comply with environmentally friendly and reduce transport costs.

2. Well maintained upkeep, or accompanied by pre-pressured precast structure will reduce cracks from dryness, and improve the quality of structure.

3. Factory production prevent pollution from site construction mix into concrete, will also avoid the structural holes and honey beehives situation in traditional construction sites.

4. Steel rebar is placed interior to reduce rust, also provides concrete with a strong hold.

5. Precast concrete, high-strength using traditional RC than the general use of concrete strength and material life and durability are better.

6. The uncleanness of the construction site from traditional methods of lumber cutting, discarded woods, rebar, residuals of concrete or leakage of concrete, large numbers of workers waste, resulting in difficult movement of walking, and etc., can all be improved by using precast method.

7. Precast requires a high threshold, currently only large manufacturers have precast capacity in Taiwan, and large construction companies can improve the fulfillment of the project contract.

8. Pre-mixed plants need to prepare a dedicated production line production with on-site manufacturing assembly continuous rotation, pre-mixed concrete factory can feed daily manufacturing, productivity and quality are also relatively easy to control.

4.2 Precast Plant Prouction Energy Saving and Carbon Reduction Inventory Section Discussion

4.2.1 Study of Inventory Investigation Methods

As a result of the location uncertainty of the exploitation of raw material production, the gathering information in similar locations is used and also compared Taiwan to the selected raw materials carbon emission factor as the basis of raw material production phase. The transportation distance during the raw material production phase is considered the distance between the raw materials site and the manufacturing plants, because their contractual and localization reasons. According to the calculation unit is divided into three stages:

1. Raw material stage cement, natural granules: production + transportation, ash: Handling + Transport

2. Manufacturing stage - the ratio: non-reference case study; mix of settings: device energy such as electricity, transport phase

3. Transportation stage - Product transportation, maintenance process built-in: transport equipment for the distance calculation

This study uses the lab formula Xc%&Xw% = Hearthstone with (1) = Hearthstone, (2)= recycled materials; a gray = 0 (with pre-MOLTEN Products Quality Requirements: Not Use);

Tin Port Pilot quantity 3^3=27 group arrangements with ratio adjustment try mix test informed the research needs of the ratio of the test and the test results of this study to Discussion.

◎Cement:

Cement, cement is one of the concrete materials. The major raw materials are limestone, clay, silicon sand, iron slag and gypsum. In the exploitation of coarse limestone, according to a certain proportion and clay, silicon sand and iron slag mixed, but internally there is no raw material extraction and transport-related research data and information obtained not easily, the exploitation of raw materials and Cement Transportation is not included in the scope of this study to assess follow-up concrete units, carbon emissions contains only the manufacturing process and product transportation. The transport phase are as follows: Table 4-2 as the research computing cement units average carbon, made after the organize this data to represent the cement unit and the subsequent carbon products Calculate carbon emissions, are this data.

Tab. 4-2 Cement unit process emissions

Section	Product (ton)	Transport(ton)
Kg-eCO2/unit	813	5.98
Cement Total=813+5.98=819.27 Kg-eCO2/T		

◎Hearthstone

The current domestic production from China Steel Company water-hardening hearthstone is significant, and China Resources Company is mainly converting the China Steel Company production of water-hardening hearthstone into water-hardening stone powder. The research is using the China Resources Company standard as listed in table 4-3 as the base unit for the water-hardening hearthstone powder calculation.

Tab. 4-3 Slag unit process emissions

Species	Electricity Power(kw-hr / ton)	Coal(Kg/ton)
Slag 100	70	5.98

Table10 is the summary of this research by computing hearthstone average carbon emission units made after this data. It represents the Slag carbon emission unit.

Tab. 4-4 Slag unit CO_2 emissions

Species	Material Transpot	Process	Good Transpot
unit	Ton		
CO_2 emission	0	80.54	13.92
Total unit CO_2 emissions =80.54+13.92=94.46 Kg-eCO_2/T			

Summarize Table 8, Table 9 and Table 10 computing cement concrete material handling and transport energy-carbon emission unit into table 11 as follows:

Tab. 4-5 Cement concrete unit Material Transpot and Process emissions

Material	Product	Transport	unit CO_2 emissions
Gravel (G)	3.45	10.25	13.70(kg-eCO_2/m3)
Cement(C)	940	5.98	945.98(kg-eCO_2/T)
Slag(B)	80.54	13.92	94.46(kg-eCO_2/T)

◎Structural Steel:

There are two major steel making methods, high temperature furnace steel making method; another is electrical furnace steel making method. The differences between is in the main materials used, the high temperature furnace steel making is using iron ore and electric furnaces steel making is from scrap metals. There exists a huge difference in terms of the energy used in both methods as follows in Table 4-6:

Tab. 4-6 Structural Steel unit carbon emission tables source: This study to collate.

Material	Unit	Product	Transport	Total
Steel embryo (blast furnace)	T	2119.65	5.62	2125.27
Steel embryo (electric arc furnace)	T	364.79	5.62	370.41
Steel and iron pieces	T	888.07	7.96	896.03
Section steel	T	904.26	7.96	912.22

Structure material carbon emissions Summary as follows in Tab.4-7

Tab. 4-7 Coarse and fine aggregates material carbon emissions summary

Name	Unit	eCO2/g	Year	Country
Gravel	M3	3.11	2012	Taiwan
Aggregate	T	5.20	2006	U.K.
Sand	T	4.80	2006	U.K.
Coarse aggregate	T	5.10	2006	Korea
Fine aggregate	T	1.60	2006	Korea
Gravel 1	T	1.03	2008	Japan
Gravel 2	T	1.17	2008	Japan

Cement carbon emissions Summary as follows in Table 4-8:

Tab. 4-8 cement carbon emissions Summary

Species	Carbon Emissions (kg eCO2/T)	Source	Country
Cement	503	Report of the Ministry of the Environment of Japan on GHG	Japan
	930(Type I) 880(Avg)	British Cement ssociation	U.K.
	930	-	India
	890	-	U.S.
	880	-	China
	940	Ministry of Economic Affairs	Taiwan

Cement Replacement carbon emissions Summary as follows in Table 4-9:

Tab. 4-9 Replacecement in carbon emissions Summary

Material	limestone (kg)	Coal burning (kg)	Electricity (degree)	Carbon Emissions (kg-eCO2/T)
Slag	0	14	70	52.2
Cement	1200	110	110	940
difference	-1200	-96	-40	-887.8

Note: Factory use sub-meter single power computing and Taiwan Power Company with the table and power factor electricity price differences as the basis of error correction reference. as follows in Table16 , Table 17and Table 4-10:

Tab. 4-10 Equipment Mixed concrete plant energy consumption

kgf/cm2	210	245	280	280(W)	350	350(SCC)
Electricity (degree)	1.6493	1.7409	1.6135	1.5657	1.6092	1.1433

Tab. 4-11 Comparison of Two Kinds of Premixed Truck Transportation

	Car species	Business	For Personal Use
Pre Mixer Concrete	Weight(Ton)	1,821,430	85,675,803
	Yenton kilometers (Ton-Kms)	38,107,313	1,109,768,261
	Freight rate per metric ton (Average Freightper Ton-Km)	13.2434	-
	Average distance (Km)	13.12 13.12	13.12
	Carbon emissions (kg CO2-e/m3)	2.28	

Tab. 4-12 Comparison of Transport Stages at Different Stations

	Plant A	Plant B	Plant C	Plant D
Average distance (km)	60-80	20-40	15	10-20
Car species (m3)	6	6	8	8
Fuel consumption (L/km)	0.4	0.4	0.4	0.4
Diesel Coefficient (kg-eCO2/L)	2.61	2.61	2.61	2.61
Carbon emission (kg-eCO2/m3)	10.44-13.92	3.48-6.96	13.1-2.61	1.31-2.61
Yield(m3)	240000	100000	200000	413700

Weighted average (kg-eCO2/m3)	3.83-5.91

4.2.2 Carbon Reduction Benefits Analysis of Products

Methodology: Calculation of the product life cycle all occurred in raw materials, energy and waste phase of activities multiplied by its corresponding emission factors and is added to the total carbon footprint of calculation. Calculated as follows: activities of carbon footprint = Activity Data Quality/volume) x /kwh/km emission factors (CO2E per unit) due to the PAS 2050 Considerations Product carbon storage in effect, the sum of the emissions after deducting the amount of carbon storage, which is a product lifecycle greenhouse gas emissions. In addition, PAS 2050 and requires the calculation should note the quality balance (mass balance, i.e. inflow into the quality process should be equal to the outflow of uneven quality, if the quality is a part of the process flow is not computing (usually a waste) whereby view is complete computing a process of carbon emissions.

◎Portland cement concrete proposals to reduce carbon benefits analysis

Cement concrete is to cement or cement the right amount is mixed with the materials, water and coarse and fine aggregates, or add additional agents or other materials to press an appropriate proportion with a mix of mixed property to the Gate Building in a time process and freezing of the artificial stone. But it is also present concrete construction energy consumption and carbon dioxide emissions in industrial and is thus able to control the use of concrete materials to achieve the energy is the best path to a carbon footprint.As concrete proposals to achieve the savings less carbon reduction in the emissions of carbon is usually the most direct way to cement usage by reducing the hand, the most frequently used substitutes is water-heaters stone powder, the research that is calculated in the direction toward the reduction of their carbon benefits.

◎Self Compacting Concrete carbon reduction benefits analysis

The fill Self-Compacting- Concrete (SCC) means the internal process does not require the imposition of vibration, completely smashed by its own gravity filler to steel and steel and steel and template of the corners of the Special concrete. Because their mobility and fill performance filler steel clearance and templates in every corner of the world to minimize human rate for an improper and save manpower and improve traditional steel and concrete pouring into the secret because it is not easy to persuade or causing the cellular" phenomenon. So the refill concrete effectively to overcome traditional concrete construction in real bad, missing the ills, improves the quality of concrete filling achieve better performance and material homogeneity.

◎Carbon footprint calculation and life cycle assessment

According to the Environmental Protection Department, by carbon footprint calculation guidelines, the study of the spirit of integration in the past for product carbon footprint calculation or life cycle assessment studies related to the assessment of the law as indicated in table 17 &17 will be used as the basis for the follow-up research literature as follows in Table 4-13:

Tab. 4-13 Construction structure product need with carbon reduction benefits unit

item	Product	Formula
1	Protland Concrete	724.81×B+805.35×F kg-eCO2/m3
2	Self Compacted Concrete	724.81×B+805.35×F +Po -SPo kg-eCO2/m3
3	Rebar and Item(St)	247.312 St kg-eCO2/T
4	Steel(Se)	263.536 Se kg-eCO2/T
5	Stainless steel (Ss)	315.936 Ss kg-eCO2/T
6	Hot rolled coil (Hr)	281.992 Hr kg-eCO2/T
7	Cold rolled coil (Cr)	253.424 Cr kg-eCO2/T
8	Stainless steel pipe (Ps)	317.488 Ps kg-eCO2/T
9	Galvanized steel pipe (Pg)	283.456 Pg kg-eCO2/T
10	Cold-rolled steel pipe (Pc)	250.152 Pc kg-eCO2/T

4.3 Foreign and Domestic precast project inventory of carbon benefits Discussion

4.3.1 Foreign precast concrete energy saving _ carbon emissions

The European technology cooperation in the precast concrete manufacturers an 2 ELEMATIC, Finland and Germany PCE by the European use of cement material used in the precast Taiwan also consider more than the ambient temperature difference resulting from], precast plant has been designed central air conditioning full operating environment construction to ensure the quality of precast concrete; in this study does not include this item as follows in Table 4-14:.

Tab. 4-14 Difference Subcontacts Products Carbon Emissions Calculations

	Electricity (degree)	Fuel consumption (L)	Yield (T)	Carbon Emissions	Weighted Average
				kg-eCO2/T	kg-eCO2/T
Subcontact A	9600	120	4000	1.56	1.74
Subcontact B	-	1000	960	2.68	
Subcontact C	8200	350	3500	1.69	
Foreign data trial	(0.132+0.039) /0.03[thinkness] /2.35[Mixproportion] *2.61[Diesel carbon emission coefficient]			6.33	

4.3.2 OPC & SC concrete products calculation

Tab. 4-15 OPC & SCC Concrete Products Carbon Emissions Calculations

OPC	Cement	Water	Chemical	Slag	Aggregate	Sand	Total
Unit	(kg CO2/m3)						
280kgf/cm2	307.35	11.76	0.24	-	42.58	22.80	384.73
350kgf/cm2	347.59	11.69	0.29	-	42.58	20.91	423.07
SCC	Cement	Water	Camical	Slag	Aggregate	Sand	Total
Unit	(kg CO2/m3)						
280kgf/cm2	226.85	10.08	0.34	11.17	35.86	27.44	311.73
350kgf/cm2	256.12	11.45	0.39	13.62	36.45	25.63	343.66

The data source is from the Environmental Protection Department 1. Refer to the Environmental Protection Department's new http://cfp.epa.gov.tw/carbon/defaultpage.aspx factor

2. weight unit of data on the basis of actual mix 3. Product Carbon Footprint process in accordance with item 4. Uncertainty added to the calculation.

4.3.3 Progress Comparison

Technology, precast structure with at least shortened 7 days per story; G traditional structure, 7 days one story, 14 days inspection, and precast construction and decoration to every floor from a batch of reply, non-cultivation-base thin toner light, from ground frame decoration, motor and device can synchronize construction works, precast structure to 45 days after completion may apply for the use license as follows in Fig 4.3 and Fig 4.4 and OPC compare SCC reduce carbon emissions calculations as follows Table 4-16:

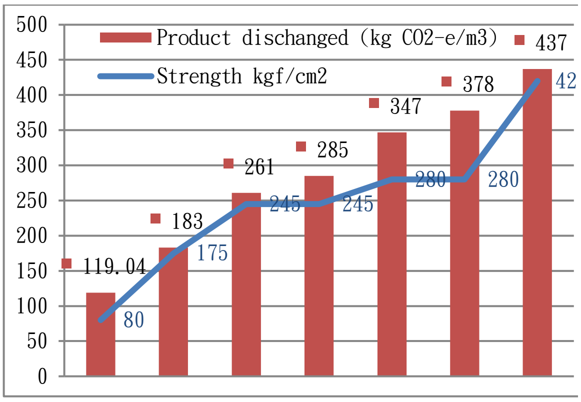


Fig 4.3 Concrete Strength and Carbon Emissions

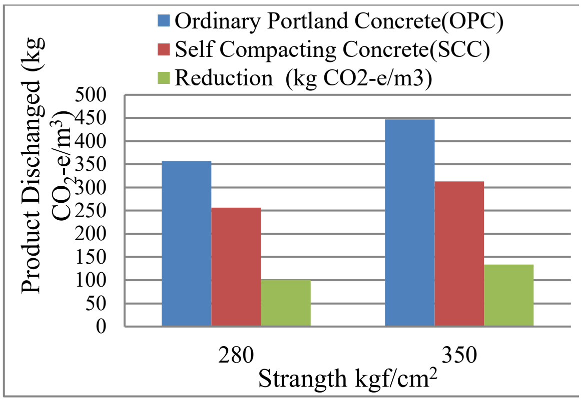


Fig 4.4 OPC and SCC Produce Carbon Emissions

Tab. 4-16 OPC & SCC Concrete Reduce Carbon Emissions Calculations (350kgf/cm2)

	OPC	SCC
Material(kg CO2/m3)	423.07	343.66
Production(kg CO2/m3)	1.747	1.144
Transport(kg CO2/m3)	4.87	4.87
Total (kg CO2/m3)	429.68	349.67
Reduce(kg CO2-e/m3)		80.01

4.3.4 Precast factory Lifecycle

Japan had to office buildings 50 years lifecycle for economic assessment and found that the initial planning, design, construction cost is only 26 percent of trading, repair, update, accounted for 27%, 50 years of hydroelectric energy expenditure accounted for 21%, taxes, interest and insurance general management costs accounted for 26 percent. I.e. the LCA investment from the economic perspective, office building of the initial cost accounted for only about a quarter of the cost of the operation up to three times that of the initial cost. Thus the green building designers and must never be ignored after construction is completed environmental impact assessment, only to the LCA assessment is modern green building features. Lca is modern Value Engineering The basic doctrine".

E-management and information platform control construction management

To achieve the project can be completed on schedule (time), cost budget (budget) to complete the project scope (Scope) with quality, allows owners satisfied with the ultimate goal of the project management from concept to actual investment project level of control for project teams and a more effective functioning of the best environment and functionality.

Manufacturers supply energy saving and carbon reduction benefits as follows in Table 4-17

Tab. 4-17 Benefit of Precast Concrete

Item	Reduce Carbon Emissions	Cost Down (NTD)	Note Data From
Cement Factory(Supplier)	23,311ton	35,020,000	Economic Daily
Hearing Impaired Olympics	51,485m2	2,316,825	Runhong Net
Neutralize Site Project	365.123ton	683,280	This research 5,694 m3*120
Total=NTD		38,020,105	

4.4 Summary

4.4.1 Conclusion

The study collected all raw material carbon emission factors from all over the world within a range, a reasonable inference is that due to different carbon emission factors used throughout countries. Cement concrete products carbon emissions maximum impact factor is a product of cement material, if the proportion of the same design under the intensity of the nature of their works, if you can increase the volume of cement material is replaced with the highest minus carbon benefits.

Concrete itself in the production must be on to use more attachment, but differences can cause the resin itself less carbon effects and therefore to a larger overall product carbon emissions, 280kgf/cm2 concrete per ton of carbon emissions reduced 384.73 kg Co2-e/m3 to 311.73 kgco2e/m3 about 72.99 kgco2e/m3 of approximately 18.97%.

4.4.2 Recommendations

Precast plant derived energy research issues related carbon reduction recommendations are as follows:

1. Production Equipment Automation generate energy carbon reduction effects of system study and channel research, such as layout automatically Steel Bending Machine processing of human machine infeed law ring savings effect reflected in reduced carbon computing.

2. Application ISO 14000 environmental management system, establish a complete set of energy saving and carbon reduction building management and audit system.

Chapter 5. Automatic Image Recognition of Pavement Distress for Improving Pavement Inspection

Frequent road inspections are key to maintaining road quality and avoiding casualties associated with poor road conditions. In Taiwan, open contractors conduct inspections of roads and ancillary facilities daily or weekly according to the requirements of the agency awarding the contracts. Unfortunately, the equipment used for inspections the inspection data lacks follow-up applications and numerical conversions, such as the Pavement Condition Index (PCI), to compile a large-scale database to facilitate the long-term conservation of roads. This study developed back-end image recognition software using existing road inspection methods and existing equipment. This was aimed at enhancing inspection efficiency by enabling the automatic identification of road damage. Resulting observations can then be converted into PCI values in accordance with ASTM D6433-16 to be exported as a numeric value indicative of road quality. A vehicle-mounted traffic recorder and imaging device with Wi-Fi transmission capability are used as hardware, and the relationship between the captured images and the speed of the car is used to obtain an accurate indication of road conditions across the surface. The SLIC Superpixels algorithm (using two stages of image grouping) is used to identify areas with pavement damage as patches, potholes, longitudinal cracking, and crocodile cracking. The results of the proposed fully-automated method conform strongly with those obtained using semi-automated pavement inspection software. Despite the restrictions imposed by the limited depth measurement of 2D images, our method achieved results close to those obtained using manual inspection. Future developments will include the application of artificial intelligence to enhance the effectiveness of this software.

5.1 Case study

The Construction and Planning Department of the Ministry of the Interior in Taiwan has adopted the pavement condition index (PCI) described in ASTM D6433-11 (A. Miraliakbari, S.Sok, Y.O. Ouma, and M. Hahn, 2016) as the primary index for monitoring pavement conditions (高嘉鴻, 2020). Unfortunately, PCI inspections are time-consuming and laborious, and the current inspection method relies on contractors recording pavement distress types in PCI numerical format. This makes it difficult to apply data collected during inspections to the calculation of PCI values or to make a long-term pavement maintenance plans (F. Zhu and Y. Wu, 2014) . This study held the following five objectives: 1) improve road inspection methods using the superpixels method for automated recognition of distress signs; 2) develop software based on the superpixels method to facilitate pavement distress recognition; 3) use clustering to extract indicators of distress from images; 4) develop automatic road inspection software capable of capturing and analyzing images covering the expanse of pavement; 5) compare our fully-automated inspection method with semi-automated methods and conventional manual pavement inspection in terms of cost and efficiency.

The current (semi-automated) road inspection method developed by National Central University relies on visual inspections of images captured at a spacing of 25 m for the recognition of distress signs. Specially trained engineers input the captured images and determine the severity of the distress, whereupon the software calculates the scope of the distress and assigns a PCI value for each 100-meter section of roadway. This method is based on grayscale images using a set threshold value obtained from the average grayscale value of every pixel or segment in the image (H. Wei, Z. Dong, and B. Liu, 2017). Nonetheless, additional image processing techniques are also required to differentiate signs of distress from traffic markers, shadows, and corrupted images. The disadvantage of this method is the fact that it processes only grayscale values; i.e., it disregards other information from the original image (M. Gavilán et al.,2011). Removing arbitrary distractions from images while retaining signs can be exceedingly difficult, particularly in cases where the pavement images are homogeneous. Multiple filtering methods must be employed to extract information from the images, thereby making it nearly impossible to conduct automatic inspections based on this method.

5.1.1 Pavement Image Recognition

Our primary objective in this research was to improve the quality of the road inspection methods currently used by contractors. The equipment used for road inspections includes an inspection vehicle, a driving recorder, and GPS vehicle trajectory recorder. Author developed software for the automated identification of pavement distress from captured images of roads. This process involves capturing and processing images followed by analysis. The image capture system provides sufficient resolution to improve on the accuracy of exiting systems. The primary analysis method used in this study was the SLIC superpixels algorithm, which is based on lab pixel analysis, K-means pixel clustering, and distress identification. Superpixels analysis is more efficient than conventional binary image thresholding in terms of identifying pavement distress. A flowchart of the study is presented in Fig. 5-1.

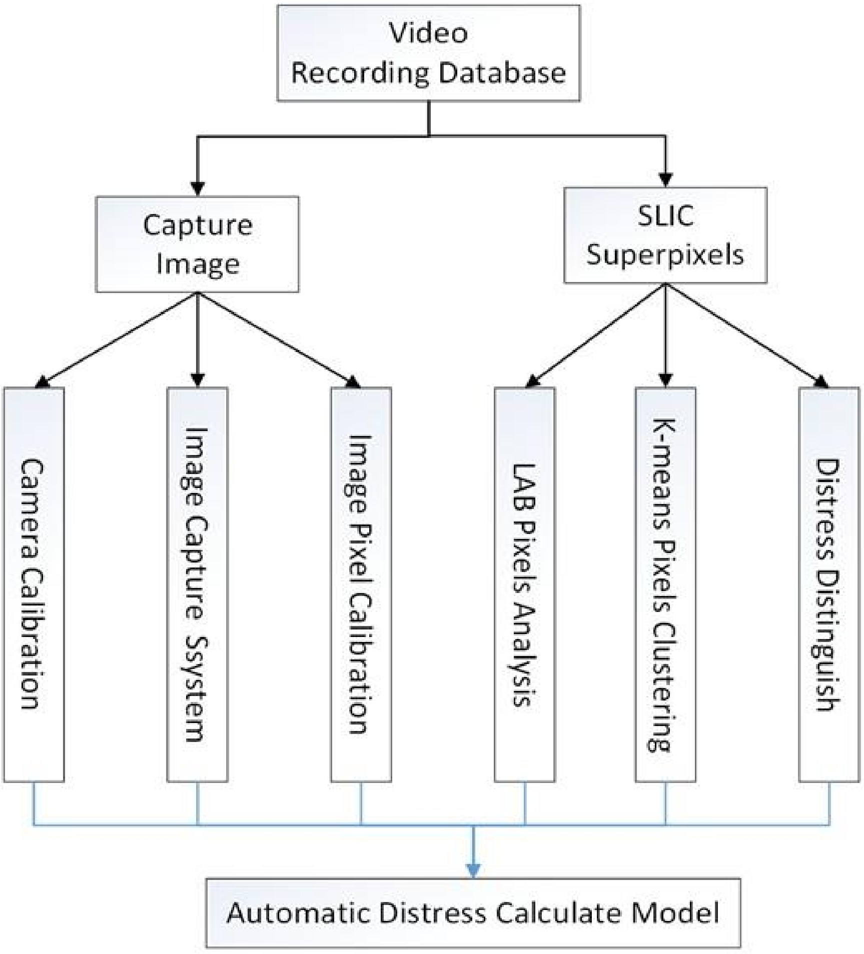


Fig. 5-1 Flow Chart

5.1.2 Equipment and Database

Three cameras were used in this study: two inexpensive dash cams (RadiQ R32 and ONPRO GT-Z01). The RadQ R32 provides superior performance in terms of image sensing and resolution; however, it lacks a GPS system. The ONPRO GT-Z01 provides GPS capability. Even these inexpensive devices provide high video resolution. Data was collected from four types of road: a high-speed freeway with no motorcycle access (presumed to have pavement conditions with the highest quality), a freeway that allows large motorcycles (second highest quality), a provincial road similar to a city street but with a higher speed limit (third highest quality), and a city road (lowest quality).

Firstly obtained video recordings of pavement conditions in the form of consecutive images appearing at a set frequency expressed in frames per second (fps). The human visual system is able to process and individually perceive 10 to 12 images per second. Higher frame rates are perceived as motion. Most modern video cameras feature frame rates of 30 fps to 240 fps and most dash cams record video at 30 fps to 60 fps. Under a set frame rate, the driving speed determines the distance between images. Fig. 1 indicates the distance between images at various speeds and frame rates. At a speed of 80 km/h and recording frequency of 15 fps, the distance traveled between images is 1.5 m. Facilitating inspection of the entire road while reducing computational overhead requires minimizing the number of images necessary for a complete survey. For example, 6 fps would be the minimum number of images required for a complete survey at 80 km/h, whereas 4 fps would be required at 40km/h. In this study, we assumed that the speed limit on National Freeways is 90 km/h, the speed limit on urban roads is 50 km/h, and the width of the selected area is 4 meters. Thus, we adopted a frame rate of 6 fps for national freeways and 4 fps for urban roads.

5.1.3 Inspection of Pavement Conditions

This study conducted manual inspections of a section of Taiwan National Freeway No. 3 from km 83 to km 89, also conducted inspections on sections of urban roads in order to formulate an accurate indication of the quantity and severity of damage throughout the road sections. Manual inspection of pavement conditions is considered the most accurate method; however, it is time-consuming and expensive. This is the reason that inspections based on the PCI focus on specific areas of the road (C. H. Linda and G. W. Jiji, 2011). Manual inspection allows the extraction of 19 types of distress, including data pertaining to length and depth. National Central University has developed a semi-automated system for the inspection of pavement conditions, wherein an encoder records a road image every 20 m from a camera based on GPS coordinates. An engineer attempts to identify the various types of distress including severity and scope but excluding depth, whereas software is used to calculate the PCI according to the scope of the distress. Then compared the performance of manual, semi-automated, and fully-automated pavement condition inspection methods.

5.1.4 Automatic Image Recognition and Image Preprocessing

Our objective in this study was to develop software for the automated analysis of pavement conditions using conventional equipment. A dash cam would be the most practical; however, the captured images would include a lot of detail unnecessary to distress analysis. This means that the images would have to undergo preprocessing, including camera calibration, analysis range selection, and image pixel calibration. Calculating accurate PCI values requires precise distress data, including the type of distress, the area, and the severity. Thus, images captured from video files must be calibrated according to the angle of view, the vertical distance from the road, and the image distortion imposed by the wide angle lens, as shown in Figs. 2-2 and 5-3. Following image calibration, the pixels in the image provide an accurate indication of the damage to the pavement.

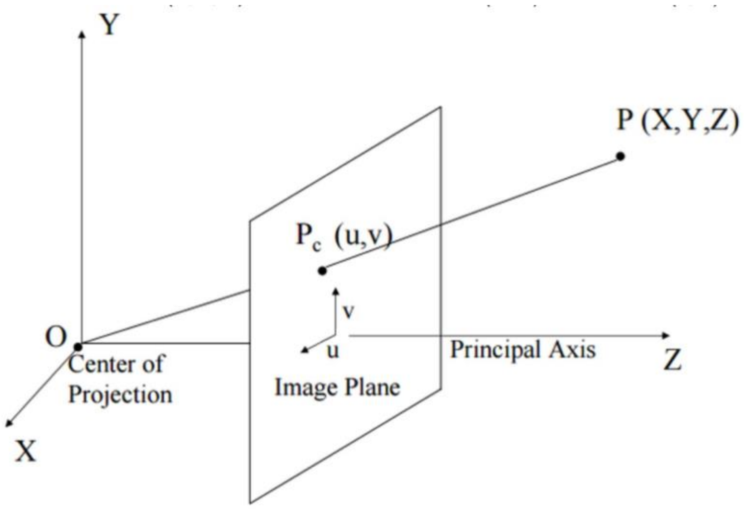


Fig. 3-2 Camera Calibration Theories

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \begin{pmatrix} f & 0 & t_u \\ 0 & f & t_u \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

Fig. 5-3 Calibration Matrixes

We set the coordinate system Ω1(X, Y, Z) ∈ R3 in the center of the camera focus O, and Z-axis perpendicular to the object surface Π1. The rays coming from the circle Γ1 form a skewed cone on surface Π1, the boundary curve C of which can be expressed as follows:

(X − αZ)2 + (Y − βZ)2 = γ2Z2

Parameters α and β specify the skewness of the cone in X and Y directions, whereas parameter γ specifies the sharpness of the cone. Thus, if the distance from the camera focus to the object surface is denoted by d, then the circle equation becomes (X − αd)2 + (Y − βd)2 = (γd)2.

The camera coordinate system Ω2(X, Y, Z) ∈ R3 is also centered in the camera focus; however, the Z-axis is orthogonal to the image plane Π2, and the x- and y-axes are parallel to image axes u and v. Thus, the transformation from Ω2 to Ω1 can be expressed using the following rotation:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

where vectors $(a_{11}, a_{21}, a_{31})^T$, $(a_{12}, a_{22}, a_{32})^T$ and $(a_{13}, a_{23}, a_{33})^T$ make for an orthonormal basis. Thus, the camera coordinates can be expressed as follows:

$$\begin{aligned} &\left[(a_{11} - \alpha a_{31})x + (a_{12} - \alpha a_{32})y + (a_{13} - \alpha a_{33})z\right]^2 \\ &+\left[(a_{21} - \alpha a_{31})x + (a_{22} - \alpha a_{32})y + (a_{23} - \alpha a_{33})z\right]^2 \\ &= \gamma^2 (a_{31}x + a_{32}y + a_{33}z)^2 \end{aligned}$$

The part denote the focal length (i.e. orthogonal distance between O and Π2) using the symbol f . Thus, the intersection Γ2of C and Π2 is expressed as follows:

$$\begin{aligned} &(n^2 + k^2 - r^2)x^2 + 2(lk + np - rs)xy + (l^2 + p^2 - s^2)y^2 \\ &+2(km + nq - rt)x + 2(lm + pq - st) + m^2 + q^2 - t^2 \\ &= 0 \end{aligned}$$

Where

$$\begin{aligned} &k = a_{11} - ta_{31} \\ &n = a_{21} - sa_{31} \\ &r = \gamma a_{31} \\ &la_{12} - ta_2 \\ &p = a_{22} - sa_{32} \\ &s = \gamma a_{32} \\ &m = (a_{11} - ta_{31}) f \\ &q = (a_{31} - sa_{33}) f \\ &t = \gamma a_{33} f \end{aligned}$$

This equation shows that the projection is a quadratic curve, the geometrical interpretation of which can be a circle, hyperbola, parabola, or ellipse. In practice, due to a limited field of view, the projection will be a circle or ellipse. From this equation the center of the ellipse (uc, vc) can be expressed as follows:

$$u_c = \frac{(kl - nl)(lq - pm) - (ks - lr)(tl - ms) - (ns - pr)(wp - qs)}{(kp - nl)^2 - (ks - lr)^2 - (ns - pr)^2}$$

$$v_c = \frac{(kl - nl)(mn - kq) - (ks - lr)(mr - kt) - (ns - pr)(qr - nt)}{(kp - nl)^2 - (ks - lr)^2 - (ns - pr)^2}$$

To determine the projection of the circle center, let us consider a situation in which the radius of the circle is zero; i.e., y = 0. This means that r, s, and t also become zero, and we obtain the position of the projected point due to the symmetry of the circle as well as the projection of the circle center (uc, vc), as follows:

$$u_0 = \frac{(lq - pm)}{(kp - nl)}$$

$$v_0 = \frac{(mn - kq)}{(kp - nl)}$$

In the case of a non-zero radius (γ > 0) there are some special cases in which the rotation is performed around the Z-axis (a31 = a32 = 0). Generally, we can state that the center of the ellipse and projected center of the circle are not the same when applied to circular features with a non-zero radius.

In this study developed object-oriented programming software for a variety of vehicles and cameras. Finding a method by which to transform pixel values into actual parameters is the key to developing object-oriented programming software. Transforming the parameters requires that the scale of the image be derived from objects with known length. Paved roads generally lack objects by which to derive the scale. Thus, most existing PCI software measures the angle, elevation, and the pixel scale beforehand. The size of traffic signs, markings, and lights are strictly regulated; therefore, traffic markings can be used as objects from which to derive the image scale. Two axes in the images require adjustment: the X-axis and Y-axis. The distance between traffic marking is 4 m, and the width of the traffic lanes on national freeways is 3.75 m. Using the length and width of known objects enabled us to derive the following formula to transform images without being influenced by the angle or height from which the image was captured. The original image presents parallel lane markings, which are affected by the filming angle, such that extending the lines would cause them to intersect. Thus, Eq. 1 transforms the x-axis of the image into disjoint parallel lines, as follows:

$$F(x) = x \cdot \left(1 + \frac{(x_0 - x_1)}{Y_0}\right) \cdot y$$

where x is the location of the pixel on the x-axis, x0 indicates the bottom location of the lane marking on the x-axis, x1 indicates the top location of the lane marking on the x-axis. L1 is the length of the first marking in the photo, and L2 is the length of the line at the bottom of the photo.

$$L1 = l_0 \cdot N - \int_{0}^{L1} d_y$$

$$L2 = l_0 \cdot N - \int_{L} 2^{L3} d_y$$

L1 = L2 = Markinglength

FindlO

The next step involves associating each pixel i with the center of the nearest cluster, as shown in Fig. 4. This is the key to speeding up the algorithm, i.e., limiting the size of the search space in order to reduce computation time. In contrast, conventional k-means clustering would conduct a comparison of all cluster centers for every pixel. The search region in this study is an area 2S × 2S around the superpixel center. As shown in the CIELAB image, image pixels are assigned by the clustering cover, such that once the clustering is completed, the cluster centers are adjusted using the mean [L A B X Y] vector of the pixels belonging to that cluster. Thus, the cluster region can be considered a new segment of the image.

To summarize, the image is clustered into 200 segments, for use in executing the 2nd phase of K -means clustering, in which the image is clustered into three groups and presented in different colors. One of the colors is then identified as distress, depending on the area or the shape of the colored region.

Ensuring computational efficiency requires that a limit be placed on the number of images required for distress analysis and that the selection of images include only those that are likely to include indications of stress. Thus, we adopted a distress image filter using the RGB Standard Deviation (S.D.) of image segments as a standard. Sensitivity analysis of the image database involved grayscale processing of various parts of the image, marking the various colors to differentiate among blocks, and then analyzing the blocks indicative of damage. Thus, only images with an S.D. value exceeding 20 would be subjected to distress analysis; i.e., blocks indicative of major damage are larger than the others. The images are then clustered again. In this second-stage of K-means clustering, the basic unit of the image is the segments clustered in the first stage. Clustering is performed according to the mean LAB color value of every segment and the specified N2 value, which is generally 2 or 3. Overall, the purpose of clustering is to differentiate areas of distress from those that are in good condition.

To summarize, camera calibration is used to remove distortion, image scaling is derived from the length of known markers, and the ROIs are differentiated from areas presenting little indication of distress. The ROI is then subjected to automated superpixels recognition to extract evidence of distress.

5.2 Distress Type Classification

Once distress indicators are extracted from the image, they are identified as signs of Patching, Potholes, Alligator Cracking, or Manholes. Data pertaining to the distance, length, and region of the distress is then input into PCI. The areas of distress are initially separated into large-area distress (e.g., patching) and local distress (e.g., cracking). Classifying additional types of distress requires differentiation according to the ratio of vertical and horizontal distress segments. Distress analysis cannot be categorized according to its characteristics or frequency but is based on the influence of weight in the network pavement conditions of certain defects that have reduced density values but a higher percentage of total deduct value as Potholes (G. Loprencipe & Antonio P., 2017). Crack connectivity is evaluated as follows: The Status Matrix is scanned block by block to find crack blocks. They are given corresponding id numbers and the length of the crack is added to the Length Table of the current branch. To improve recognition accuracy, after analyzing the damaged blocks in the photos, the software automatically retrieves the four previous and following photos and analyzes them for damage as well. If only one neighbor shows signs of cracking, then the length of the crack is added to the corresponding items in the Length Table. Otherwise, proceed to the neighboring block and repeat the process. If more than one neighboring block shows signs of cracking, then select one of them to indicate the direction of the current branch and continue to check for further extension. As mentioned above, if the damaged part appear in multiple photos, then the damage progression and calculations are combined. If none of the neighboring blocks present indications of cracking, then the last block is treated as the end of the branch extension. If the length of the branch is shorter than a given threshold, then the branch is disregarded. The algorithm then finds the next candidate branch in the Branch

Candidate Table, and repeats the extension check iteratively until the table is empty. The length of a crack is the sum of the length of all of the branches contributing to that crack. Finally, if the length of the crack is shorter than a given threshold, then it is not considered to be considered worthy of concern. The threshold for crack ck and branch length are adjusted according to the size of the window. In the literature, the threshold TC is calculated as follows:

1. TC = 1.8s

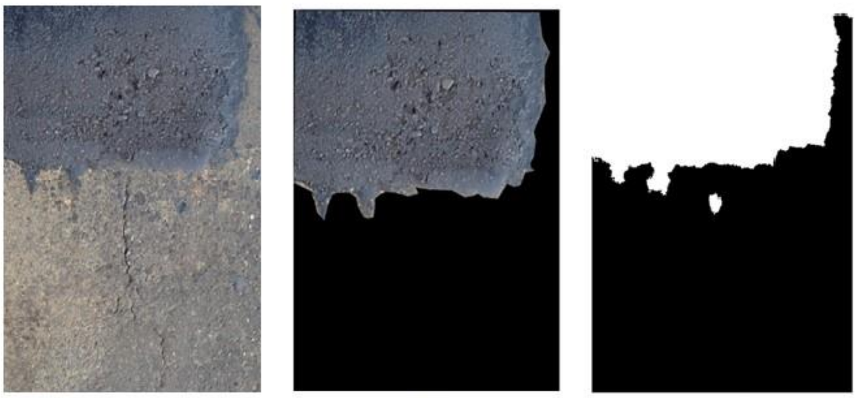
2. where S is the size of the window. Cracks are classified into three types: longitudinal, transverse, and alligator. The type of crack is determined by its angle measured against the horizontal axis (Ω) and the number of branches in the crack. Note that the angle is calculated according to the start and end points of each crack. If there are branches (regardless of the angle), then the crack is considered a block type.

5.2.1 Superpixels Reliability

The Author sought to determine the reliability of the proposed superpixels pavement detection application by conducting a comparison with semi-automatic image detection methods based on the manual identification of distress regions (via the human eye), which is the current inspection method in Taiwan. Fig. 17(a) presents an image showing an area of asphalt patching used in the performance comparison. The patching area is first examined by eye to verify that it is as an actual region of distress, whereupon the numbers of pixels in the region is calculated. The total number of pixels in Fig. 17(b) is 5,557,948 and the distress ratio is 39.26%. Fig. 17(c) presents the results of superpixels analysis, wherein the number of pixels in the region of distress in 14,155,776, resulting in a distress ratio of 39.15%. The variables in the superpixels are the initial clustering number N1 and the second clustering number N2. As shown in Table 5-1, a high clustering number does not have a positive effect on accuracy due to the effects of noise. Overall, the accuracy is ±2% of the true value, with the best performance achieved when N1 is 800 and N2 is 2. To account for the fact that the resolution of the dash cam is lower than that when capturing images from up close, we selected an N1 value of 100. Based on these comparison results, we determined that the best performance could be achieved by adopting an N1 value of less than 500. In subsequent analysis, we adopted an N1 value of 200.

Tab. 5-1 Reliability of automated Superpixels extraction

Pieces	Distress pixel snumber	Total pixels number	Distress pixels rate	Accuracyy
300	4721480	14155776	0.34	98.97%
400	4836756	14155776	0.34	99.72%
500	5240733	14155776	0.37	98.81%
800	5139003	14155776	0.36	99.24%
1000	4951139	14155776	0.35	100.24%
1200	5076777	14155776	0.36	100.22%
1500	5179682	14155776	0.37	102.33%



(a) (b) (c)

Fig. 5-5 Indications of distress extracted using proposed superpixels application

5.2.2 SuperPixels Comparison

In the following analysis, we focus on National Freeway No. 3, Guanxi Section (83km to 89km). Road conditions were evaluated using manual inspection, semi-automated inspection, and fully-automated inspection. Our primary objective in this study was to improve on current road inspection methods, the success of which is predicated on the ability to derive an accurate impression of road conditions through analysis of captured images.

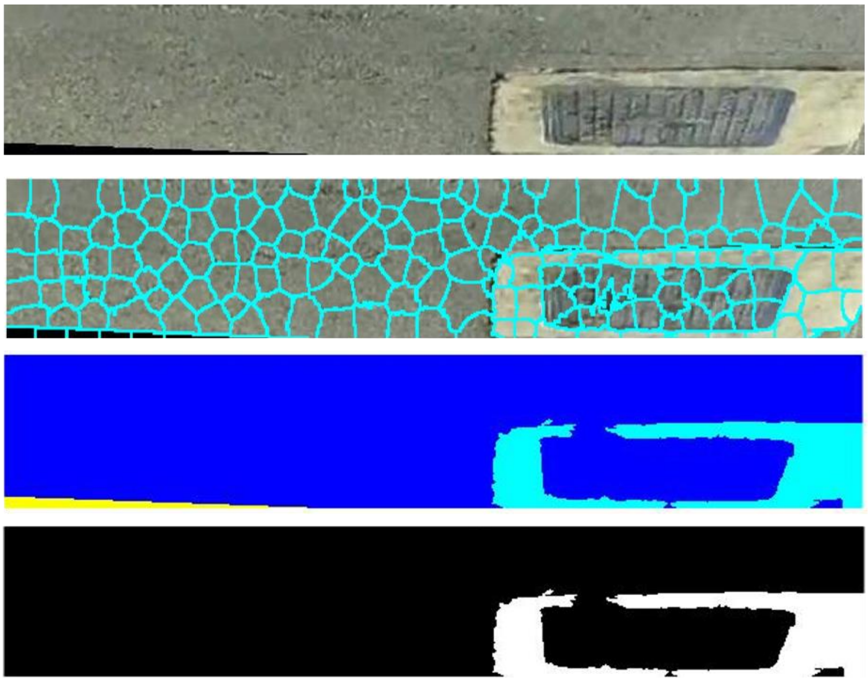


Fig. 5-6 Images obtained using automated Superpixels recognition

A frame-rate of 60 FPS at a driving speed of 100 km/h would result in image spacing of 0.5 m. The length of the selected area is 4 m, which means that 15 images would be analyzed for each second of video, and 250 images would be required to cover a distance of 1 km. The spacing used in the NCU semi-automated inspection system is 25 m, which means that 40 images would be required to cover a distance of 1 km.

Table 5-2 compares the quantity of distress regions and PCI values obtained using the three inspection methods, clearly indicating that the proposed Superpixels extraction scheme outperformed semi-automated extraction. Analysis of the 2nd Taiwan Provincial Rd. in Keelung, the three detection methods varied in the number of stress regions identified. We adopted the values from manual inspection as the actual number of distress regions, for use as a reference in evaluating the performance of the fully-automated Superpixels scheme and the semi-automated NCU scheme.

Table 5-3 indicates the quantity of patched areas, Ravels, potholes, and expansion joints. The proposed Superpixels scheme achieved the following coincidence rates: patched areas (91%), ravels (25%), potholes (100%), and expansion joints (100%). The wide image spacing used in the semi-automated scheme prevented the accurate detection of areas of distress.

Table 5-4 presents the analysis results from the 31th Taiwan Provincial Rd 235 (16km to 13 km). Automated Superpixels extraction identified 87.5% alligator cracks, 83.3% weathering and raveling, 77.8% patched areas, 66.7% potholes, and 55.6% long/trans cracking.

Table 5-5 presents a comparison of automated Superpixels extraction and the semi-automated extraction in terms of distraction region. Clearly, the proposed scheme is effective in measuring the area of distress; however, the width of cracks cannot be derived due to limited resolution. In this analysis, five engineers were asked to identify various forms of distress based on visual acuity.

Using the average distress makes the automatic inspection method reproducible. The S.D. (σ) values were as follows: potholes (0.3%), patches (2.71%), and trans/long cracking (5.3), as shown in Table 5-6.

Tab. 5-2 Methods Comparison

	Manual	NCU Semi-Auto	Auto-Superpixel
Numbers of image		40pic/km	7
Pothole	8	3	7M
Severity	5M+2H+1L	3M	54
PCI	43	71	74.4%
Accuracy		34.9%	

Tab. 5-3 Coincidence Rate Comparison in 2nd Taiwan Provincial Rd

	Patching	Ravels	Potholes	Expansion Joints
1.Man-eye	11	4	3	1
2.NCU Semi-Auto	5	1	1	1
3.Auto-Superpixel	10	1	3	1
Coincidence rate (1 vs 3)	91%	25%	1	1

Tab. 5-4 Detection Rate of automated Superpixels extraction algorithm

Distress Type	Alligator Cracking	Weathering & Raveling	Patching	Potholes	Long/Transs Cracking

Total	4	6	9	3	9
Check	3.5	5	7	2	5
	87.5%	83.3%	77.8%	66.7%	55.6%

Tab. 5-5 Comparison of extraction performance: Superpixels algorithm and manual inspection

Distress Type	1	19	11	13	10
Total	4	6	9	3	9
Check	3.5	5	7	2	5
	87.5%	83.3%	77.8%	66.7%	55.6%

Tab. 5-6 True Value from Multiple Semi-Auto Selection

Semi-Automated Selection	SA1	SA2	SA3	SA4	SA5	Avg.	
Potholes	6.2%	6.92%	7.08%	6.74%	6.56%	6.7%	0.3%
Patching	35.46%	33.18%	28.95%	29.66%	33.16%	32.08%	2.71%
Trans/Long Cracking	184.95	196.47	193.55	192.92	184.95	190.57	5.3

5.2.3 Software Development

In this study, Microsoft Visual C++ was used to combine the various functions of Matlab including video capture, image calibration, superpixels clustering, K-means clustering, distress classification, and PCI calculation. The user performs four actions: Step 1 – selection of road inspection video; Step 2 – camera calibration involving the selection of four traffic markers and image coordinates (Fig. 5-6); Step 3 – selection of analysis area; Step 4 – input of the frame interval based on driving speed and cutting number for superpixels clustering (200) and the number for K-Means Clustering (3).

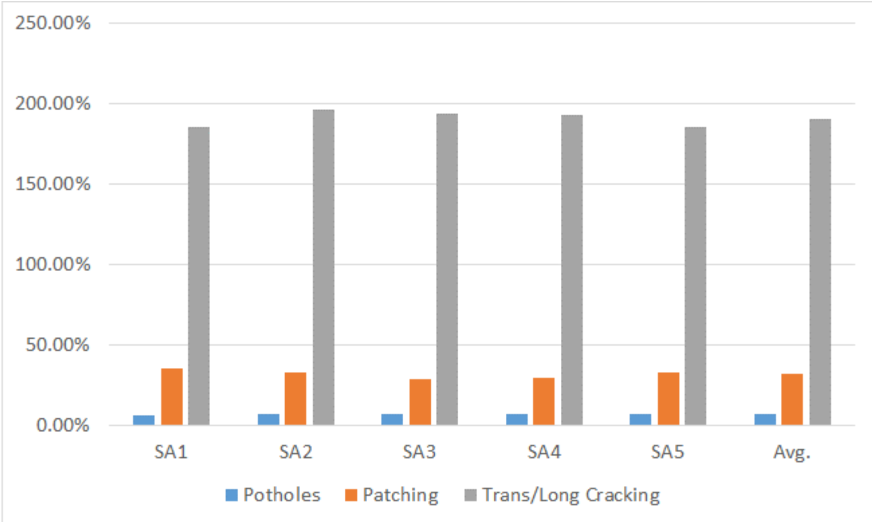


Fig. 5-6 True Ratio from Multiple Semi-Auto Selection

Finally, the SD value is input to enable the filtering out of unblemished areas in order to enhance processing efficiency.

5.3 Summary

The automated Superpixels extraction algorithm was shown to outperform conventional binary methods, as it requires only two parameter settings for image extraction. The proposed scheme opens the door to the fully-automated inspection of pavement conditions. A comprehensive view of the road surface can be obtained simply by adjusting the number of images captured from video sequences based on the driving speed. Six images per second is required for video obtained at 90 km/h (freeway driving), whereas four images are required for video obtained at 50 km/h (urban driving). SD values are used to differentiate between damaged and undamaged sections of road in order to enhance computational efficiency. The fact that the proposed Superpixels scheme has 95 percent confidence level with the semi-automatic distress recognition indicates the efficacy of using software as an alternative to current methods. The result in Taiwan 31th Provincial Road inspection could match 85.7.

Chapter 6. Analysis of Pavement Maintenance Budget Through Game Theory

6.1 Location Analysis of Taiwanese Asphalt Vendors

Industrial location theory was adopted to examine the theoretical and analytical solutions concerning the industrial layout and vendor location of Taiwanese asphalt vendors. The analysis was divided into a macro-analysis and a micro-analysis. The macro-analysis analyzed sectional and national industrial layout. The micro-analysis examined vendor choice theory. The analyses were based on the locations of the vendors along different national freeway sections. The outcomes were used to propose transport and labor location principals for the various sections. Finally, equal-cost charts were illustrated for the different sections to determine the optimal vendor location.

6.1.1 Macro-Analysis of Industrial Location

This paper analyzed the effective national freeway resource allocation. First, a macro-analysis was performed to examine the industrial location and analyze the logistics costs of asphalt vendors. The equal-cost method introduced in Weber's agglomeration principals was adopted to quantify minimum logistics costs and contracts and determine the optimal asphalt vendor locations along the northern, central, and southern freeway sections.

1. Northern Region Engineering Office

An optimization analysis and a cost optimization analysis was performed to analyze three sections of National Freeway No. 1 (0K+000-100K+800) and three sections of National Freeway No. 3 (0K+000-110K+700) affiliated with the TANFB Northern Region Engineering Office. The sections were National Freeway No. 1 0K+000, 50K+400, and 100K+800 and National Freeway No. 3 0K+000, 55K+350, and 110K+700. The analysis outcomes for the six maintenance points are illustrated in Fig. 6-1.

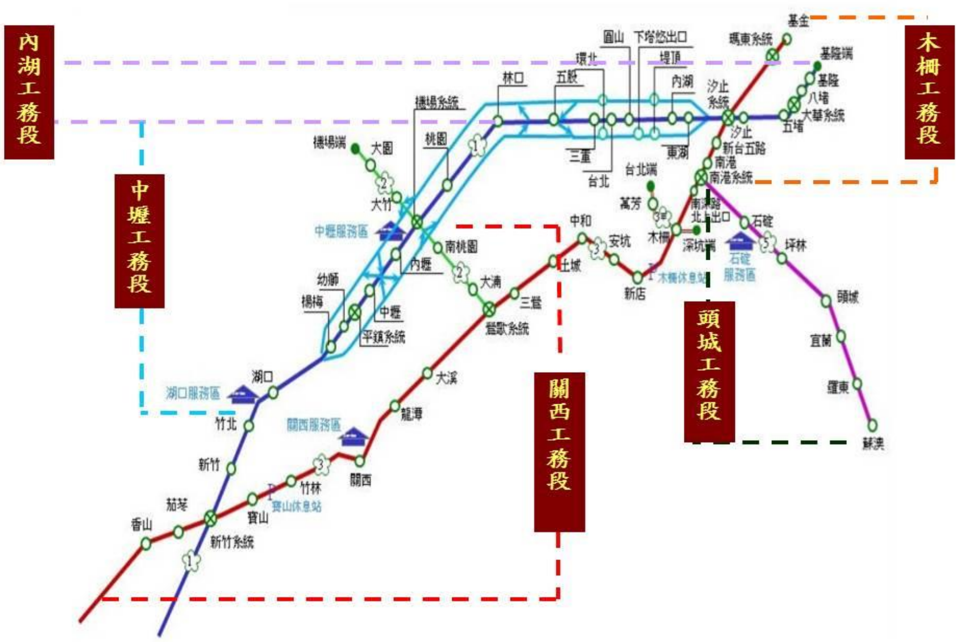


Fig. 6-1 Jurisdiction of TANFB Northern Region Engineering Office

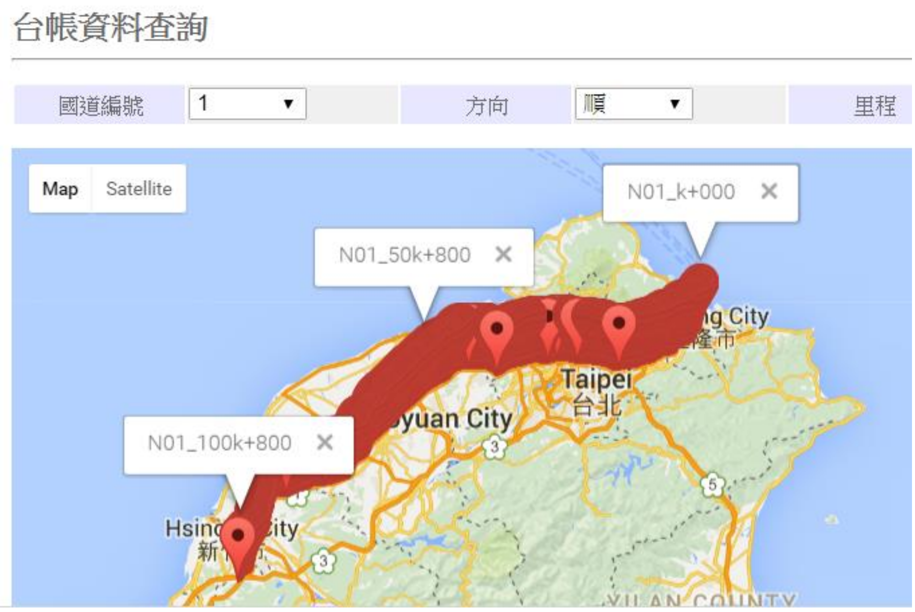


Fig. 6-2 Basic Freeway Information and GPS Modules

Radii of 10, 20, 30, 40, and 50 km from the center of the six points were analyzed to highlight two vendors with the optimal route distances. The analysis diagram and outcomes are illustrated in Fig. 6-2 and tabulated in Table 6-1, respectively.

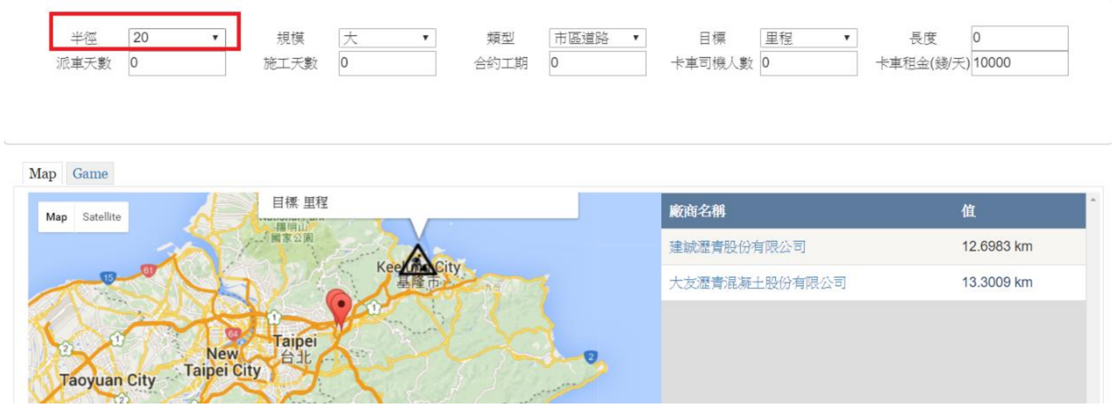


Fig. 6-3 Vendor with Optimal Distance

Tab. 6-1 Preliminary Route Optimization Analysis Outcomes for the Maintenance Vendors Affiliated with the Northern Region Engineering Office

Freeway No.1	**Radius(KM)**	**Best Company**	**Distance(KM)**	**Second Company**	**Distance(KM)**
0K+000	10	none	0	none	0
	20	A company	12.7	D company	13.3
50K+400	10	B company	7.8	E company	7.9
100K+800	10	C company	5.2	F company	7.0
Freeway No.3	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
0K+000	10	none	0	none	0
	20	A company	10.0	D company	10.6
55K+350	10	B company	3.7	G company	6.0
110K+700	10	C company	8.5	F company	8.6

Analysis outcomes indicated different optimal vendors in the start, mid, and end sections of National Freeway No. 1 (0K+000-100K+800) and National Freeway No. 3 (0K+000-110K+700). A subsequent analysis was performed to analyze 25K+200 and 75K+600 of National Freeway No. 1 and 27K+675 and 83K+000 of Freeway No. 3. The analysis outcomes are tabulated in Table 6-2.

Tab. 6-2 Route Optimization Analysis Outcomes for the Maintenance Vendors Affiliated with the Northern Region Engineering Office

Freeway No.1	**Radius(KM)**	**Best Company**	**Distance(KM)**	**Second Company**	**Distance(KM)**
0K+000	10	none	0	none	0
	20	A company	12.7	D company	13.3
25K+200	10	none	0	none	0
	20	H company	11.0	D company	12.3
75K+600	10	I company	9.3	K company	9.6
Freeway No.3	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
0K+000	10	none	0	none	0
	20	A company	10.0	D company	10.6
27K+675	10	J company	9.9	none	0
	20	D company	9.9	A company	10.4
83K+000	10	I company	3.6	L company	6.2

2. Central Region Engineering Office

An optimization analysis and a cost optimization analysis was performed to analyze three sections of National Freeway No. 1 (100K+800-251K+100) and three sections of National Freeway No. 3 (110K+703-270K+000) affiliated with the TANFB Central Region Engineering Office. The sections were National Freeway No.1 100K+800, 76K+000, and 251K+100 and National Freeway No. 3 110K+703, 190K+350, and 270K+000. The analysis outcomes for the six maintenance points are illustrated in Fig. 6-5.

Fig. 6-5 Jurisdiction of TANFB Central Region Engineering Office

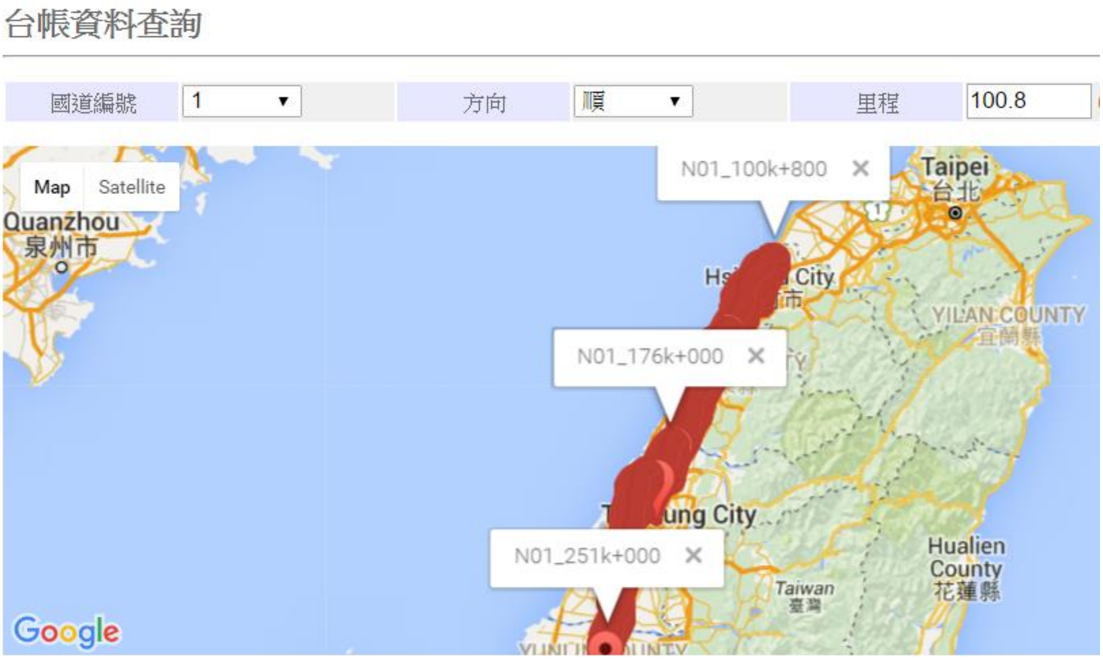


Fig. 1 Basic Stations in the Jurisdiction of the Central Region Engineering Office

Radii of 10, 20, 30, 40, and 50 km from the center of the six points were analyzed to highlight two vendors with the optimal route distances. The analysis outcomes are tabulated in Table 6-3.

Tab. 6-3 Preliminary Route Optimization Analysis Outcomes for the Maintenance Vendors Affiliated with the Central Region Engineering Office

Freeway No.1	**Radius(KM)**	**Best Company**	**Distance(KM)**	**Second Company**	**Distance(KM)**
100K+800	10	C company	5.2	F company	7.0
176K+000	10	M company	4.9	Q company	5.6
251K+100	10	N company	4.9	R company	5.0
Freeway No.3	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
110K+703	10	C company	8.5	F company	8.6
190K+350	10	O company	3.9	S company	4.1
270K+000	10	P company	1.4	T company	6.5

Analysis outcomes indicated different optimal vendors in the start, mid, and end sections of National Freeway No. 1 (100K+800-251K+100) and National Freeway No. 3 (110K+730-270K+000). A subsequent analysis was performed to analyze 138K+400 and 213K+500 of National Freeway No. 1 and 150K+500 and 230K+200 of Freeway No. 3. The analysis outcomes are tabulated in Table 6-4.

Tab. 6-4 Route Optimization Analysis Outcomes for the Maintenance Vendors Affiliated with the Central Region Engineering Office

Freeway No.1	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
100K+800	10	C company	5.2	F company	7.0
138K+400	10	U company	6.3	Y company	6.77
213K+500	10	V company	2.6	Z company	7.6
Freeway No.3	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
110K+703	10	C company	8.5	F company	8.6
150K+500	10	W company	8.6	A1 company	8.9

230K+200	10	X company	1.79	B1 company	4.6

3. Southern Region Engineering Office

An optimization analysis and a cost optimization analysis was performed to analyze three sections of National Freeway No. 1 (251K+100-372K+760) and three sections of National Freeway No. 3 (270K+000-431K+525) affiliated with the TANFB Southern Region Engineering Office. The sections were National Freeway No.1 251K+100, 311K+930, and 372K+760 and National Freeway No. 3 270K+000, 350K+750, and 431K+525. The analysis outcomes for the six maintenance points are illustrated in Fig. 6-6.

Fig. 6-6 Jurisdiction of TANFB Southern Region Engineering Office

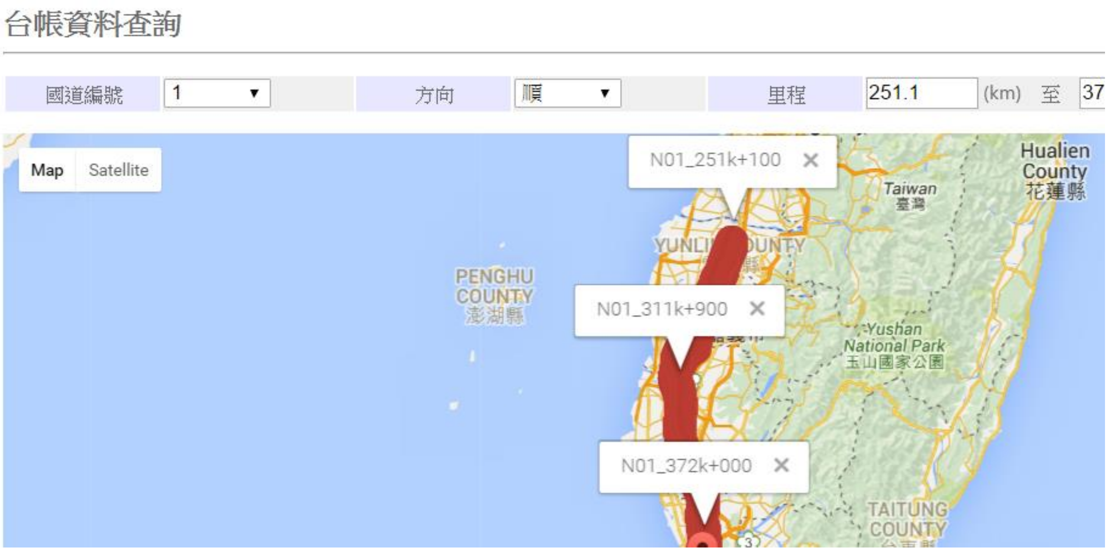


Fig. 6-7 Basic Stations in the Jurisdiction of the Southern Region Engineering Office

Radii of 10, 20, 30, 40, and 50 km from the center of the six points were analyzed to highlight two vendors with the optimal route distances. The analysis outcomes are tabulated in Table 6-5.

Tab. 6-5 Preliminary Route Optimization Analysis Outcomes for the Maintenance Vendors Affiliated with the Southern Region Engineering Office

Freeway No.1	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
251K+100	10	N company	4.9	R company	5.0
311K+930	10	C1 company	4.7	E1 company	9.1
372K+760	10	D1 company	5.0	G1 company	6.0
Freeway No.3	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
270K+000	10	P company	1.4	T company	6.5
350K+750	10	E1 company	5.2	H1 company	6.2
431K+525	10	F1 company	8.9	none	0
	20	F1 company	8.9	I1 company	11.1

Analysis outcomes indicated different optimal vendors in the start, mid, and end sections of National Freeway No. 1 (251K+100-372K+760) and National Freeway No. 3 (270K+000-431K+525). A subsequent analysis was performed to analyze 281K+500 and 342K+300 of National Freeway No. 1 and 310K+300 and 391K+100 of Freeway No. 3. The analysis outcomes are tabulated in Table 6-6.

Tab. 6-6 Route Optimization Analysis Outcomes for the Maintenance Vendors Affiliated with the Southern Region Engineering Office

Freeway No.1	**Radius(KM)**	**Best Company**	**Distance(KM)**	**Second Company**	**Distance(KM)**
251K+100	10	N company	4.9	R company	5.0
281K+500	10	J1 company	3.1	N1 company	6.3
342K+400	10	K1 company	6.9	O1 company	8.3
Freeway No.3	Radius(KM)	Best Company	Distance(KM)	Second Company	Distance(KM)
270K+000	10	P company	1.4	T company	6.5
310K+300	10	L1 company	4.2	P1 company	6.1
391K+100	10	M1 company	3.3	Q1 company	4.2

6.1.2 Macro-Analysis of Industrial Location

The macro-analysis of industrial location was divided into the analysis of internal economy and external economy. When vendors expand their production, their average production cost reduces concurrently with technological reform and performance improvement, leading to the conservation of production costs. Thus, internal economy refers to vendors' scale of self-production. External economy refers to the agglomeration of vendors producing similar products to facilitate production and logistics. Aglomeration benefits the spread of technological reform and the reduction of general, indirect costs.

An analysis was performed on the equal-cost range of industrial location to identify ideal vendors in different maintenance stations. The radius data contained in the analysis outcomes were used to illustrate the equal-cost paths (Fig. 6-8 and Fig. 6-9).

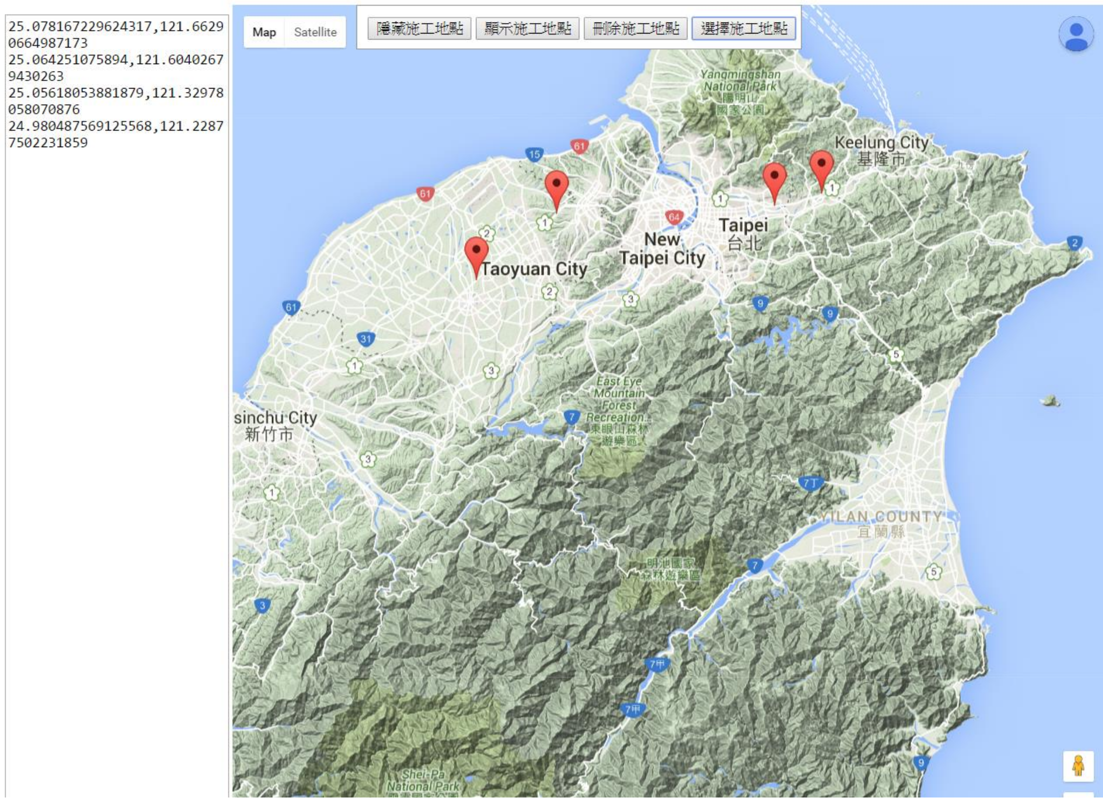


Fig. 6-8 Maintenance Construction Locations and Selection

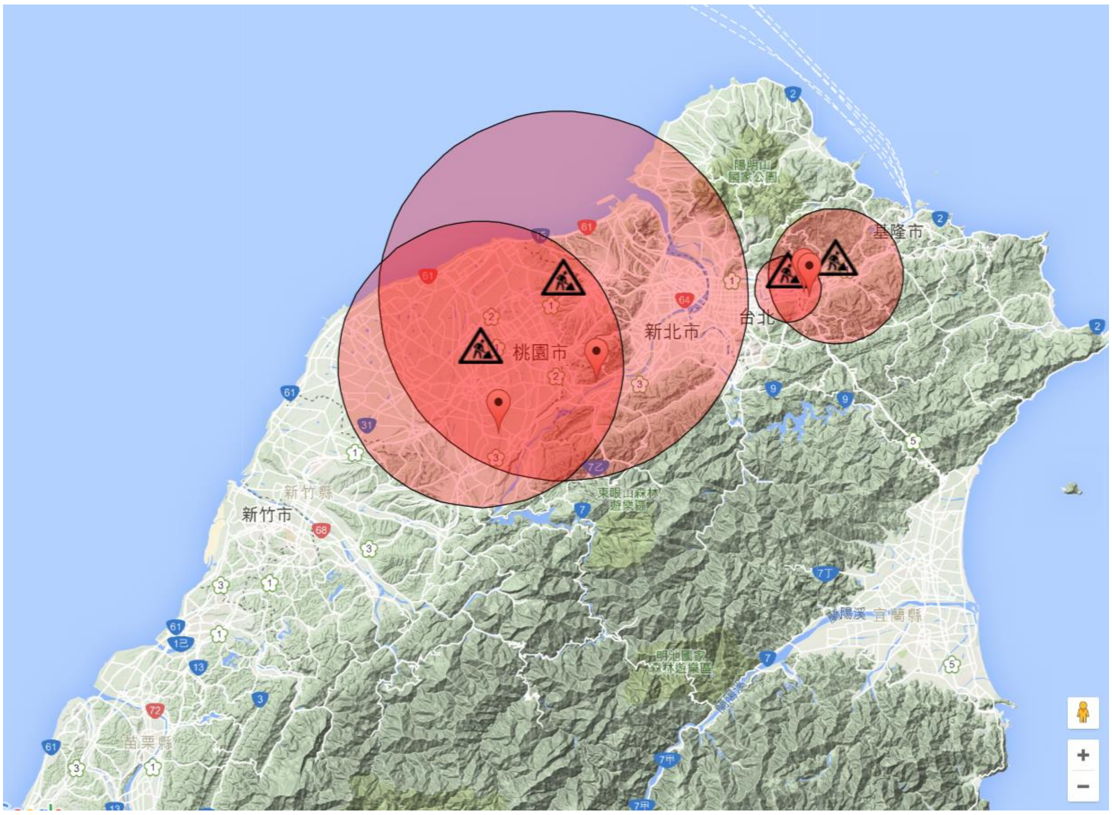


Fig. 6-9 Equal-Cost Distribution of Asphalt Vendors

First, the longitude and latitude data of the Taiwanese asphalt vendors were entered into the system. The radius of the closest vendor was selected as the optimal location radius. This radius was used to illustrate an equal-cost chart for different construction locations. The area formed by the intersecting equal-cost paths was the agglomeration area.

The jurisdictions of the northern, central, and southern engineering offices were analyzed. The boundaries of the jurisdictions were set as the construction locations for analysis. The analysis outcomes are discussed in the following section:

1. Northern Region Engineering Office:

Construction sites along National Freeway No. 1, National Freeway No. 2, National Freeway No. 3, and National Freeway No. 5 affiliated with the Northern Region Engineering Office were selected, and the start and end the jurisdiction were established. The station numbers are illustrated in Fig. 6-10. An analysis was performed to examine the industrial locations of these stations to highlight three intersections ideal for vendor establishment. The outcomes are illustrated in Fig. 6-11.

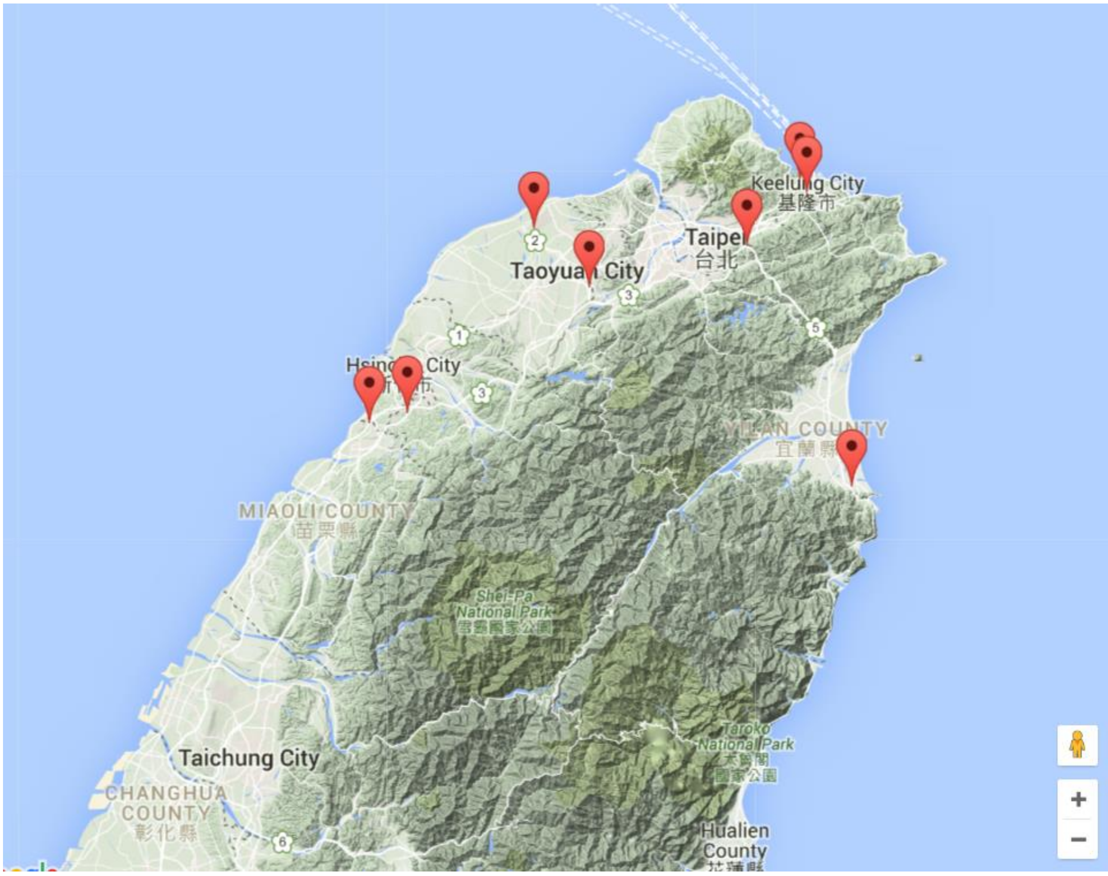


Fig. 6-10 Locations in the Jurisdiction of the Northern Region Engineering Office

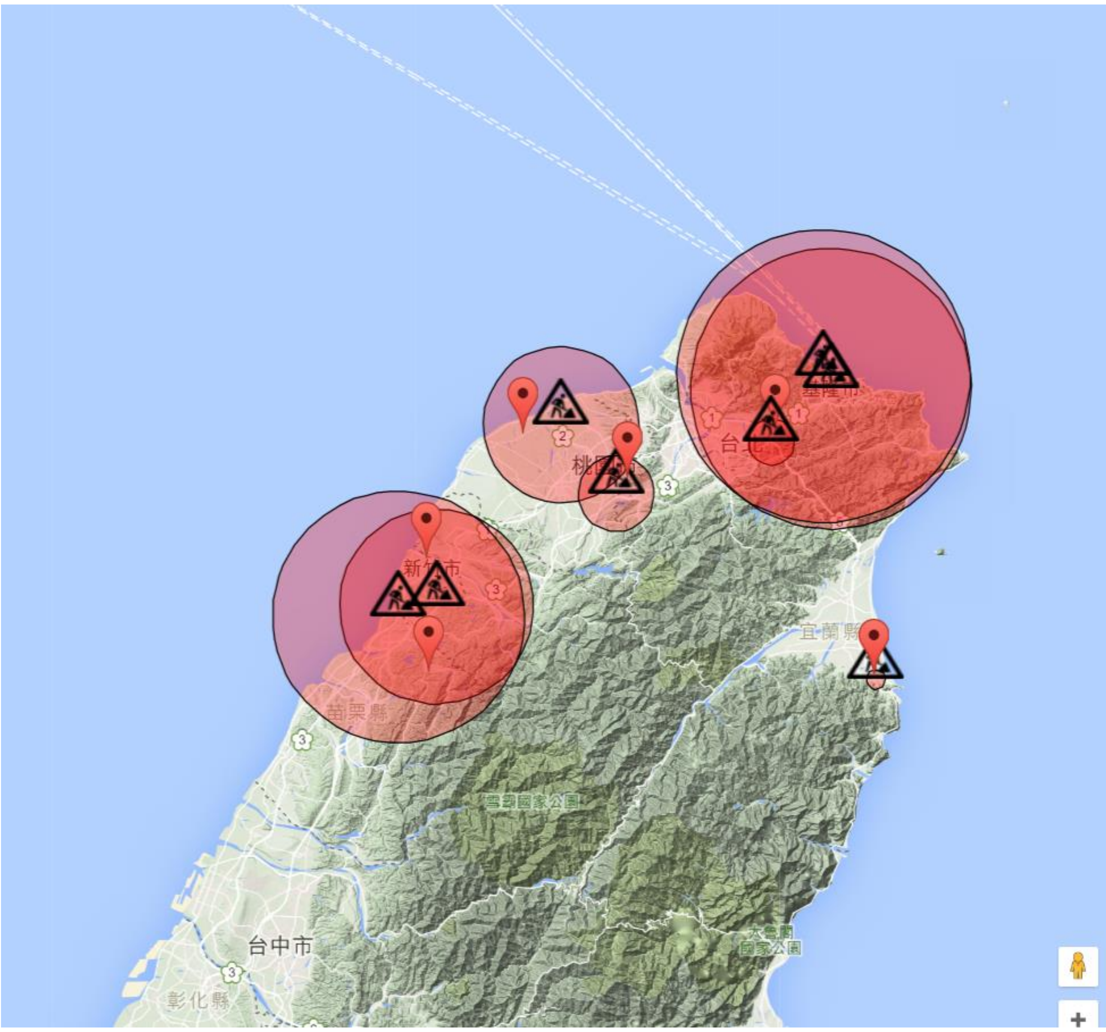


Fig. 6-11 Equal-Cost Chart for the Northern Region Engineering Office

2. Central Region Engineering Office:

Construction sites along National Freeway No. 1, National Freeway No. 3, National Freeway No. 4, and National Freeway No. 6 affiliated with the Central Region Engineering Office were selected, and the start and end the jurisdiction were established. The station numbers are illustrated in Fig. 6-12. An analysis was performed to examine the industrial locations of these stations to highlight three intersections ideal for vendor establishment. The outcomes are illustrated in Fig.6-13.

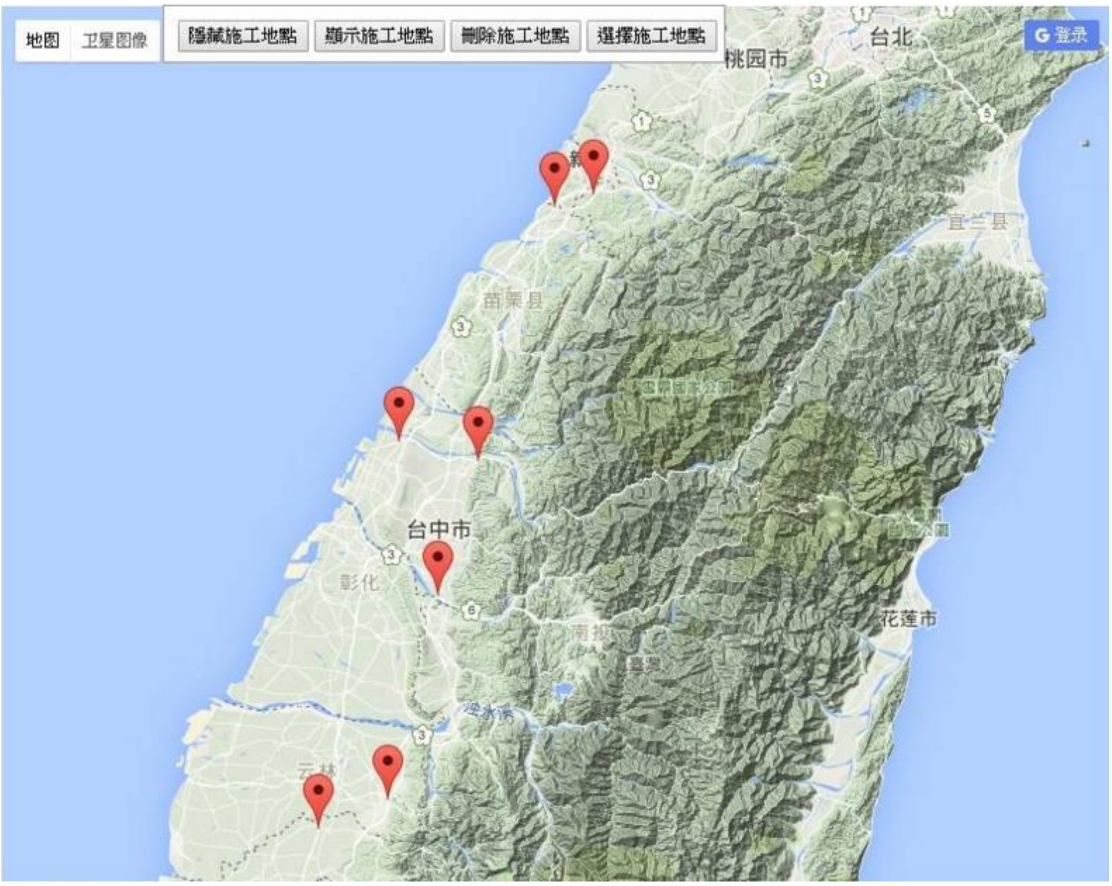


Fig. 6-12 Locations in the Jurisdiction of the Central Region Engineering Office

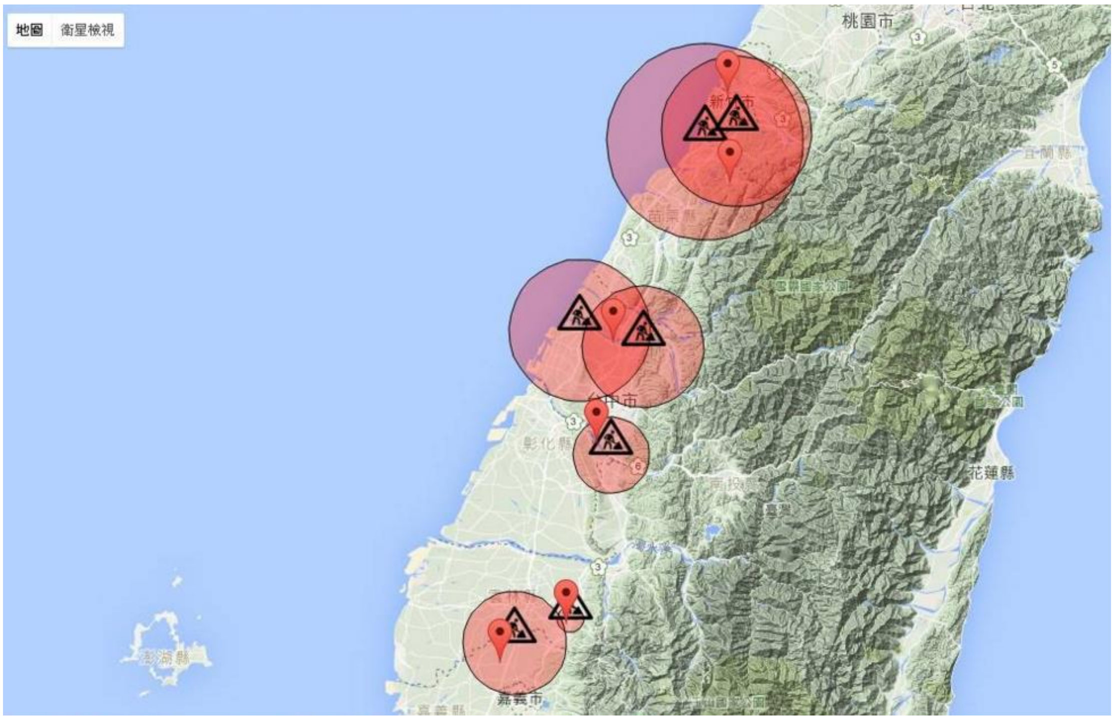


Fig. 6-13 Equal-Cost Chart for the Central Region Engineering Office

3. Southern Region Engineering Office

Construction sites along National Freeway No. 1, National Freeway No. 3, National Freeway No. 8, and National Freeway No. 10 affiliated with the Southern Region Engineering Office were selected, and the start and end the jurisdiction were established. The station numbers are illustrated in Fig. 6-14. An analysis was performed to examine the industrial locations of these stations to highlight three intersections ideal for vendor establishment. The outcomes are illustrated in Fig.6-15.

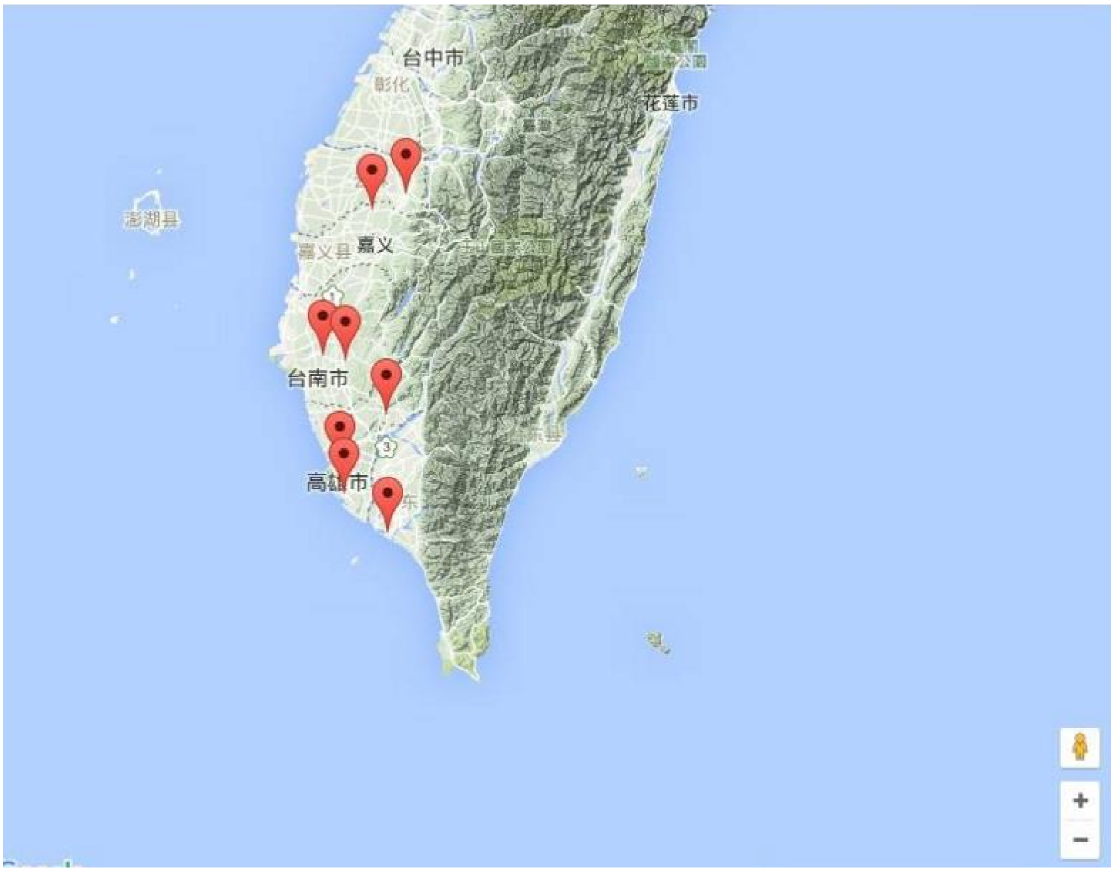


Fig. 6-14 Locations in the Jurisdiction of the Southern Region Engineering Office

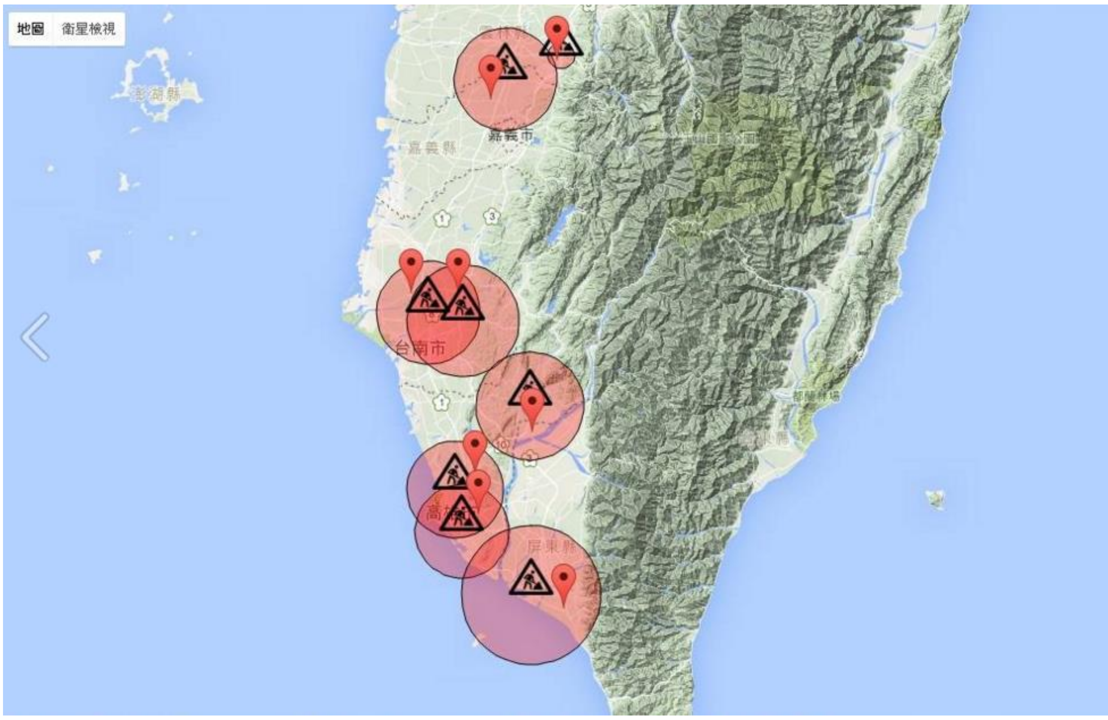


Fig. 6-15 Equal-Cost Chart for the Southern Region Engineering Office

Once the equal-cost charts for the three engineering offices were established, the area ideal for vendor establishment was examined, as illustrated in Fig. 6-16. The analysis outcomes of the three offices are tabulated in Table 6-7.

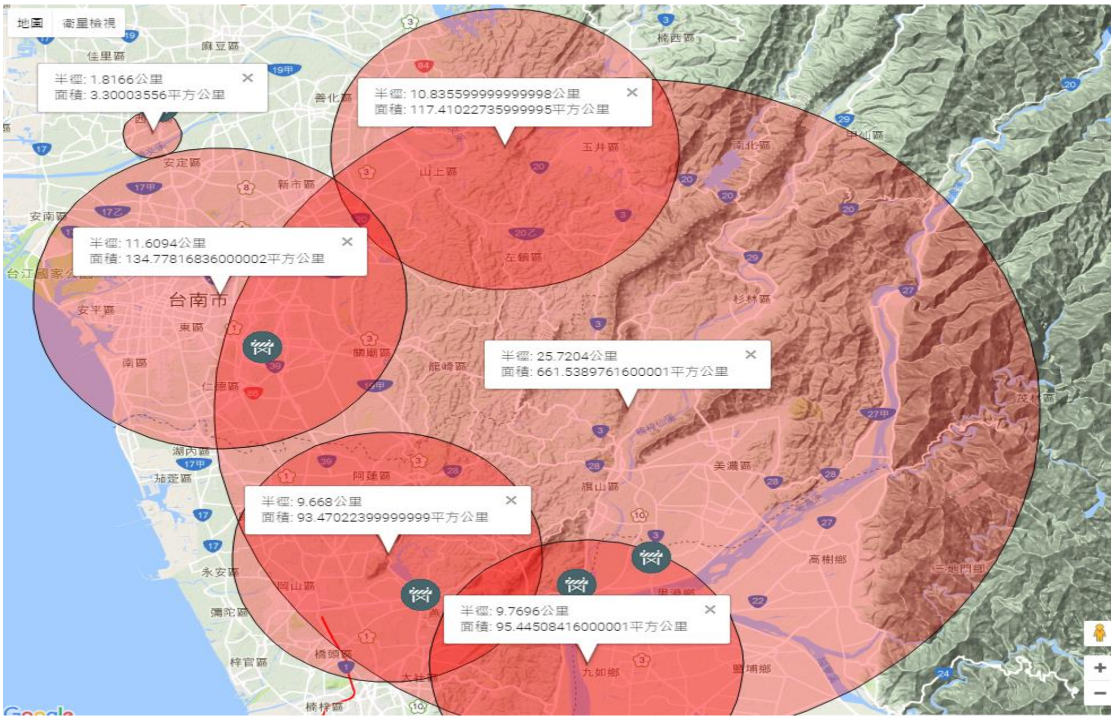


Fig. 6-16 Area of Intersecting Equal-Cost Paths

Tab. 7-7 Equal-Cost Paths and Overall Area

Engineering Office	Equal-cost line Intersection	Equal-cost line Intersection Area (KM2)
Northern Region	3	392
Central Region	3	178
Southern Region	4	173

6.2 Pavement Maintenance Lean Management Non-Cooperative Game Theory Analysis

This study deal with asphalt concrete pavement construction, focusing on the cost, working duration, and effects on the environment. A lean management system is built with game theory. Through the concepts of lean management, and with the principles of Environment Impact Assessment introduced to the establishment of the lean management system, this research then uses the life cycle of the asphalt concrete industry as its main experimental subject. Analysis were conducted for construction sites of different locations and construction scales before establishing the system. From the employer's perspective, a contractor with the optimised route, the minimal cost, and the minimal environmental impact can be identified. As for the contractor, the optimal arrangement for different plants and construction sites can be identified. Through the game theory with the optimised route, the best asphalt plant is identified to be the one with the minimal cost and the minimal environmental impact.

6.2.1 Non-Cooperative Game Strategy Development

Within the NE game, the authors characterised the maintenance contracts of different road types into three categories for discussion, specifically, those that focus on construction period, those that focus on construction budget, and those that focus on CEQ. The authoers collected the basic demographics of all the asphalt vendors in Taiwan, including the coordinates of the vendor, construction date, responsible parties, and scale evaluation, among others. The coordinate information was used to build a database and determine the shortest routes between the vendor's location and the construction sites. Scale evaluations entail the assessment of vendor's cost estimates and monthly turnover. These evaluations were then examined to characterise the vendors by scale, allocating them into three classes in descending order of superiority, namely, S Class, A Class, and B Class. Vendors of a higher class possess a greater advantage when performing maintenance tasks or applying similar strategies than those in a lower class (Alvin, E. R. 2002).

The present study aimed to elucidate the strategies employed by asphalt manufacturers during the tendering of pavement construction projects and the tendering process using the analytical hierarchical process (AHP) technique. Based on the contractual criteria established by different manufacturers, the authors of the present study adopted AHP in the design of a questionnaire survey. The purpose of this survey was to perform a weighted analysis on manufacturers with time superiority, fund superiority, and carbon reduction superiority, and determine which type of manufacturer was more likely to win tender. Finally, the present study analyzed the third-tier weights based on the tender decisions adopted by the various manufacturers. The weights results were then incorporated into a Nash Equilibrium Model (Game Theory) for further analysis.

◎AHP Procedures:

A three-tier AHP simulation was adopted to determine the decision weights in Tiers 2 and 3. The weights results were then incorporated into a game simulation to analyze the winner of specific tendered projects. In the simulation, S refers to the various manufacturers, X refers to strategies aiming to optimize cost, Y refers to strategies aiming to reduce transportation distance, and Z refers to strategies aiming to reduce environmental impact. The analysis procedures are illustrated in the following Fig.6-17

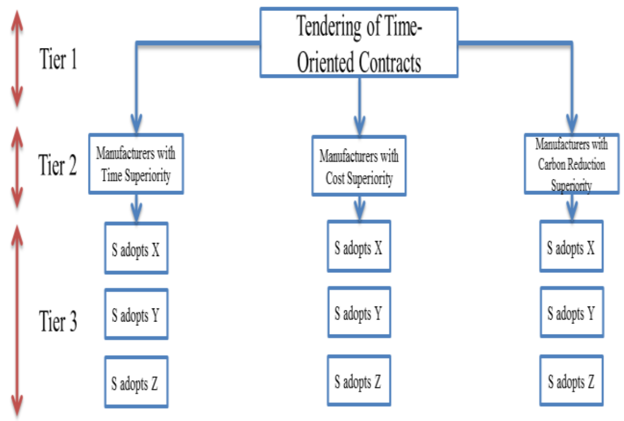


Fig. 6-17 AHP Analysis Procedures for the Tendering of Pavement Construction Projects

◎Weight Analysis in Each Tier:

The weights in Tiers 2 and 3 were calculated based on the responses of 25 experts collected using a questionnaire survey. The weights results is using computer to calculate.

http://140.115.61.193/RoadRepair/Quest_result_eng.aspx

Based on the aforementioned analysis method, the present study further analyzed Tier 3, which was the strategy tier. The analysis results are illustrated in the following flow Fig. 6-18:

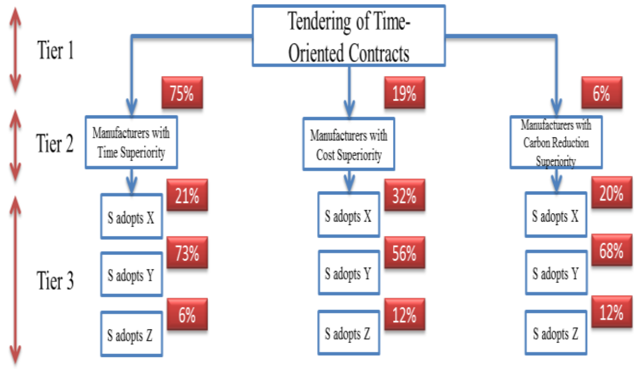


Fig. 6-18 Overall Results in Time-Oriented Contracts

The present study aimed to elucidate the tendering outcomes of time-oriented contracts by major asphalt manufacturers using different tendering strategies. Multi-attribute methods in road construction can be used on the national, organization and project levels. However, most assessment methods are investigating to find how to make the most economic construction decisions, and most of all these decisions are intended only for economic objectives (Sivilevicius, Zavadskas, & Turskis, 2008). First, AHP was adopted to determine the weight values of the various strategies, as shown in Fig. 37. The objective of this analysis was to elucidate the weighted results of different strategies applied by the manufacturers, each of which possess distinct advantages. The weighted results are expressed as a percentage in Fig. 6-19. These weighted results were used in a subsequent NE analysis.

First, analytical hierarchical process (AHP) technique is used to determine the weights manufacturers with different superiorities use in selecting operating strategies. Next, game theory analysis is used to identify the superiority and operating strategies of the winning manufacturer with various contract conditions.

The weights of the analytic hierarchy process (AHP) results for contracts with different priorities were adopted to perform a subsequent Nash game analysis. First, time-priority contracts were analyzed. The manufacturer with the advantage of distance that adopted the cost-saving strategy (Strategy X) exhibited a weight value in the Nash equilibrium game of 0.75*0.21. Similarly, the manufacturer with the advantage of cost that adopted the environment-protection strategy (Strategy Z) exhibited a weight value of 0.19*0.12. These AHP weights were used to commence the game.

The authors simulated and analysed two games, and discussed the possibilities and the NE results of these games. The analysis conditions are as follows:

Criteria hypotheses:

A=X represents a strategy focused on cost planning, B=Y represents a strategy focused on reducing transportation distance, and C=Z represents a strategy focused on reducing environmental impact. The present study renamed the two competing manufacturers as S1 and S2. Three types of strategies were available to the manufacturers, namely, the cost-saving, time-reduction, and environmental-protection strategies. Subsequently, S1 employing the cost-saving strategy was defined as A, S1 employing the cost-saving, time-reduction, and environmental-protection strategies were separately defined as A, B, and C; whereas S2 employing the cost-saving, time-reduction, and environmental-protection strategies were defined as X, Y, and Z, respectively.

Under different contract requirements, different strategies influence game outcome differently. Thus, discussions should be based on the focal items of the contracts to elucidate the factual game outcomes of different strategies. In addition to these focal items, the performance of the route optimisation and budget optimisation plans of two competing vendors also influence game outcome. Therefore, the performance of the cost plans and distance plans employed by the two vendors must first be determined prior to game initiation.

In a game where the two players are S-Class vendors, the first vendor is S1 and the other S2. Each player implements three strategies, specifically, S1: A, B, and C, and S2: X, Y, and Z. The strategies of one player are simulated against the strategies of the other.

a. When the performances of the route and cost optimisation plans of S1 are similar to those of S2, and the maintenance contract focuses on construction period, the NE outcome is given as Table 6-8:

Tab. 6-8 The Game 1 for Nash Equilibrium Comparison which contract focuses on construction period

S1				
S2	Strategy	A	B	C
	X	(1,1)	(1,1)	(7,1)
	Y	(1,1)	(1,1)	(7,1)
	Z	(1,7)	(1,7)	(1,1)

where, the NE outcomes are plotted at (A,Z), (B,Z), (C,X)and (C,Y), suggesting that the cost and route plans of the two vendors are similar and that no superiority is exhibited in the game outcomes.

b. When the maintenance contract focuses on construction period, and the performances of the route and cost optimisation plans of S1 outperform those of S2, S1 wins the game; otherwise, S2 wins the game.

c. When the maintenance contract focuses on construction period, the performance of the route optimisation plan of S1 outperforms that of S2, and the performance of the cost optimisation plan of S2 outperforms that of S1, the NE outcome is given as Table 6-9

Tab. 6-9 The Game 3 for Nash Equilibrium Comparison which contract focuses on construction period

S1				
S2	Strategy	A	B	C
	X	(26,9)	(51,3)	(11,5)
	Y	(3,4)	(22,5)	(2,3)
	Z	(4,1)	(47,2)	(27,8)

where, the NE outcome is plotted at (A,X) and (C,Z), suggesting that when the contract focuses on construction period and the performance of the route optimisation plan of S1 outperforms that of S2, and the performance of the cost optimisation plan of S2 outperforms that of S1, S1 wins the game. Subsequently, both players in the competitive NE outcome employ environment-based strategies as their optimal construction strategy.

By contrast, when the performance of the route optimisation plan of S2 outperforms that of S1, and the performance of the cost optimisation plan of S1 outperforms that of S2, the positions of S1 and S2 in Table 5-9 are interchanged.

d. When the performances of the route and cost optimisation plans of S1 are similar to those of S2, and maintenance contract focuses on construction budget, the NE outcome is given as Table 6-10:

Tab. 6-10 The Game 1 for Nash Equilibrium Comparison which contract focuses on construction budget

S1				
S2	Strategy	A	B	C
	X	(1,1)	(7,2)	(9,1)
	Y	(2,7)	(1,1)	(8,3)
	Z	(1,9)	(3,8)	(1,1)

where, the NE outcomes are plotted at (A,Y) and (B,X), suggesting that the cost and route plans of the two vendors are similar and that no superiority is exhibited in the game outcomes.

e. When the maintenance contract focuses on construction budget, and the performances of the route and cost optimisation plans of S1 outperform those of S2, S1 wins the game; otherwise, S2 wins the game.

f. When the maintenance contract focuses on construction budget, the performance of the route optimisation plan of S1 outperforms that of S2, and the performance of the cost optimisation plan of S2 outperforms that of S1, the NE outcome is given as Table 6-11:

Tab. 6-11 The Game 3 for Nash Equilibrium Comparison which contract focuses on construction budget

S1				
S2	Strategy	A	B	C
	X	(1,4)	(1,12)	(2,39)
	Y	(1,1)	(3,8)	(1,4)
	Z	(5,4)	(1,2)	(2,7)

where, the NE outcomes are plotted at (B,Y), (C,X) and (C,Z) in Table 5-11, suggesting that when the contract focuses on construction budget, the performance of the route optimisation plan of S1 outperforms that of S2, and the performance of the cost optimisation plan of S2 outperforms that of S1, S2 wins the game. Subsequently, S1 employs environment-based strategies and S2 employs either route-based or environment-based strategies in the competitive NE outcome as their optimal construction strategy.

By contrast, when the performance of the route optimisation plan of S2 outperforms that of S1, and the performance of the cost optimisation plan of S1 outperforms that of S2, the positions of S1 and S2 in Table 5-11 are interchanged.

g. When the performances of the route and cost optimisation plans of S1 are similar to those of S2, and maintenance contract focuses on construction environment, the NE outcome is given as Table 6-12

Tab. 6-12 The Game 1 for Nash Equilibrium Comparison which contract focuses on construction environment

S1				
S2	Strategy	A	B	C
	X	(1,1)	(2,5)	(2,9)
	Y	(5,2)	(1,1)	(4,7)
	Z	(9,2)	(7,4)	(1,1)

where, the NE outcomes are plotted at (B,Z) and (C,Y), suggesting that the cost and route plans of the two vendors are similar and that no superiority is exhibited in the game outcomes.

h. When the maintenance contract focuses on environment quality, and the performances of the route and cost optimisation plans of S1 outperform those of S2, S1 wins the game; otherwise, S2 wins the game.

i. When the maintenance contract focuses on environment quality, the performance of the route optimisation plan of S1 outperforms that of S2, and the performance of the cost optimisation plan of S2 outperforms that of S1, the NE outcome is given as Table 6-13

Tab. 6-13 The Game 3 for Nash Equilibrium Comparison which contract focuses on construction environment

S1				
S2	Strategy	A	B	C
	X	(7,13)	(12,7)	(6,1)
	Y	(1,5)	(2,3)	(19,9)
	Z	(2,17)	(1,5)	(5,8)

where, the NE outcomes are plotted at (A,X) and (C,Y) in Table 5-13, suggesting that when the performance of the route optimisation plan of S1 outperforms that of S2 and the performance of the cost optimisation plan of S2 outperforms that of S1, S2 wins the game when the outcome is plotted at (A,X) , and S1 wins the game when the outcome is plotted at (C,Y). This implies that S1 must select Strategy C in order to win the game.

By contrast, when the performance of the route optimisation plan of S2 outperforms that of S1, and the performance of the cost optimisation plan of S1 outperforms that of S2, the positions of S1 and S2 in Table 42 are interchanged.

6.2.2 Non-Cooperative Game Strategy Analysis

In strategic games, it is assumed that the entire game framework is known to all players, including the reward functions of the other players. However, decision-makers may not necessarily possess such complete information in real-time interactive scenarios. The Bayesian game is used to analyse interactive scenarios with incomplete information. Bayesian games are static incomplete information games because players make decisions simultaneously.

The authors of the present study selected two competing vendors in the same class for analysis. The BNE outcomes of the players were discussed in three dimensions, namely, strategy employment, method selection, and new materials R&D.

Prior to analyzing Bayesian Nash equilibrium (BNE), an AHP analysis was performed to calculate the weights of each manufacturer employing the different strategies. Then, individual cases were examined based on the dimensions of strategy application, new processes, and new materials to elucidate the position in which the Nash equilibrium occurred in the BNE game. The advantage is that it can solve and design the problem of distributed resource allocation mechanisms on incomplete information (Akkarajitsakul, Hossain, & Niyato, 2011). An inverse analysis was adopted to determine the critical success rate for research and development to be beneficial to the developer. In the BNE game, success rate and failure rate must be separated into two sub-games. The results of these sub-games are the combined into one set of game analysis results. Therefore, the present study defined the success rate sub-game as Game A and the failure rate sub-game as Game B for further elaboration.a.Strategy Employment:

In this game, the road maintenance contract contains special work items. When a solution for these work items is not universally available across all vendors, the game outcome is affected by the success of these work items. The authoers were able to determine the success rate of vendors with special techniques which is using for the construction of pavement and determine the appropriate strategy. The authors want to try which data of the chance is the minimum, in this case the success rate of using special instruments for S1 to be 0.3. They further determined the failure rate of using special instruments in Game A to be 0.7. The analysis for Game B is tabulated in the Table 6-14 and Table 6-15.

It is assumed that S1 is the vendor with the instruments to meet the special request of the contractor, S2 is the competing vendor, A is the reduced-cost strategy, B is the reduced-period strategy, XH refers to continued high costs after the use of the special instrument, and XL refers to reduced cost after the use of the special instrument.

Tab. 6-14 Bayesian Game A Strategy Analysis for using the special instrument

S2			
S1		A	B
	XH	(3,2)	(3,1)
	XL	(5,2)	(6,2)

Tab. 6-15 Bayesian Game B Strategy Analysis for using the special instrument

S2			
S1		A	B
	XH	(1,3)	(2,6)

	XL	(3,8)	(4,8)

Tab. 6-16 BNE Game Summary for using the special instrument

S2			
S1		A	B
	(XH,XH)	(2.3,2.7)	(2.3,4.5)
	(XH,XL)	(3,6.2)	(3.7,5.9)
	(XL,XH)	(2.2,2.7)	(3.2,4.8)
	(XL,XL)	(2.9,6.2)	(4.6,6.2)

The BNE outcomes of the Bayesian games suggest that BNE is achieved when S2 employs the reduced-period strategy and S1 employs the technical strategy for the special request to reduce costs. However, the success rate of the technical strategy is relatively low. Thus, S2 wins the games as shown in Table 6-16.

b. Method Selection

Different construction methods influence overall construction period and fluency, which consequently affects overall constructions costs and the surrounding environment. Subsequently, different road types require different construction environments and methods. Therefore, in a Bayesian game, the development of innovative methods or the new techniques of vendors change the original BNE outcomes. The authors want to try which data of the chance is the minimum, in this case the success rate of developing new methods for S1 to be 0.3. They further determined the failure rate developing new methods in Game A to be 0.7. The analysis for Game B is tabulated in the Table 8 and Table . 9

Tab. 10 Bayesian Game A Strategy Analysis for using the new construction method

S2			
S1		A	B
	XH	(5,1)	(4,1.5)
	XL	(8,2)	(6,2)

Tab. 11 Bayesian Game B Strategy Analysis for using the new construction method

S2			
S1		A	B
	XH	(1,4)	(1,3)
	XL	(2,6)	(1.5,4)

Tab. 12 BNE Game Summary for using the new construction method

S2			
S1		A	B
	(XH,XH)	(2.2,3.1)	(1.9,2.55)
	(XH,XL)	(2.9,4.5)	(2.25,3.25)
	(XL,XH)	(3.1,3.4)	(2.5,2.7)
	(XL,XL)	(3.8,4.8)	(2.85,3.4)

The BNE outcomes of the Bayesian games suggest that BNE is achieved when S2 employs the reduced-cost strategy and S1 employs the method-development strategy to reduce costs. However, the success rate of the method-development strategy is relatively low. Thus, S2 wins the game as shown in Table 13

C. New Materials R&D

Different materials influence construction quality, and different materials are required for different road types. In recent years, the development of renewable asphalt concrete has been a major breakthrough in the development of new materials. Therefore, various vendors have invested considerable funds into research and development. In the Bayesian game, vendors who invest an increased amount of funds into research and development manifest a higher chance of discovering new materials to reduce construction costs. The authors employed this concept to elucidate the changes to the BNE outcome. The authors want to try which data of the chance is the minimum, in this case the success rate of developing new materials for S1 to be 0.4. They further determined the failure rate of developing new materials in Game A to be 0.6. The analysis for Game B is tabulated in the Table 14 and Table 15

Tab. 16 Bayesian Game A Strategy Analysis for using the new construction material

S2			
S1		A	B
	XH	(4,0.5)	(4,1)
	XL	(7,2)	(6,2.5)

Tab. 17 Bayesian Game B Strategy Analysis for using the new construction material

S2			
S1		A	B
	XH	(2,3)	(3,7)
	XL	(2,5)	(4,6)

Tab. 18 BNE Game Summary for using the new construction material

S2			
S1		A	B
	(XH,XH)	(1.9,2)	(3.4,4.6)

	(XH,XL)	(2.8,3.2)	(4,4)
	(XL,XH)	(4,2.6)	(4.2,5.2)
	(XL,XL)	(4,3.8)	(4.8,4.6)

The BNE outcomes of the Bayesian games suggest that when S2 employs the reduced-period strategy and S1 employs the new-materials-development strategy to lower their cost, S1 achieves BNE and wins the Bayesian game with the new-materials-development strategy as shown in Table 191.

6.3 Pavement Lean Management Cooperative Game Selection Analysis

Pavement engineering has gradually and progressively shifted from construction to maintenance. Therefore, different construction, machinery, and maintenance strategies should be formulated for different road types. These strategies should aim to create a mutually beneficial situation for the outsourcing strategies and regulation enforcement between providers and asphalt companies. The present study developed a lean management system for pavement maintenance to elucidate and optimize construction costs and construction periods. Moreover, a three-dimensional superiority analysis was adopted to evaluate environmental impact. The analysis results were incorporated into a cooperative and a non-cooperative game model to identify the optimal manufacturer under different contractual terms and conditions.

6.3.1 Cooperative Game Theory Analysis

The present study adopted the principle of proportionality to investigate expansion competition and cross-factory cooperation. One hundred and eight asphalt manufacturers in Taiwan were classified into three classes based on their capital, namely, Class A, B, and C. The proportion of competition for manufactures in Classes S, A, and B was set at 3:2:1 in the sub-perfect Nash equilibrium (SPNE) game. The different competition radii of the manufacturers were used to analyze expansion competition and cross-factory cooperation.

a. Expansion Competition

The authors used Type-W Industrial Co. Ltd., which was a Class S vendor in Taiwan as an example. Three other asphalt vendors are located within a 10-km radius, namely, Type-L Industrial Co. Ltd., Type-S Asphalt Co. Ltd., and Type-B Industrial Co. Ltd., which were Class S, A, and B vendors, respectively, as shown in the game tree diagram in Fig. 6-19.

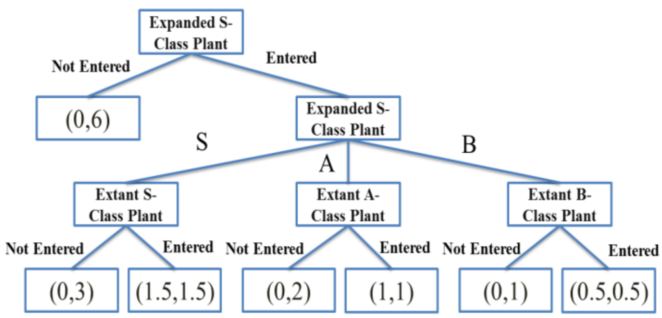


Fig. 6-19 Small-Scale Expansion SPNE Game Decision Tree Diagram

When Type-W Industrial Co. Ltd. decides to expand new S-Class plants, the plant is faced with competition from neighbouring vendors. If the plant chooses not to establish the plant, then no new profits are created. If the plant decides to establish a plant near an extant S-Class plant, the analysis results indicate that profits are shared between the plants. The SPNE game decision tree diagram illustrates that profits are higher when competing with S-Class vendors (Mao 2014). Thus, when pavement engineering is the primary service within a 10-km range, the plant chooses to compete with the S-Class vendor.

Then, the authors simulated the same game within a 20-km radius. A total of nine asphalt vendors were found, three vendors in each Class. The game outcomes are shown in Fig. 6-20.

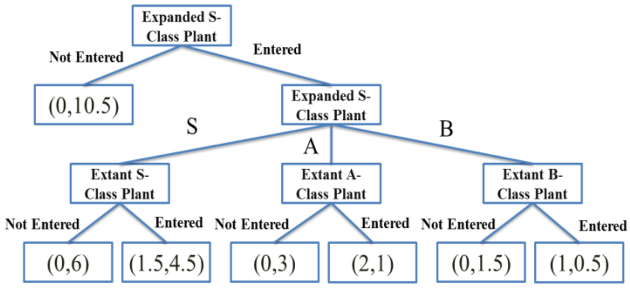


Fig. 6-20 Large-Scale Expansion SPNE Game Decision Tree Diagram

Fig. 6-20 illustrates when the plant decides to expand its pavement engineering services to a 20-km radius, the analysis results indicate that establishing a plant near extant A-Class plants is most beneficial, followed by establishing a plant near extant S-Class plants. Thus, the SPNE game decision tree diagram illustrates that competing with the extant A-Class vendor is most feasible.

b.Inter-Plant Cooperation

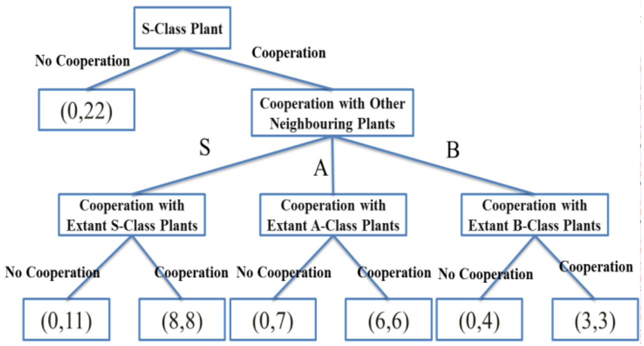


Fig. 6-21 Inter-Plant Cooperation SPNE Game Analysis Diagram

Fig. 6-21 illustrates in terms of inter-plant cooperation with neighbouring vendors, the analysis results indicate that cooperating with extant S-Class vendors is most beneficial, followed by cooperating with A-Class vendors. However, cooperation reduces the overall efficiency of the original plant. Thus, in practice, more information is required to improve the overall analysis results.

6.3.2 Cooperative Game Performance Analysis and Evaluation

Pavement engineering plays a major role in civil engineering. Pavement engineering produces considerable economic benefits for construction projects across Taiwan. However, it is not financially self-liquidating. Thus, appropriate contract requirements and bidding prices effectively improves the quality of major asphalt vendors, further improving the overall road quality of Taiwan. In this context, providing relevant assistance and subsidisation can create a triple win situation for the contractor, vendor, and the public. The authors of the presents study employed game theory to analyse the relationship between contractors and vendors. Game simulations were conducted from a contractor's perspective and a vendor's perspective, and a comprehensive comparison between the two results was conducted to elucidate how contractors formulate comprehensive and rational maintenance contracts in Fig. 6-22 From a contractor's perspective, different contract requirements influence the decisions of competing vendors, consequently affecting the outcomes of the game models. From a vendor's perspective, the authors attempted to identify the optimal strategies and partners for various vendors by simulating various games with known conditions of location, price, requirements, and construction period, and analysing subsequent simulation outcomes.

The authors examined the outcomes of three game types to develop a set of analytical methods suitable for contractors (Chen 2014). The outcomes of the three games types can serve as a reference for contractors for improving contract effectiveness and achieve expected performance. The advantages that contractors gained from the game simulation results of the various vendors are listed as follows:

1.Improving the rationality of pavement maintenance budgeting and bidding

2.Selecting the optimal vendor

3.Selecting the optimal construction period

4.Reducing the impact of construction on the environment

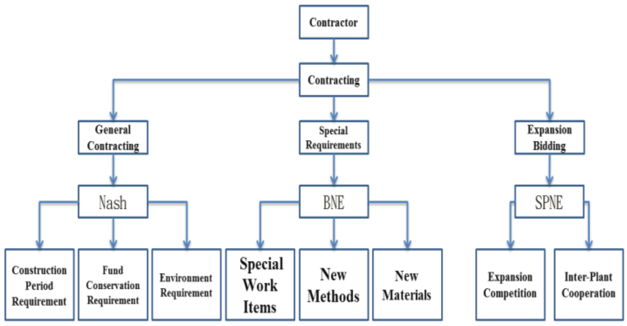


Fig. 6-22 Contractors' Game Simulation Analysis Flow Chart

NE Game Outcomes

An analysis of the NE outcomes indicated that among the vendors of the same class, the vendor with an advantage won the game, and the winning vendor likely employed a strategy that focused on environmental protection. For example, when the contract requires a reduced construction period, the vendor closest to the construction site wins the game. Moreover, the advantageous vendor that employs an environmental-protection strategy would achieve NE. (Masilionyte, Maiksteniene, Velykis, &Satkus, 2014).

The NE outcomes of the games suggest that NE is achieved when Same-level manufacturers compete against one another, where S1 and S2 exhibit similar competitive advantages. However, the carbon reduction strategy must be adopted as the main operating strategy to win the game. And on the other hand, when Same-level manufacturers compete against one another, where S1 exhibits time and cost conservation advantages over S2, Nash equilibrium occurred when S1 and S2 adopted the cost conservation and carbon reduction strategies as the main operating strategies. S1 won the game. The result as shown in Table 202.

Tab. 21 Nash Equilibrium Game Results Analysis for Time Conservation

Competing Manufacturers /Contract Requirements	Time Conservation
Same-level manufacturers compete against one another, where S1 and S2 exhibit similar competitive advantages.	S1 and S2 exhibited similar advantages in the game. However, the carbon reduction strategy must be

(S1 V.S S2)	adopted as the main operating strategy in order to win the game.
Same-level manufacturers compete against one another, where S1 exhibits time and cost conservation advantages over S2. (S1 V.S S2)	Nash equilibrium occurred when S1 and S2 adopted the cost conservation and carbon reduction strategies as the main operating strategies. S1 won the game.

And if the constracts are focused on Cost Conservation, where S1 exhibits time and cost conservation advantages over S2. Nash equilibrium occurred when S1 adopted the cost conservation strategy or carbon reduction strategy as the main operating strategy. However, S2 won the game. The result as shown in Table 223

Tab. 23 Nash Equilibrium Game Results Analysis for Cost Conservation

Competing Manufacturers /Contract Requirements	Cost Conservation
Same-level manufacturers compete against one another, where S1 and S2 exhibit similar competitive advantages. (S1 V.S S2)	S1 and S2 exhibited similar advantages in the game. However, the time conservation strategy must be adopted as the main operating strategy in order to win the game.
Same-level manufacturers compete against one another, where S1 exhibits time and cost conservation advantages over S2. (S1 V.S S2)	Nash equilibrium occurred when S1 adopted the cost conservation strategy or carbon reduction strategy as the main operating strategy. However, S2 won the game.

And if the constracts are focused on CO2 Emission Reduction conservation, where S1 exhibits time and cost conservation advantages over S2. Nash equilibrium occurred when S1 adopted the cost conservation strategy as the main operating strategy. S2 won the game.

However, S1 won the game when the carbon reduction strategy was adopted as the main operating strategy. The result as shown in Table 244

Tab. 25 Nash Equilibrium Game Results Analysis for CO2 Emission Reduction

Competing Manufacturers /Contract Requirements	CO2 Emission Reduction
Same-level manufacturers compete against one another, where S1 and S2 exhibit similar competitive advantages. (S1 V.S S2)	S1 and S2 exhibited similar advantages in the game. However, the time conservation strategy must be adopted as the main operating strategy in order to win the game.
Same-level manufacturers compete against one another, where S1 exhibits time and cost conservation advantages over S2. (S1 V.S S2)	Nash equilibrium occurred when S1 adopted the cost conservation strategy as the main operating strategy. S2 won the game. However, S1 won the game when the carbon reduction strategy was adopted as the main operating strategy.

BNE Game Outcomes

The researchers identified the success rates of various R&D projects based on the analytical results of the BNE games. According to the pros and cons of the various R&D vendors, the BNE outcomes are tabulated.

In the BNE game, contracts with special requirements were categorized into three dimensions for analysis, namely, special technique application, new process research and development, and new materials research and development. The weights of the manufacturers using different strategies obtained in the preceding AHP analysis was used in this analysis. The success rate and failure rate sub-games for these contracts were similarly defined as Game A and Game B, respectively. BNE balance solutions are obtained from each player that maximizes the expected results from the scope of the types and strategies of other players (Akkarajitsakul, Hossain, & Niyato, 2011). In terms of the contracts with special technique application requirements, the Nash analysis for Game A (Table 7) represents the successful research and development by the manufacture with special technique application requirements. Conversely, the failed research development is presented in the Nash analysis results of Game B (Table 8). Then, ρ and 1-ρ were used to represent the success rate and failure rate of research and development. Results showed that when BNE occurred in the opposing manufacturer using the time-reduction strategy, and when the manufacturer maintained a relatively low cost, the calculation equation could be expressed as $2\rho+4>8-6\rho$. This unequal equation suggests that when success rate $\rho > 0.5$, the manufacturer that possesses special techniques wins the game. The game analysis results are tabulated in Table 265.

Tab. 27Bayesian Games for Special Work Items

Bayesian Game Type	Strategy Employed for Special Work Items	
Bayesian Nash Strategy	A	B
(XH,XH)	(2ρ+1,3-ρ)	(ρ+2,6-5ρ)
(XH,XL)	(3,8-6ρ)	(4-ρ,8-7ρ)
(XL,XH)	(4ρ+1,3-ρ)	(4ρ+2,6-4ρ)
(XL,XL)	(2ρ+3,8-6ρ)	BNE(2ρ+4,8-6ρ)
BNE Success Rate	ρ>0.5	

In games that consisted of special contract requirements, the outcomes of each manufacturer using different strategies are tabulated in Table 28. Results show that manufactures with special skills that apply these skills achieved a 50% greater chance of success, consequently winning the game.

Tab. 29 Bayesian Games for the R&D of New Methods

Bayesian Game Type	R&D of New Methods	
Bayesian Nash Strategy	A	B
(XH,XH)	(4ρ+1,4-3ρ)	(3ρ+1,3-1.5ρ)

(XH,XL)	(3ρ+2,6-5ρ)	(2.5ρ+1.5,4-2.5ρ)
(XL,XH)	(7ρ+1,4-2ρ)	(5ρ+1,3-ρ)
(XL,XL)	BNE (6ρ+2,6-4ρ)	(4.5ρ+1.5,4-2ρ)
BNE Success Rate	ρ>0.4	

In games that consisted the contractual demand for new methods, the outcomes of each manufacturer using different strategies are tabulated in Table 307. Results show that manufactures with new methods that apply these methods achieved a 40% greater chance of success, consequently winning the game.

Table. 317 Bayesian Games for the R&D of New Materials

Bayesian Game Type	R&D of New Materials	
Bayesian Nash Strategy	A	B
(XH,XH)	(3ρ+1,3-2.5ρ)	(ρ+3,7-6ρ)
(XH,XL)	(2ρ+2,5-4.5ρ)	(4,6-5ρ)
(XL,XH)	(5ρ+2,3-ρ)	(3ρ+3,7-4.5ρ)
(XL,XL)	(5ρ+2,5-3ρ)	BNE(2ρ+4,6-3.5ρ)
BNE Success Rate	ρ>0.364	

The outcomes indicate that the success rate for the R&D of new materials need only be over 0.364 to win the Bayesian Nash game in Table 327. Thus, major asphalt vendors can focus on the R&D of new asphalt materials to improve their chances of winning bids.

6.4 Pavement Lean Management System Establishment

Through the concepts of lean management, and with the principles of Environment Impact Assessment introduced to the establishment of the lean management system, the subject of this research is the life cycle of asphalt concrete industry.

Analyses were conducted for construction sites of different locations and construction scales before establishing the system. From the employer's perspective, a contractor with the optimized route, the minimal cost, and the minimal environmental impact can be identified.

As for the contractor, the optimal arrangement for different plants and construction sites can be identified.

6.4.1 National Freeway Pavement Lean Management System Module Establishment

The current home screen of the system is illustrated in Figure 42. Currently, the design focuses on route optimisation. The top field is for the selection and adjustment of location data. First, the road section awaiting maintenance can be selected by clicking on the map, as shown in Figure 6-23. In this example, Zhongda Road, on which the main gate of National Central University islocated, is selected as the maintenance section. Next, the radius for optimisation analysis is set to query relevant vendors within the vicinity, as shown in Figure 6-24. The system then marks the road section awaiting maintenance with a construction sign and listed the information of the vendors within the region in sequential order from closest to furthest on the fields on the right. Clicking on a vendor displays the details of the route, as shown in Figure 6-25.

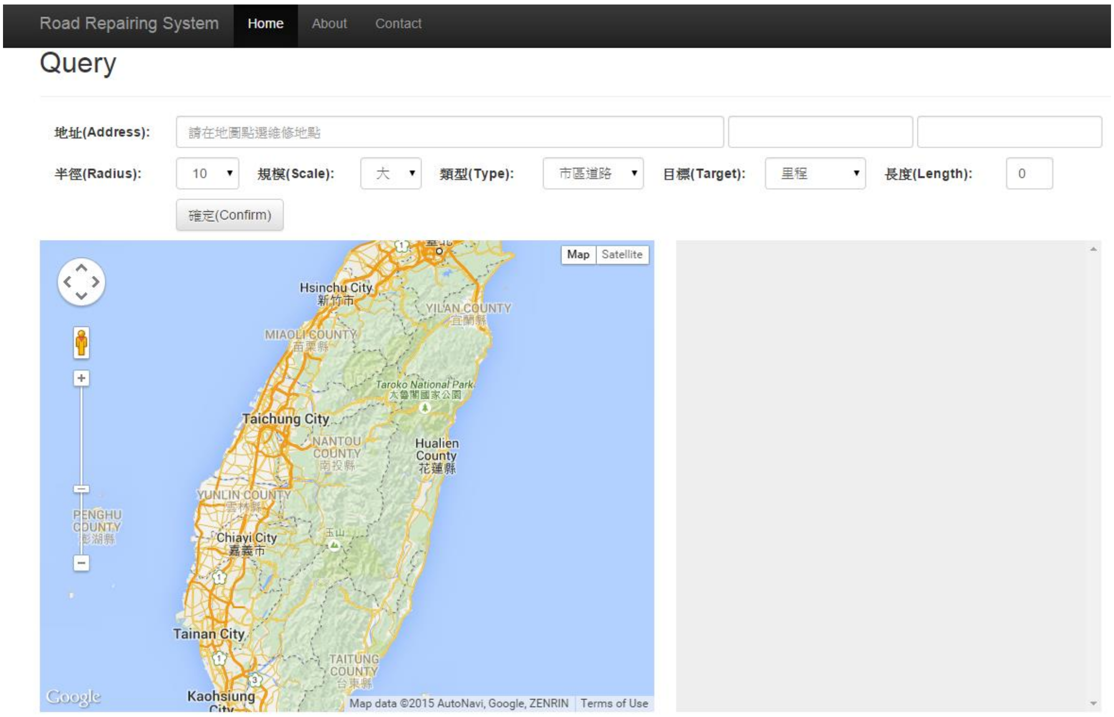


Fig. 6-23 Representational Diagram of the Home Screen

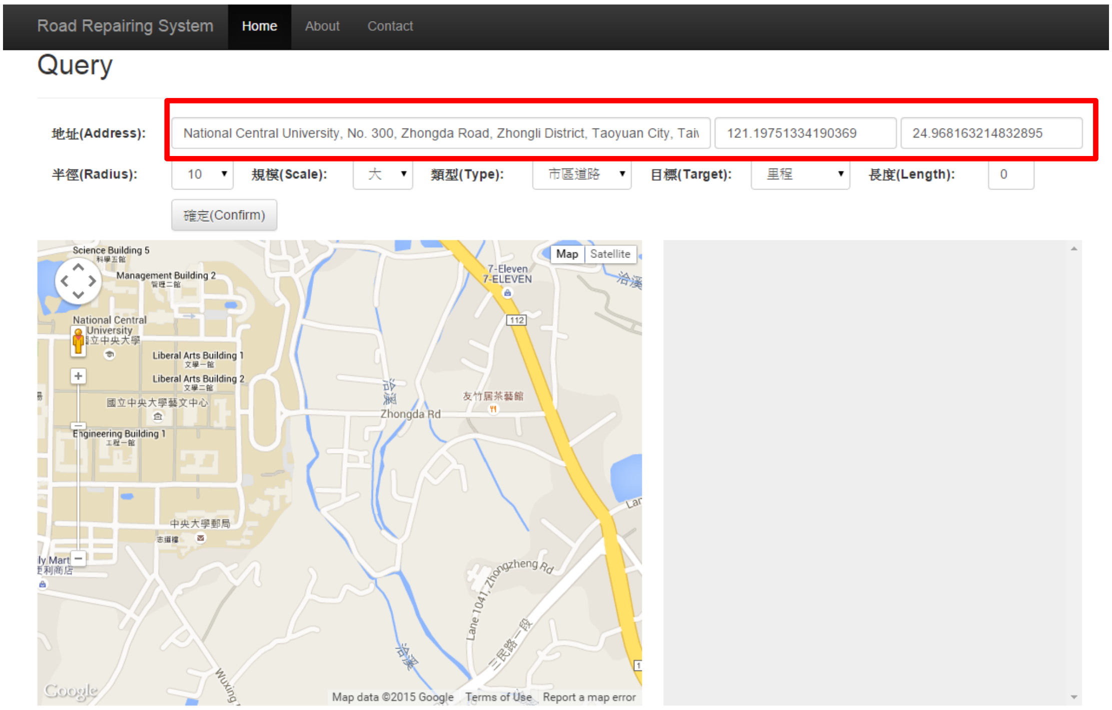


Fig. 6-24 Representational Diagram of Maintenance Location Selection

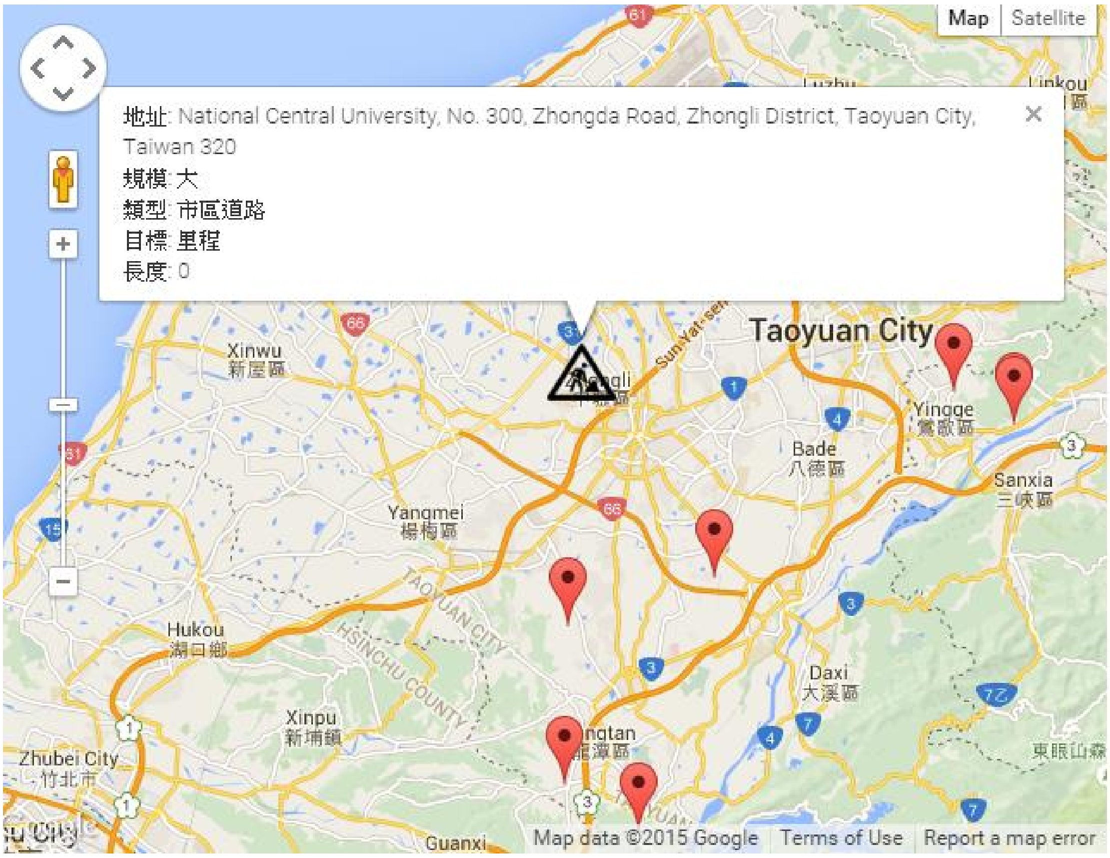


Fig. 6-25 Representational Diagram of Route Optimization Preliminary Analysis

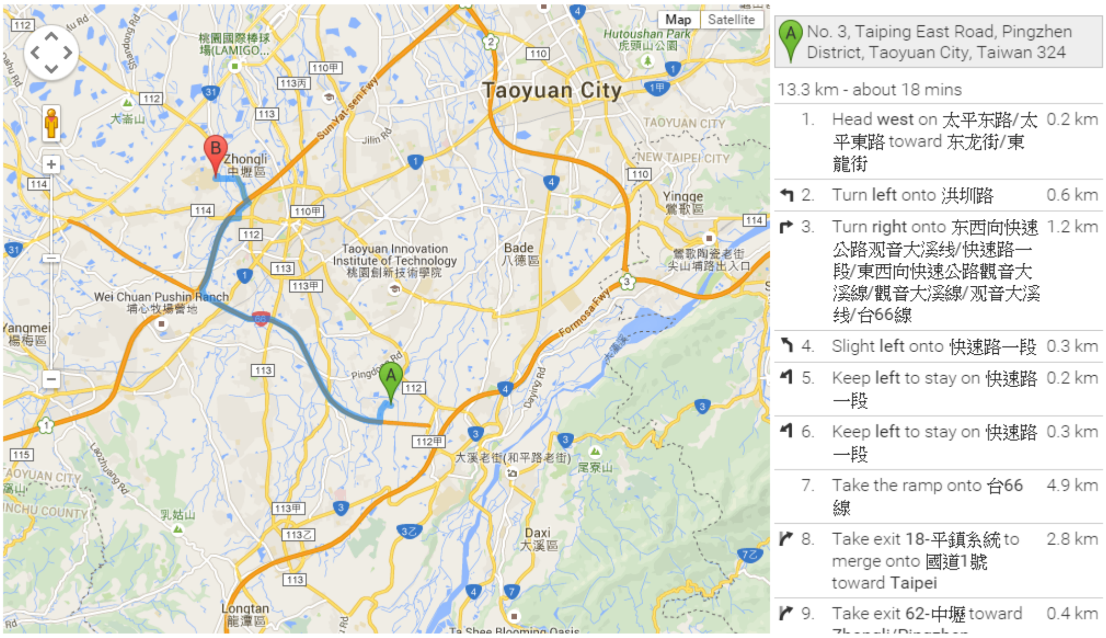


Fig. 6-26 Representational Diagram of Detailed Directions

The Minimal Cost

The budget estimation for construction was calculated from three aspects—the expenses for labor, equipment and materials. When assessing from the contractor’s perspective, different analytical methods and assessments were applied depending on the various contractors with different plant scales and numbers.

1. Construction Data

To make each major asphalt vendor understand the detailed requirements of road maintenance contracts, employers can compile relevant data into files before contracting with vendors. Relevant data include types of roads (city and district roads, provincial highways, township roads, or national highways), construction lengths (for estimating machine costs, transportation costs, and aggregate costs), expected vehicle utilization days and construction days (which affect construction vehicle dispatch and costs), contract periods (which affect companies’ operating costs), number of truck drivers, and daily rates of trucks.

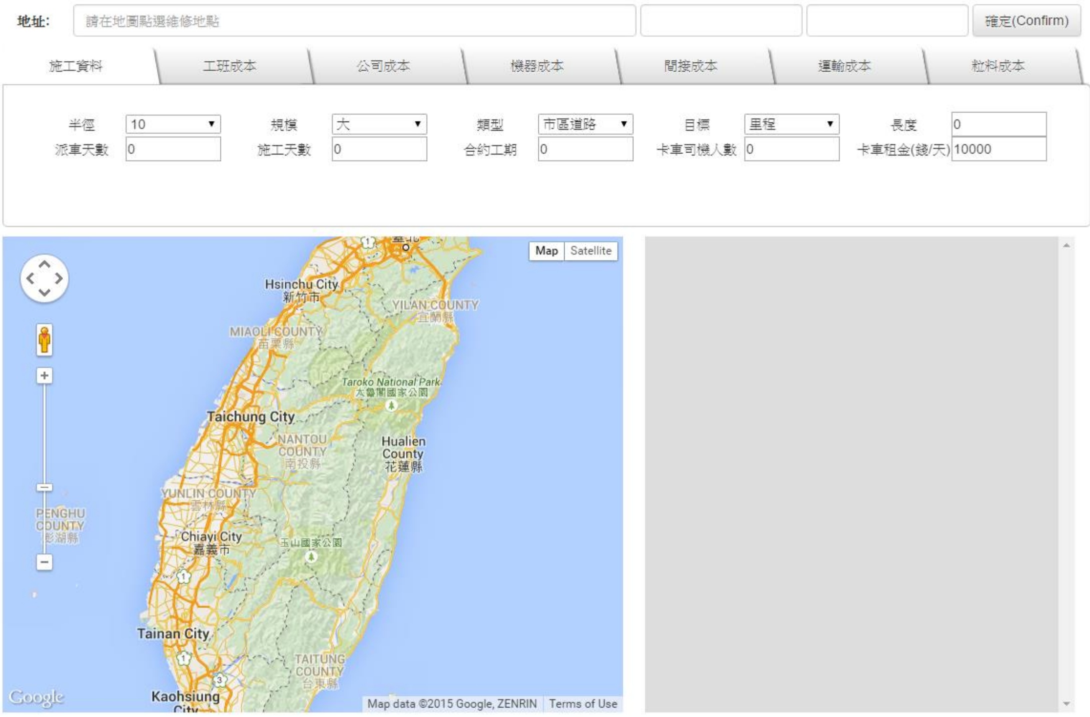


Fig. 6-27 Construction Data model

2. Labour Costs

Labour costs are affected by the number of actual expected construction days. Suspensions of work due to unforeseeable circumstances or extensions of construction periods due to coordination problems will have impacts on labour costs. For this module, the system enables different settings for actual wages and traffic control vehicle rental costs for different numbers of construction workers as well as traffic controllers.

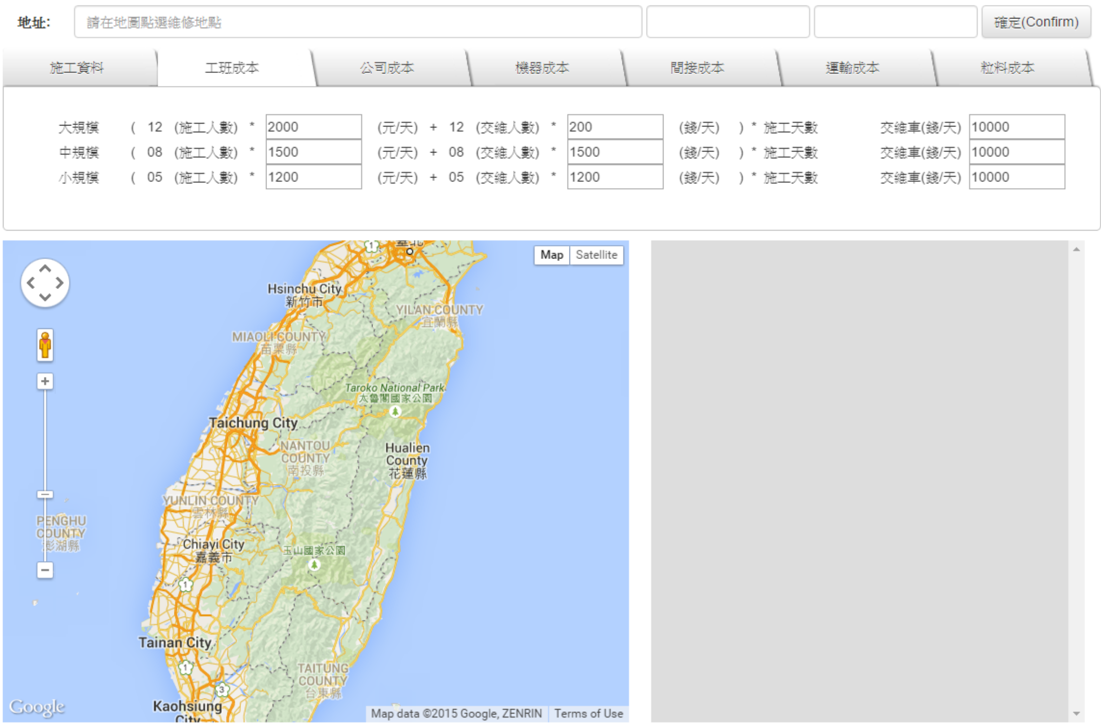


Fig. 6-28 Labour Costs model

3. Company Costs

Different companies have different operating costs. For this part of the study, the system categorizes all companies into three levels (this can be followed by research on ways of customisation), namely level S, level A, and level B, and enables inputs of different numbers of total staff and calculation of total costs based on different personnel costs.

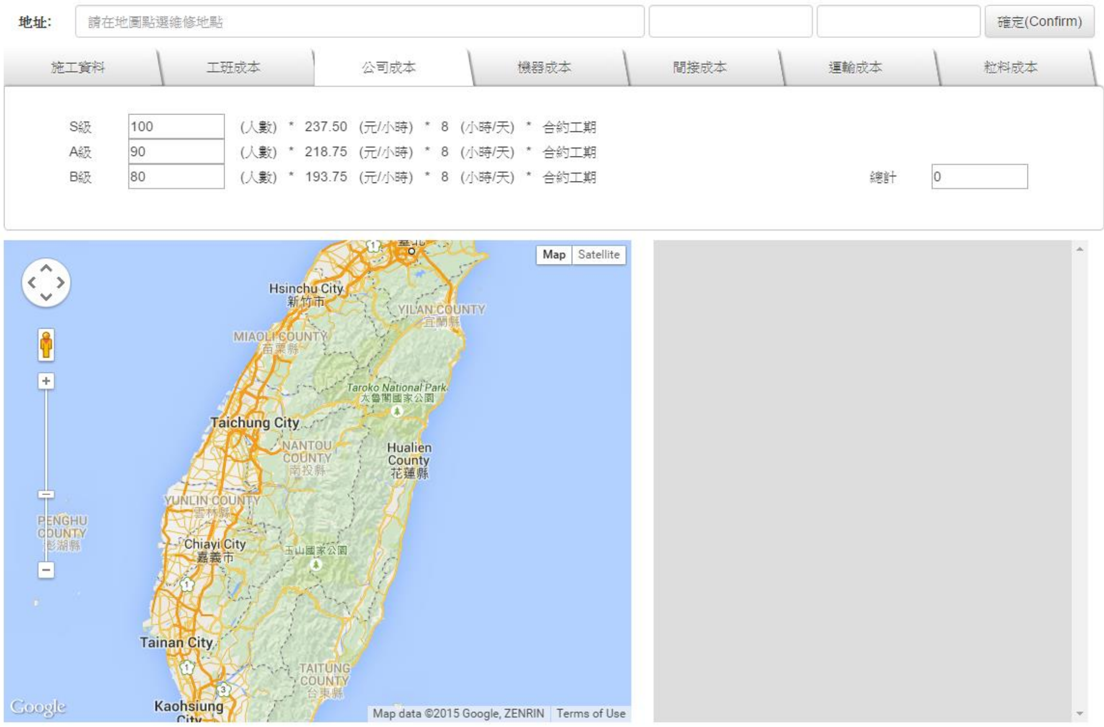


Fig. 6-29 Company Costs model

4. Machine Costs

Price estimations are conducted for paving machines used in road constructions. Items include aggregate crushers, scrapers, three-wheel rollers, cold-milling machines, excavators, rubber-wheeled rollers, road sweepers, paving machines, and asphalt distributors. Items will continue to be added to this module in subsequent studies.

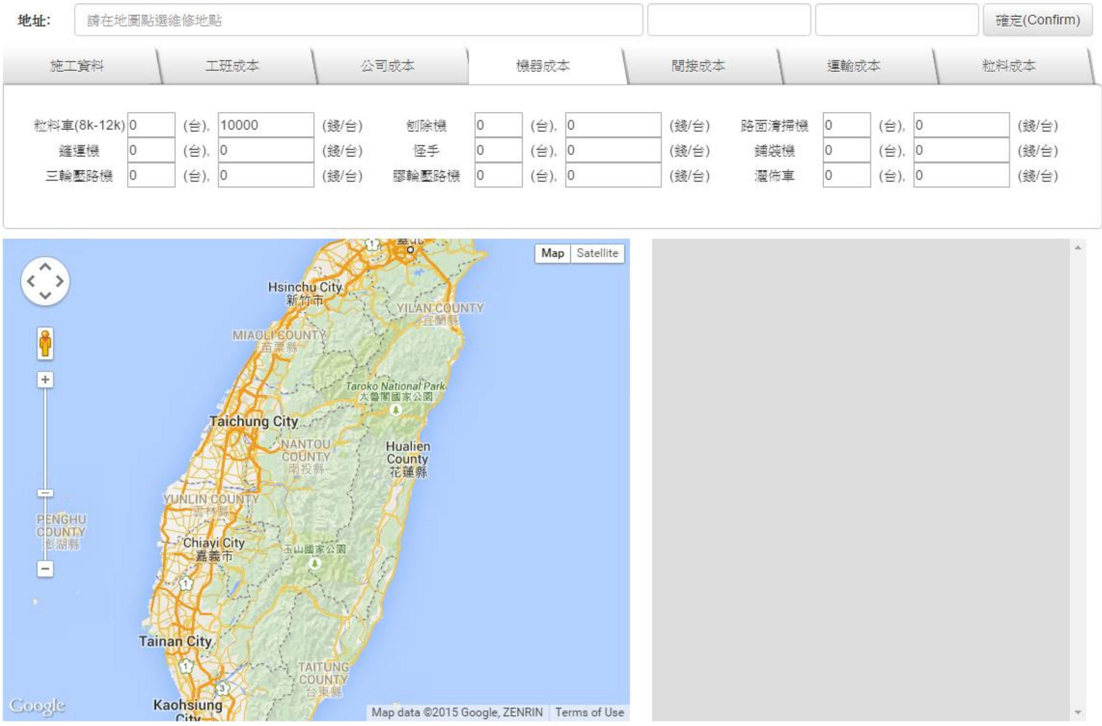


Fig. 6-30 Machine Costs model

5. Indirect Costs

Indirect costs are important cost items but may be easily overlooked in the operations of companies. Here, six indirect cost items incurred in the operations of asphalt plants are discussed, including the costs of production equipment of asphalt mixing plants, personnel costs of asphalt mixing plants, equipment depreciation, on-site construction management, construction reporting and environmental maintenance, machine rentals, etc. Moreover, this module is customizable for inputting different cost amounts of various companies. A diagram of this module is shown in the figure.

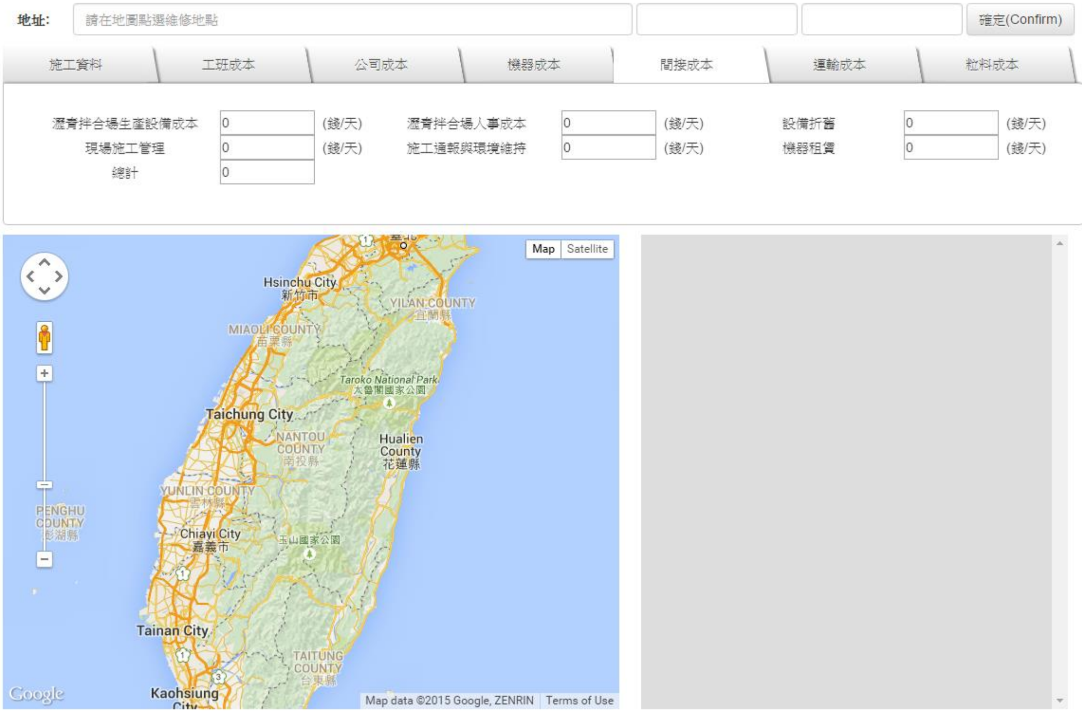


Fig. 6-31 Indirect Costs model

6. Transportation Costs

This module is to be built for all transportation costs required during road constructions. When building this module, optimized routes may be utilized for transportation planning. Whether or not to rent vehicles may also be studied in this module. Costs may be categorized into that of aggregate vehicles and traffic control vehicles, and that of departing from companies and rental companies. Actual transportation costs required for different transportation distances can therefore be calculated through simulations for route optimisation. A diagram of this module is shown in the figure.

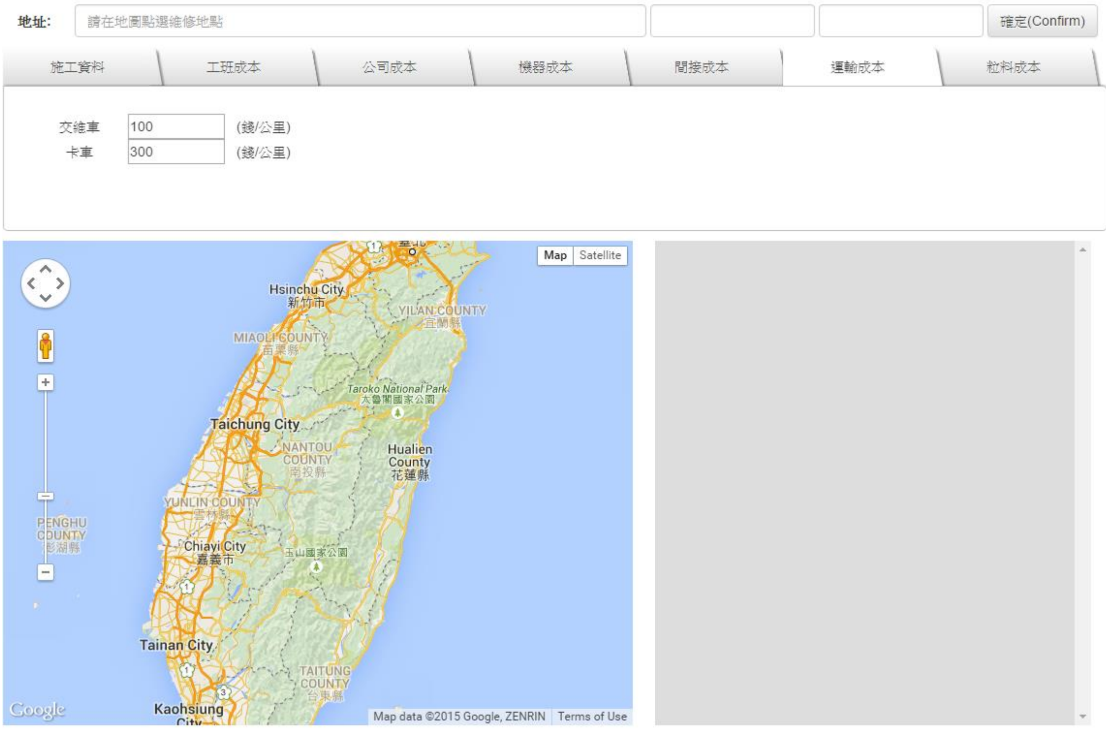


Fig. 6-32 Transportation Costs model

7. Aggregate Costs

Costs vary for different material items and different regions. Therefore, cost estimations are conducted for different materials and different required quantities. A diagram of this module is shown in the figure.

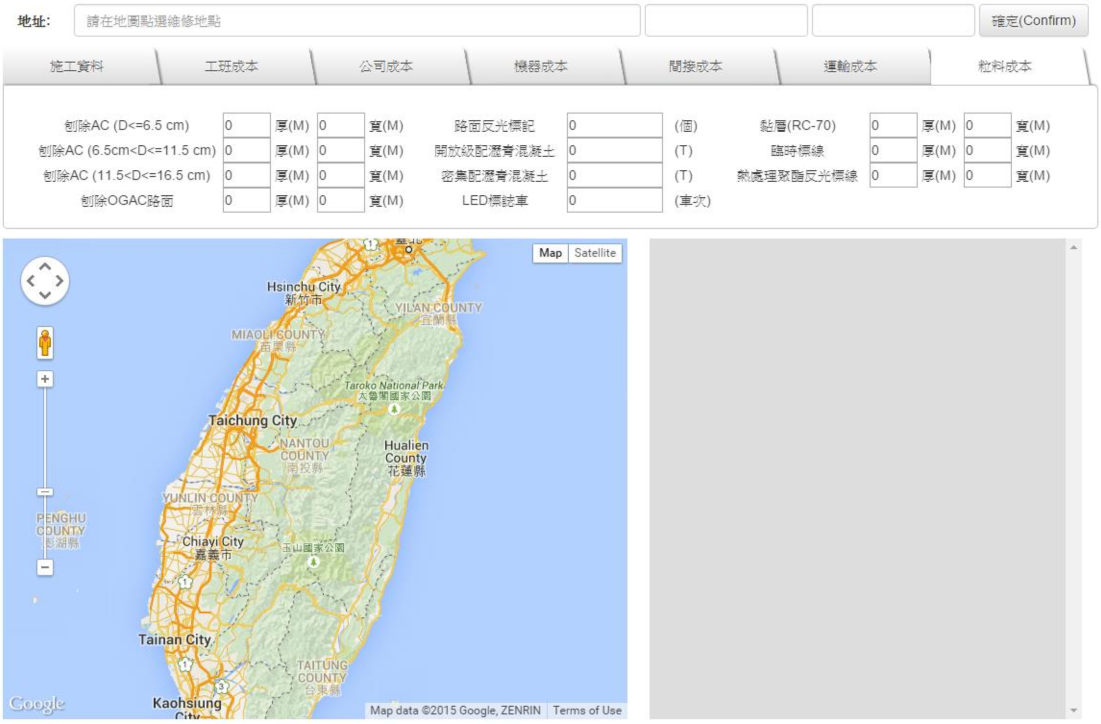


Fig. 6-33 Aggregate Costs model

6.4.2 Systematic Analysis of the Game Simulation Interface

The forward and outer lane between 83K and 89K of the Guanxi construction section was analyzed. First, the construction information was entered into the system, as illustrated in Fig. 6-34. The construction period was 70 days, and the outsourced amount was NT $63 million.

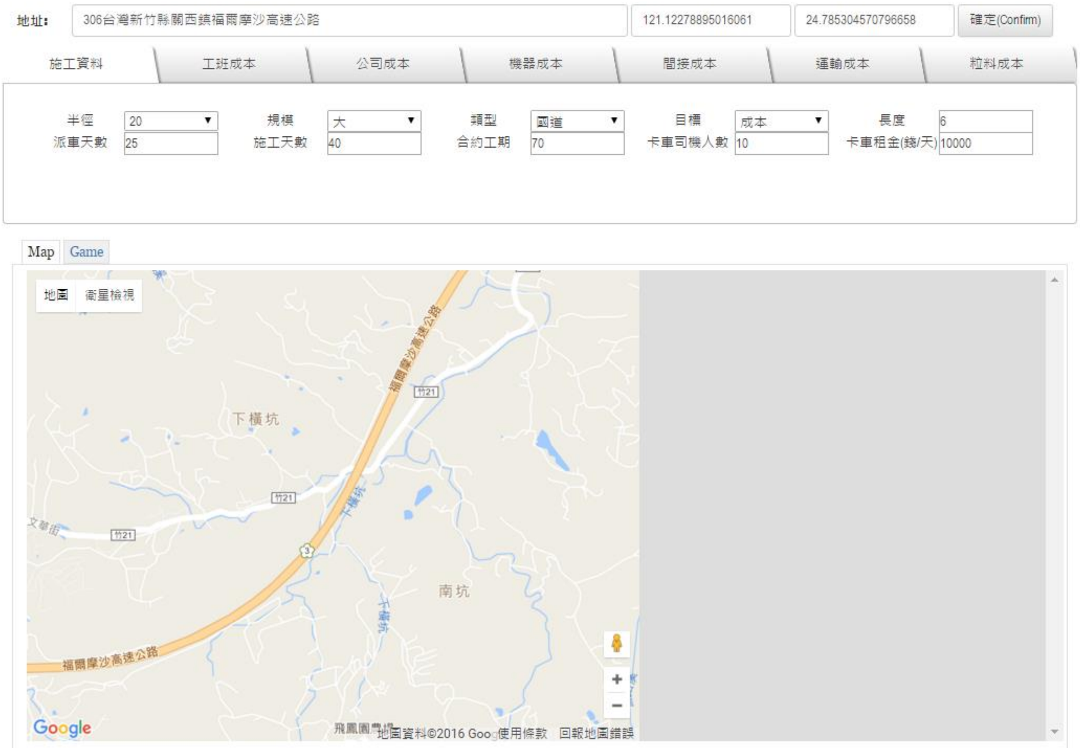


Fig. 6-34 Construction Information and Case Study

Shift, company, machinery and equipment, indirect, logistics, and feed costs were entered into the system for game simulation. The route optimization outcomes and game outcomes are illustrated in Fig. 6-35 and Fig. 6-36, respectively.

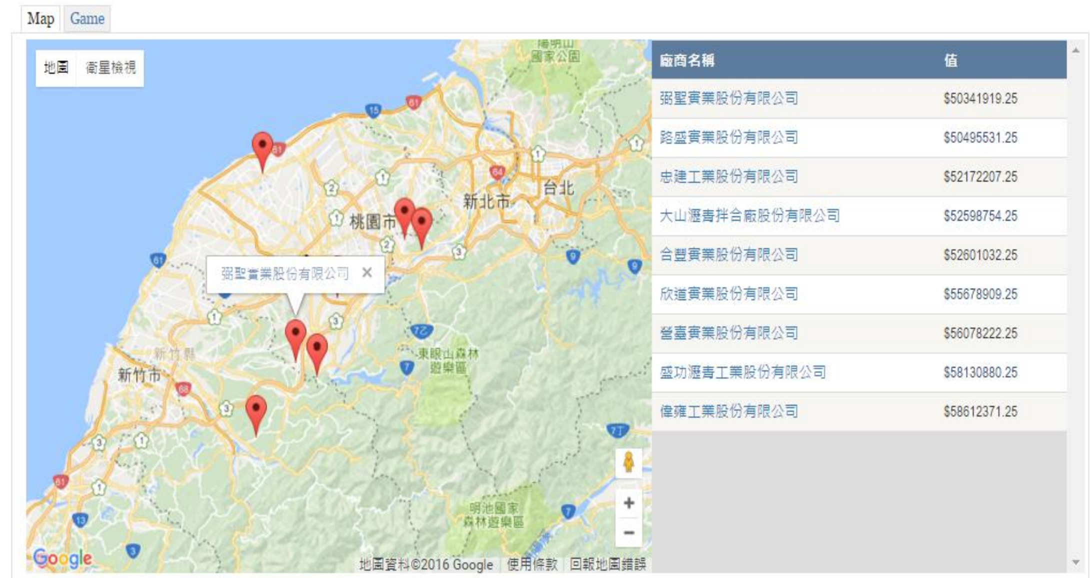


Fig. 6-35 Route Optimization Analysis Outcomes

	忠建	大山	合豐	偉雍	盛功	路盛	弼聖	欣道	營臺
忠建		忠建(B): x=52172207.25, y=15.94 大山(B): a=52598754.25, b=18.45 忠建獲勝	忠建(B): x=52172207.25, y=15.94 合豐(B): a=52601032.25, b=18.46 忠建獲勝	忠建(B): x=52172207.25, y=15.94 偉雍(S): a=58612371.25, b=5.03 忠建獲勝	忠建(B): x=52172207.25, y=15.94 盛功(S): a=58130880.25, b=2.20 忠建獲勝	忠建(B): x=52172207.25, y=15.94 路盛(B): a=50495531.25, b=6.08 路盛獲勝	忠建(B): x=52172207.25, y=15.94 弼聖(B): a=50341919.25, b=5.17 弼聖獲勝	忠建(B): x=52172207.25, y=15.94 欣道(A): a=55678909.25, b=10.42 忠建獲勝	忠建(B): x=52172207.25, y=15.94 營臺(A): a=56078222.25, b=12.77 忠建獲勝
大山			大山(B): x=52598754.25, y=18.45 合豐(B): a=52601032.25, b=18.46 大山獲勝	大山(B): x=52598754.25, y=18.45 偉雍(S): a=58612371.25, b=5.03 大山獲勝	大山(B): x=52598754.25, y=18.45 盛功(S): a=58130880.25, b=2.20 大山獲勝	大山(B): x=52598754.25, y=18.45 路盛(B): a=50495531.25, b=6.08 路盛獲勝	大山(B): x=52598754.25, y=18.45 弼聖(B): a=50341919.25, b=5.17 弼聖獲勝	大山(B): x=52598754.25, y=18.45 欣道(A): a=55678909.25, b=10.42 大山獲勝	大山(B): x=52598754.25, y=18.45 營臺(A): a=56078222.25, b=12.77 大山獲勝
合豐				合豐(B): x=52601032.25, y=18.46 偉雍(S): a=58612371.25, b=5.03 合豐獲勝	合豐(B): x=52601032.25, y=18.46 盛功(S): a=58130880.25, b=2.20 合豐獲勝	合豐(B): x=52601032.25, y=18.46 路盛(B): a=50495531.25, b=6.08 路盛獲勝	合豐(B): x=52601032.25, y=18.46 弼聖(B): a=50341919.25, b=5.17 弼聖獲勝	合豐(B): x=52601032.25, y=18.46 欣道(A): a=55678909.25, b=10.42 合豐獲勝	合豐(B): x=52601032.25, y=18.46 營臺(A): a=56078222.25, b=12.77 合豐獲勝
偉雍					偉雍(S): x=58612371.25, y=5.03 盛功(S): a=58130880.25, b=2.20 盛功獲勝	偉雍(S): x=58612371.25, y=5.03 路盛(B): a=50495531.25, b=6.08 路盛獲勝	偉雍(S): x=58612371.25, y=5.03 弼聖(B): a=50341919.25, b=5.17 弼聖獲勝	偉雍(S): x=58612371.25, y=5.03 欣道(A): a=55678909.25, b=10.42 欣道獲勝	偉雍(S): x=58612371.25, y=5.03 營臺(A): a=56078222.25, b=12.77 營臺獲勝
盛功						盛功(S): x=58130880.25, y=2.20 路盛(B): a=50495531.25, b=6.08 路盛獲勝	盛功(S): x=58130880.25, y=2.20 弼聖(B): a=50341919.25, b=5.17 弼聖獲勝	盛功(S): x=58130880.25, y=2.20 欣道(A): a=55678909.25, b=10.42 欣道獲勝	盛功(S): x=58130880.25, y=2.20 營臺(A): a=56078222.25, b=12.77 營臺獲勝
路盛							路盛(B): x=50495531.25, y=6.08 弼聖(B): a=50341919.25, b=5.17 弼聖獲勝	路盛(B): x=50495531.25, y=6.08 欣道(A): a=55678909.25, b=10.42 路盛獲勝	路盛(B): x=50495531.25, y=6.08 營臺(A): a=56078222.25, b=12.77 路盛獲勝

Fig. 6-36 Game Simulation Analysis Outcomes

6.4 Summary

The game comprises nine asphalt vendors and the terms and conditions of their contracts. They were Zhong Jian, Da Shan, He Feng, Wei Yong, Sheng Gong, Lu Sheng, Zhi Sheng, Xin Dao, and Ying Tai. Although Ying Tai was the closest vendor to the construction site, Zhi Sheng achieved the most favorable strategy selection performance, with a competitive total construction cost of NT $50.34 million.

Chapter 7. Decision-Making Optimization of National Freeway Maintenance Sections

7.1 Modulation Analysis of the National Freeway Pavement Management System

A comprehensive test was performed to examine national freeways, and historical national freeway maintenance records were collected. Subsequently, the test outcomes and collected data were analyzed. The IRI (42,540 data sets), SN (8,508 data sets), and PCI (42,540 data sets) of 4,254 km of freeway road were tested, and 6,834 sets of FWD data were collected. The analyzed data were incorporated into the National Freeway Pavement Management System. The system is compatible with all the aforementioned data types.

7.1.1 Management System Database Establishment

A basic database was established to store the relevant data of all road sections in the design freeway, including the road segments, managing department, inspect and maintenance undertaker of each construction section. In addition, basic environment information and average and heavy traffic volumes of each lane in each section were used to establish the database architecture for basic data.

Construction data largely served as the required data for expanding and upgrading the National Freeway Pavement Management System into a comprehensive analysis system. They comprised the new construction and past maintenance data of various sections, as well as the basic properties of different materials.

New Construction Data (incl., new provisions, pavement styles and thicknesses, completion drawings)

Basic national freeway data refers to the basic data concerning freeway construction. For example, the data concerning the new construction of National Freeway No. 1 was illustrated into hand-drawn completion drawings. The basic data on all upcoming national freeway route constructions are tabulated in Table 7-1 to Table 7-4.

(1) Basic road data: road grade, pavement type, section length, lane width, shoulder width, section materials and properties, and roadbed CBR

(2) Road geometry data: road slope, flat curve, speed limit, sea level, and terrain

(3) Road coordinates data: longitude and latitude and secondary zoning coordinates

Data concerning the materials used during the construction of the various freeways and design thicknesses were collected in this paper. The surface layer (OGAC) comprised two thicknesses, 1.5 and 2.0 cm. The structure surface (DGAC) comprised two thicknesses, 10 and 15 cm. The bottom layer (BTB) comprised three thicknesses, 15, 20, and 25 cm. The base layer (gravel gradation layer) comprised four thicknesses, 20, 25, 30, and 35 cm. The roadbed CBR were either 10% or 15%.

Table. 7-1 Asphalt Pavement Section Data of National Freeway No. 1

Section	Begin	End	OGAC	DGAC	BTB	SUBBASE
Neihu	0K+000	40K+850	1.5cm	10cm	18~20cm	20~25cm
Chungli	40K+850	93K+500	1.5cm	10cm	12cm	20cm
Guanxi	93K+500	100K+800	1.5cm	10cm	12cm	20cm
Miaoli	100K+800	173K+500	1.5cm	15cm	12cm	20cm
Dounan	173K+500	251K+100	1.5cm	15cm	22cm	30cm
Xinying	251K+100	320K+000	1.5cm	15cm	22cm	30cm
Gangshan	320K+000	372K+760	1.5cm	15cm	22cm	30cm

Table. 7-2 Asphalt Pavement Section Data of National Freeway No. 3

Section	Begin	End	OGAC	DGAC	BTB	SUBBASE
Muzha	0K+000	42k+000	1.5cm	10cm	20cm	35cm
Guanxi	42k+000	110k+700	1.5cm	10cm	15cm	25cm
Dajia	110K+700	195K+462	1.5cm	15cm	25cm	25~30cm
Nantou	195K+462	270K+000	1.5cm	15cm	20cm	25~30cm
Baihe	270K+000	358K+000	2.0cm	15cm	15cm	20cm

Pingtung	358K+000	431K+528	1.5cm	10~15cm	20~25cm	30~35cm

Table. 7-3 Asphalt Pavement Section Data of National Freeway No. 4, 5, 8, and 10

Freeway	Begin	End	OGAC	DGAC	BTB	SUBBASE
No.2	0K+000	20K+358	1.5cm	15cm	20cm	30cm
No.4	0K+000	9K+800	1.5cm	11cm	12cm	20cm
No.5	0K+462	53K+850	1.5cm	11cm	18cm	25cm
No.8	0K+000	15K+510	1.5cm	10cm	20cm	30cm
No.10	0K+000	33K+782	1.5cm	10cm	20cm	20~35cm

Table. 7-4 Lane Section Distribution Table – Using the Soft Pavement Between Keelung and Hsinchu on National Freeway No. 3

Section	mileage	Number of lanes	lanes	OGAC	DGAC	BTB	SUBBASE
Keelung–Xizhi section	0k+000 | 10k+100	3	1	1.5	10	20	35
			2	1.5	10	20	35
			3	1.5	10	20	35
Xizhi–Zhonghe	10k+100 | 32k+500	4	1	1.5	10	15	35
			2	1.5	10	25	25
			3	1.5	10	25	25
			4	1.5	10	25	25
		3	1	1.5	10	15	35
			2	1.5	10	25	25

			3	1.5	10	25	25
Zhonghe–Yingge Section	32k+500 | 42k+000	4	1	1.5	10	15	37
			2	1.5	10	15	37
			3	1.5	10	22	30
			4	1.5	10	22	30
		3	1	1.5	10	15	32
			2	1.5	10	22	25
			3	1.5	10	22	25
Zhonghe–Yingge Section	42k+000 | 62k+000	4	1	1.5	10	20	30
			2	1.5	10	20	30
			3	1.5	10	25	25
			4	1.5	10	25	25
		3	1	1.5	10	20	30
			2	1.5	10	25	25
			3	1.5	10	25	25
Yingge–Kanxi Section	62k+000 | 78k+000	4	1	1.5	10	15	25
			2	1.5	10	15	25
			3	1.5	10	20	20
			4	1.5	10	20	20
		3	1	1.5	10	15	25
			2	1.5	10	20	20
			3	1.5	10	20	20
Kansai–	78k+000	4	1	1.5	10	15	30

|		2	1.5	10	15	30
110k+000		3	1.5	10	20	25
		4	1.5	10	20	25
		1	1.5	10	15	30
	3	2	1.5	10	20	25
		3	1.5	10	20	25

Past Maintenance Data

The basic pavement data of the National Freeway Pavement Management System include daily construction logs. These logs contain material type, weight, and construction history. Data concerning all maintenance projects completed since the opening of the Guanxi construction section (construction data) collected by the Northern Area Engineering Office were digitized to facilitate overall lifecycle analysis. Fig. 7-1 shows that the 11.5 k southbound lanes of National Freeway No. 1 have been serviced three times.

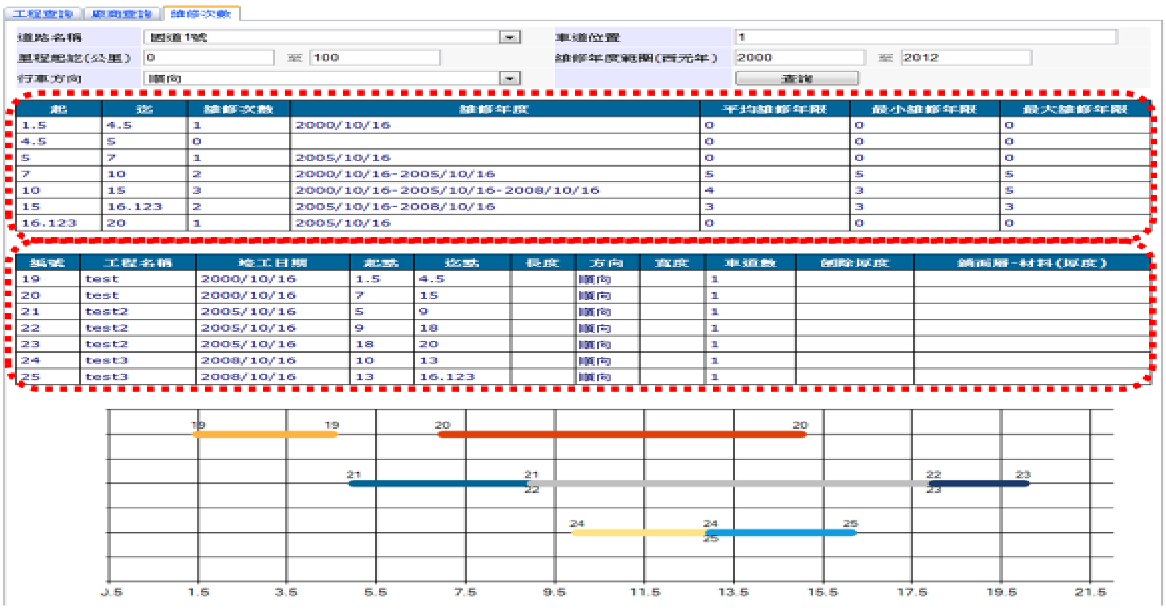


Fig. 7-1 Section Overall Lifespan Analysis

7.1.2 Establishment of Pavement Inspection Data

This paper inspected the current pavement conditions of the national freeways in Taiwan. A high-definition camera was employed to test the roughness of the pavement and capture road images. The images were incorporated into the proposed system to identify distress and evaluate distress severity and scope. The ASTM D6433 served as the pavement standards.

1.Roughness

IRI was used to test the pavement surface. This index realistically reflects the experience of road users. Three action values were established to determine whether the pavement required maintenance. They were .00<IRI<1.75, 1.75≤IRI≤3, and IRI>3.

2.Skid

National freeway sections with skid potential were analyzed using overseas regulations. The SN test outcomes were used to establish preliminary action values to determine whether the skid potential of specific sections was abnormal. They were 當 SN<35, 35≦SN≦43, and SN>43.

3.Deflection

Deflection reflects road resiliency. Deflection values obtained from a field survey were processed using rigorous inverse road intensity calculation criteria to obtain the intensities at various levels of the road section. A large amount of data collated and cross-referenced with the repetitive distress data of various construction sections. When a section achieves E3+E4≤220 Mpa and presents a high correlation with regularly maintained sections, this section is flagged. For future maintenance, the base and bottom layers of the section can be queried to check whether they are flagged. If a flag is confirmed, they traffic conditions of the section is evaluated for design.

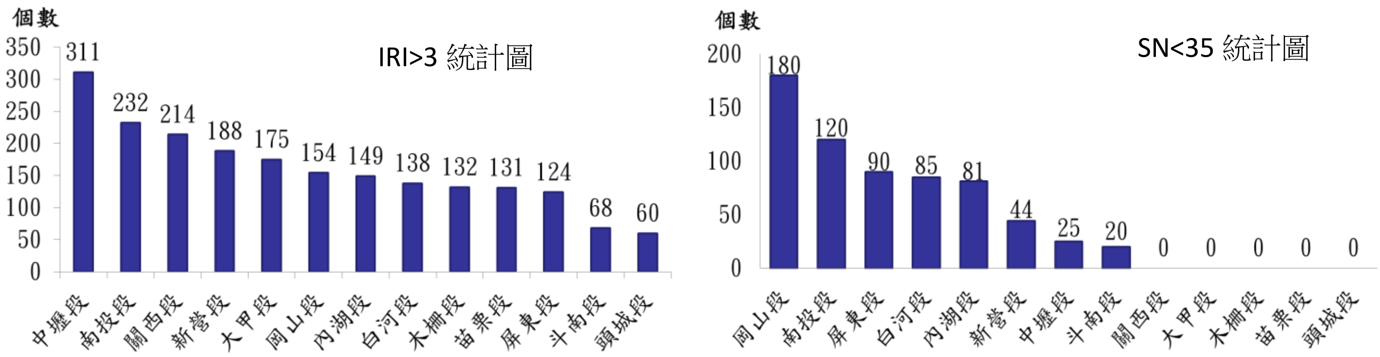


Fig. 7-2 IRI and SN Action Values Statistics

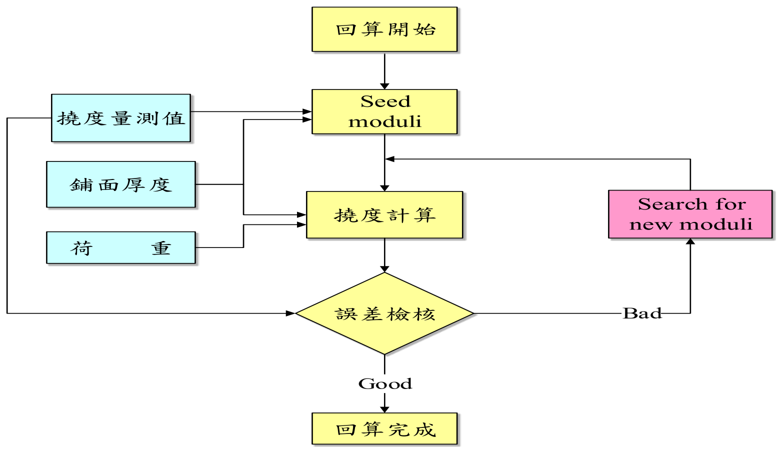


Fig. 7-3 Deflection Iteration Calculation Procedure

4. Pavement Condition Survey

The outcomes of the pavement condition survey revealed that the various construction sections were in excellent condition for road users. The majority of distress was in the form of cracks and ruptures, followed by fills. Overall, only a portion of the sections with repetitive distress show compression or depression.

5.Destructive Pavement Test

Repetitive reconstruction sections are an important component of maintaining national freeway pavements. Large teams are dispatched to the survey sites to commence destructive and non-destructive surveys. Drilling specimens are delivered to the laboratory to test the modulus of resilience. Outcomes are then analyzed to determine the road intensity of the survey site. The outcomes of ground-penetrating radar (GPR) using two frequencies were used to determine road anomaly (up to 4 meters below the surface). The modulus of resilience data and the GPR thickness data are used as key parameters during deflection calculation.

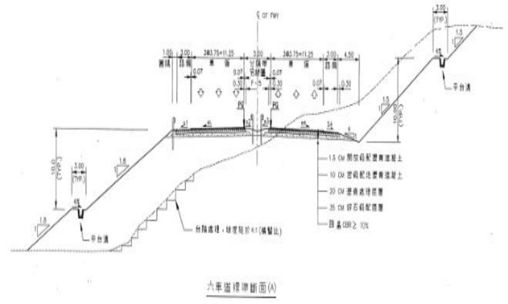
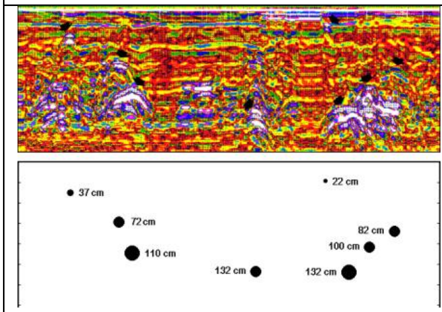
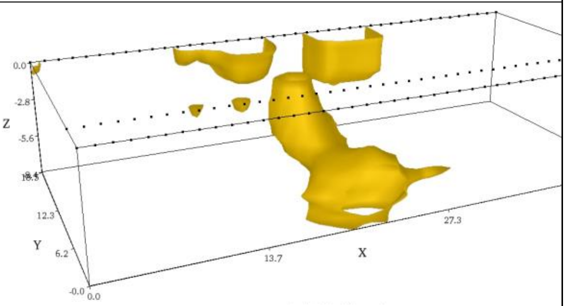
Step 1. New construction completion drawings, traffic volume/rainfall/maintenance data	Step 2. Pavement condition collection
	
Step 3-1. Comprehensive test – deflection	Step 3-2. Comprehensive test – destructive survey
	
Step 3-3. Comprehensive test – non-destructive survey	Step 3-3. Comprehensive test – non-destructive survey (3D)
	

Fig. 7-4 Project Survey Procedures

7.1.3 Establishment of the National Freeway Pavement Management System

An analysis was performed on the test data to determine the comfort, safety, structure, and fluency of the national freeway pavements. The, a pavement construction feasibility analysis was performed on the historical construction record data of the national freeways to observe the quality management during construction and post-construction effectiveness monitoring and review.

An APP for the National Freeway Pavement Management System was developed once the system was established. As a result of the changes in the natural environment (e.g., traffic, climate, and rainfall) and other factors, pavements often experience a number of different distress conditions, such as cracks, manholes, oil leaks, rutting, and potholes. Therefore, pavements must be regularly inspected to enhance their quality. A mobile APP with global positioning was developed in this paper for road users and inspectors. Road users can use the functions in the APP to upload the latest pavement conditions to the system. Inspections are performed using the latest information and uploaded to the National Freeway Pavement Management System. The system then suggests maintenance approaches and estimates maintenance costs, thereby enhancing inspection performance.

The following discussion is divided into the three modules of the system, specifically data input, system functions, and output application.

1. Basic Pavement Data Query and Construction Record Module

Construction record data were collated to develop a lifespan-based pavement management system. The system was used to evaluate the ranking mechanism for maintenance management, performance evaluation standards, maintenance management costs, and rationality of the quality standards. This module establishes the ledger data of national freeways and combines the ledger data with the rainfall and traffic data of specific corresponding sections. It uses the methods adopted by different maintenance projects to resolve problems and combines the ledger data with pavement condition images to rapidly obtain the index conditions of the selected section. The module represents data specific to the selected section, as illustrated in Fig. 7-5 and Fig. 7-6.

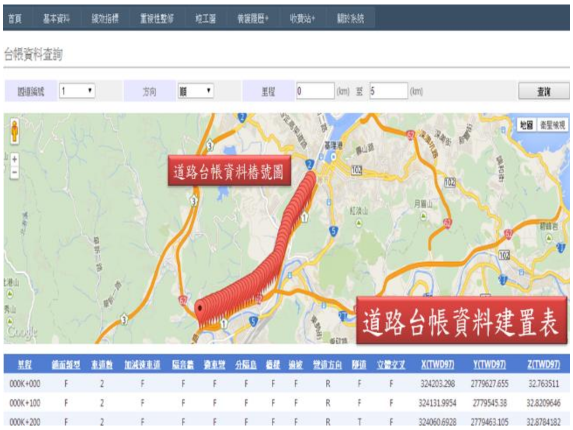


Fig. 7-5 Establishment of the Ledger Data for the Maintenance Freeway

Fig. 7-6 Rainfall Volume Query Module for the Maintenance Pavement

2. Pavement Performance Index Module

The main function of this module is to establish the various performance indices of the TANFB national freeways. These indices include PCI, CCD, FWD, SN, pavement texture (PT), and GPR. This paper re-evaluated, extracted, and omitted the abnormal data concerning the indices in the system. A foolproof mechanism was added to the automated import program to ensure the integrity of the imported images automatically. In addition, the program retains the capacity to expand the number of indices, as illustrated in Fig. 7-8. This greatly reduces the workload of the engineers. The module also utilizes the seven-in-one images in the National Freeway Pavement Management System to present relevant test data, as illustrated in Fig. 7-9. The seven types of pavement data are uploaded to the cloud system for integrated presentation and instant updating.

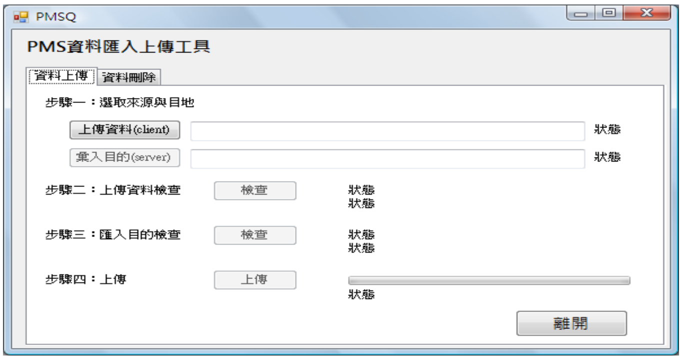


Fig. 7-7 Automatic Import of Pavement Performance Indices

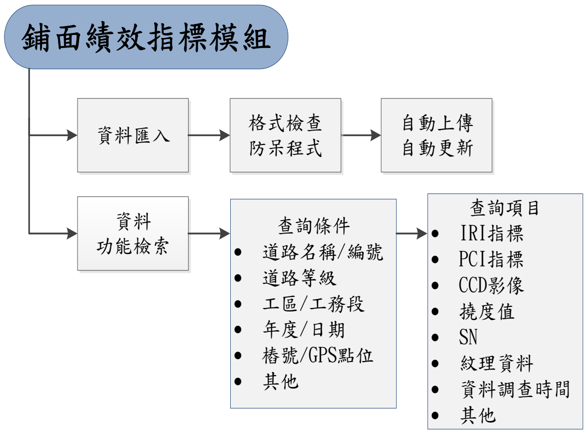


Fig. 7-8 Pavement Performance Indices Module Prototype

Fig. 7-9 Pavement Performance Indices Module Prototype

3. Maintenance Order Function Module

To enhance the practicality of the Maintenance Order Function Module, various methods and evaluation factors were adopted for road optimization and ordering. A literature review was conducted to analyze the existing factors concerning road maintenance optimization and ordering in Taiwan. The Maintenance Order Function Module was established based on the factors of maintenance cost, road roughness, traffic volume, and surface distress.

This module uses data from Google Maps for visualization. Different indices use different rating categories to present excellent sections, normal sections, and problematic sections. The system automatically formulates maintenance suggestions for sections with abnormal indices and presents corresponding reconstruction methods, estimated costs, pavement conditions, and index values, as illustrated in Fig. 7-10 and Fig. 7-11.

Fig. 7-10 Pavement Index Color Codes

Fig. 7-11 Reconstruction Methods and Estimated Costs for Sections with Abnormal Indices

4. Pavement Index Analysis Module

Database establishment is the first step for the acquisition of data in the National Freeway Pavement Management System. Statistical analysis models are then required to process the immense amount of data and formulate accuracy decisions.

a. Statistical Chart Automation

Automation functionality is included in the system to import relevant pavement indices and automatically export statistical charts automatically. This module also enables the system to query and export single sets of data concerning individual indices. Queries are divided into distance, station number, and segments to achieve dynamic segmentation, as illustrated in Fig. 7-12 and Fig. 7-13.

Fig. 7-12 Distress Distribution

Fig. 7-13 IRI Classification and Automatic Distress Report Output

b. Repetitive Reconstruction Sections and Construction Record Data

Tests concerning repetitive reconstruction sections include the drilling thickness test, water permeability test, rutting test, GPR test, roughness test, skid test, and pavement distress test. The relevant data are collated in the system and automatically exported. They are then presented to facilitate discussions concerning the maintenance of the selected section, as illustrated in Fig. 7-14.

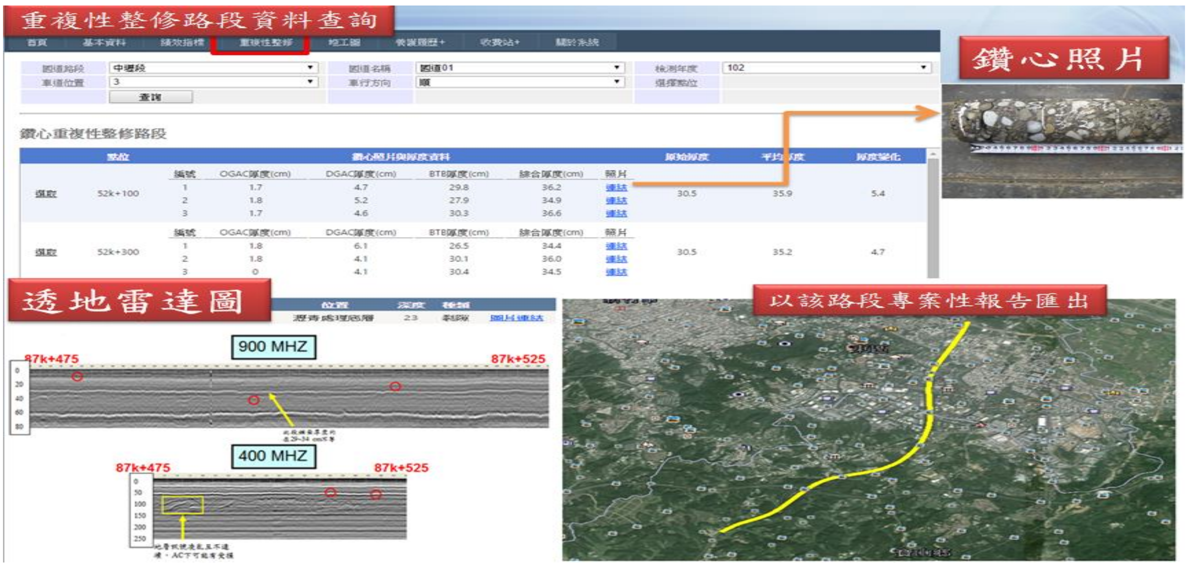


Fig. 7-14 Test Outcomes of Repetitive Reconstruction Sections

Tab. 7-5Input and Output Variables for the Functional Modules of the National Freeway Pavement Management System

National Freeway Pavement Management System Functional Modules	Database Establishment (Input)	System Function Output (Output)
1. Basic Pavement Data Query and Construction Record Module	Entering ledger data of all national freeway routes (10 data types including lane and shoulder data), GPS points (TWD97), and climate data	Selecting segmentation data and querying the ledger data for the specific section for application in later modules
2. Pavement Performance Indices Module	Entering annual national freeway IRI, PCI, SN, FWD, CCD, drilling, and GPR data	Acquiring seven-in-one data query table, including the IRI, PCI, SN, FWD, CCD, drilling, and GPR data of the selected section; performing statistical analysis of the selected section and obtain various tables
3. Maintenance Order Function Module	Entering IRI, SN, and CCD data	Selecting national freeway surface maintenance sections based on comfort and safety indices; combining the data with up-to-date CCD images to select maintenance openings
4. Pavement Index Analysis Module	Entering IRI, PCI, and SN data	Performing a statistical analysis on the pavement indices, illustrating the static segmentation data,

		and representing repetitive reconstruction project

7.2 National Freeway Pavement Graphics Module Management and Development

Pokémon GO is an augmented reality game on the mobile platform. The game enables gamers to capture, battle, and train virtual Pokémon in the real world.

Similarly, this paper aimed to incorporate graphical management applications into the National Freeway Pavement Management System, presenting the pavement indices using a graphical format. In this manner, both professionals and general road users can use the National Freeway Pavement Management System to understand the meaning of IRI, PCI, PT, and FWD.

7.2.1 Establishment of a 3D Pavement Network

In the past, the National Freeway Pavement Management System only provided a 2D view of the road network and data import and query functionality, as illustrated in Fig. 7-15. This paper aimed to convert past road network and basic pavement data into 3D representations, as illustrated in Fig. 7-16.

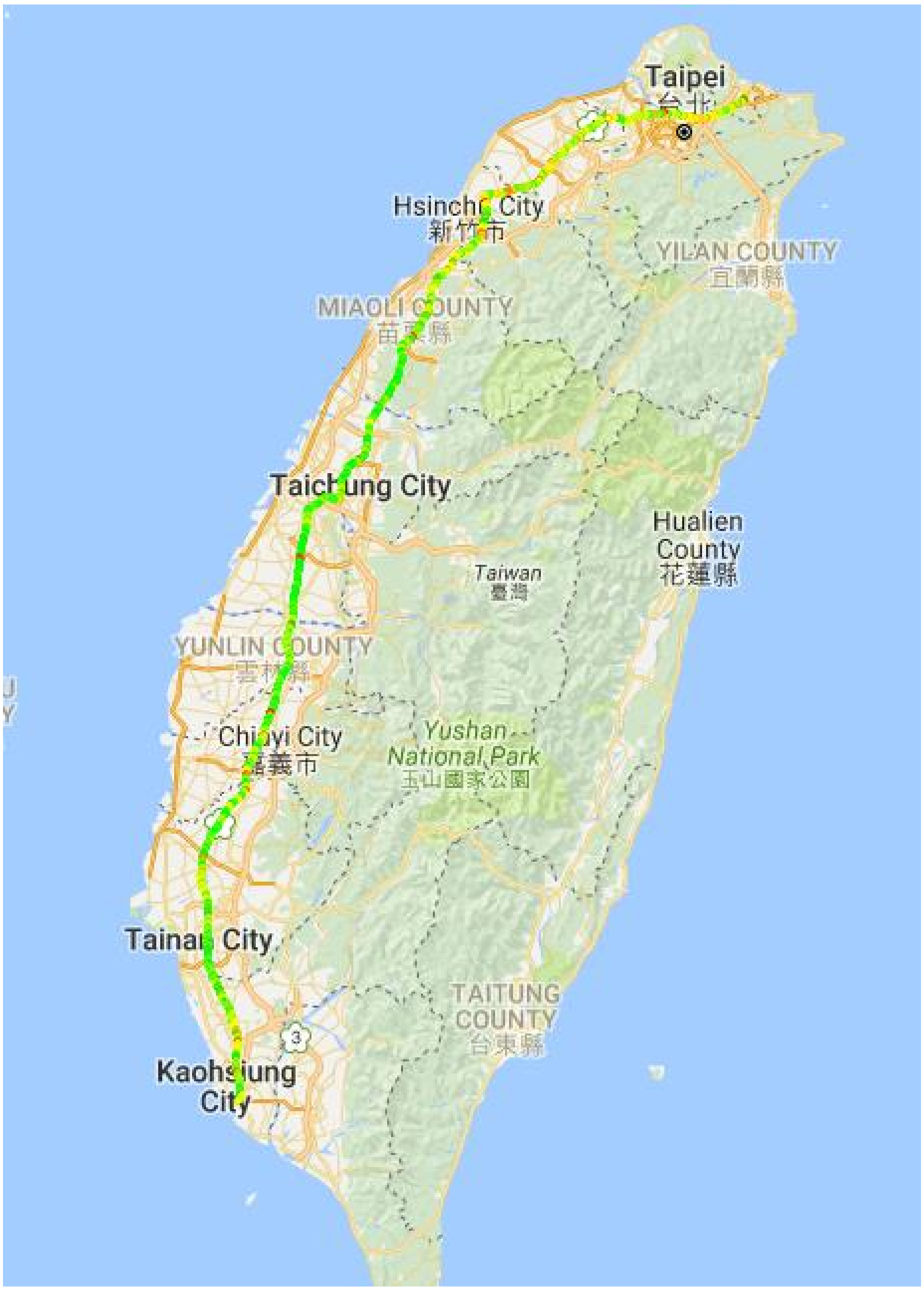


Fig. 7-15 Road Network of the 2D System

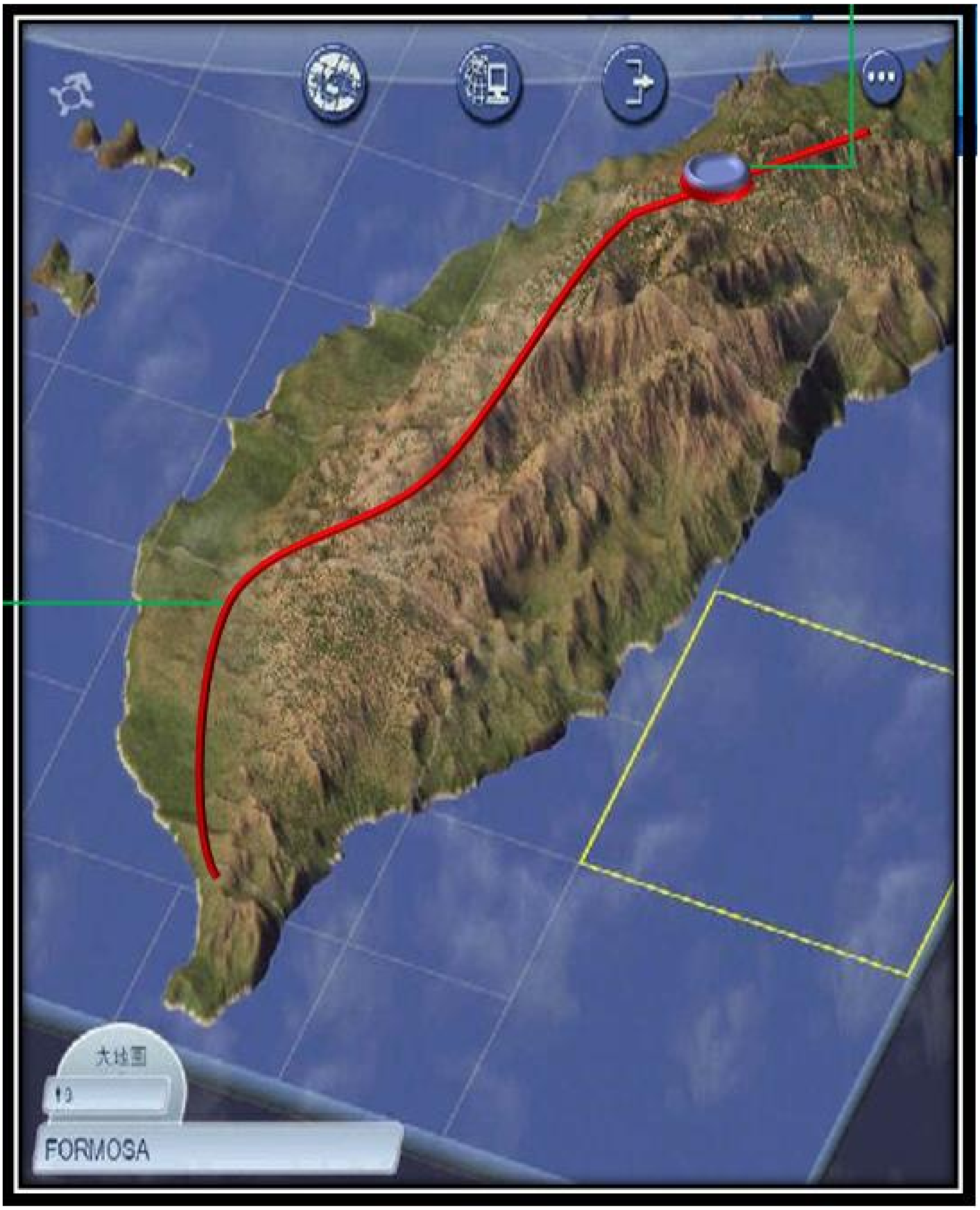


Fig. 7-16 3D-Rendered Road Network

Pavement section data were also converted from 2D to 3D to achieve graphical management, improve the overall effectiveness of the plan and design evaluations, present accurate construction progress during pavement construction, and effectively import data and archive recorded data during the establishment of maintenance records.

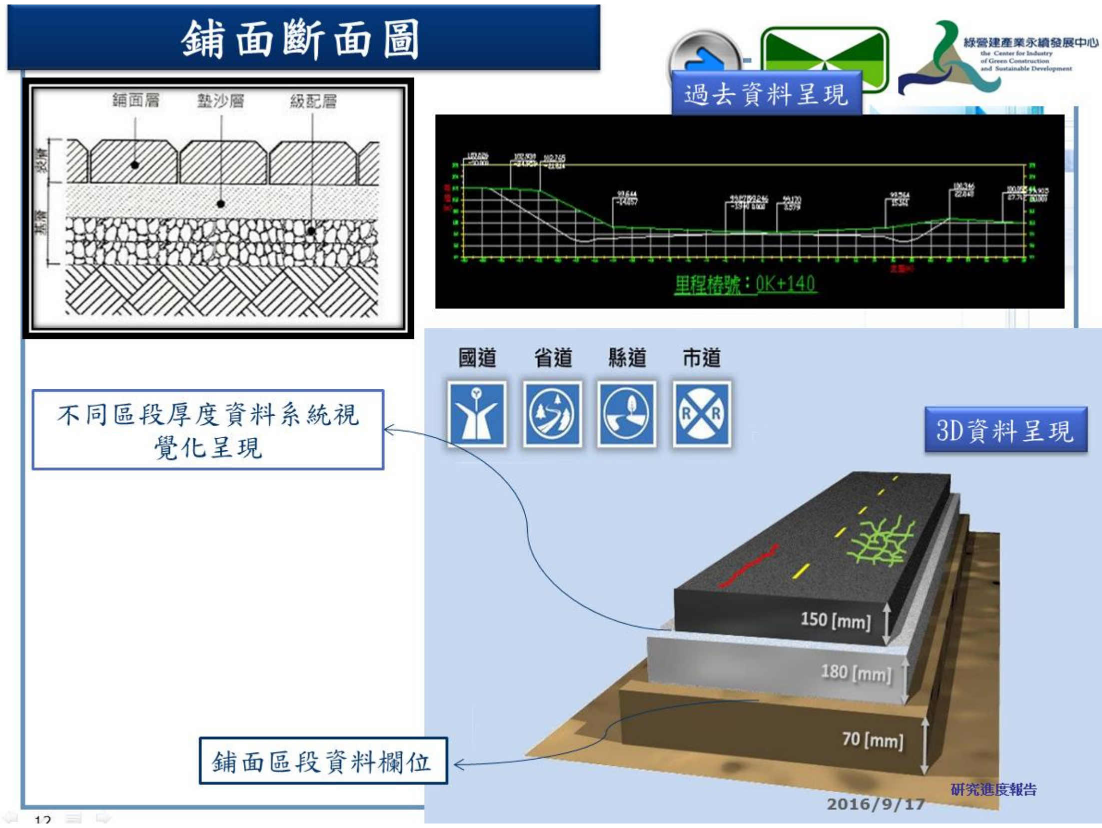


Fig. 7-17 3D Pavement Section System

7.2.2 Graphical Management of Pavement Indices

A database for the pavement indices in the previously developed National Freeway Pavement Management System was established. The data were then categorized and managed by graphics modules. The purpose of this process was to enable users to more quickly and effectively use the National Freeway Pavement Management System and enhance management performance. The IRI, PCI, and SN indices, as well as overall pavement conditions, were visualized and analyzed.

1. IRI Visualization

IRI data were analyzed using a laser tracker and stacked to form a 3D image, enabling users to rapidly view the flatness of different road sections using this module. Users can select a layer of the pavement in the 3D image to view the IRI value of the layer and obtain the recommended traveling speed for the section. The 3D information was used to develop a driving APP, as illustrated in Fig.7 -18.

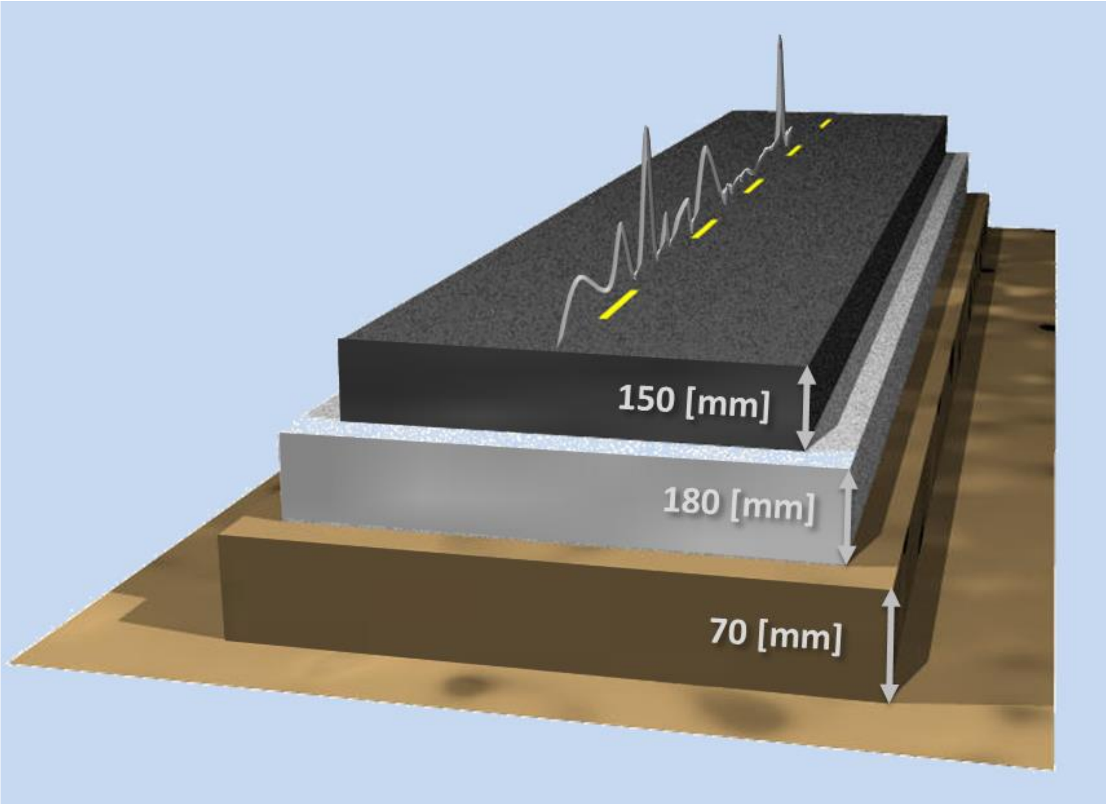


Fig. 7-18 IRI Obtained Through Dynamic Driving Simulation

2. PCI Visualization

PCI data were analyzed using a CCD camera and stacked to form a 3D image, enabling users to rapidly view the pavement distress conditions of various sections using this module. Users can select a layer of the pavement in the 3D image to view the PCI value of the layer. The 3D information was used to develop a driving APP, as illustrated in Fig. 7-19.

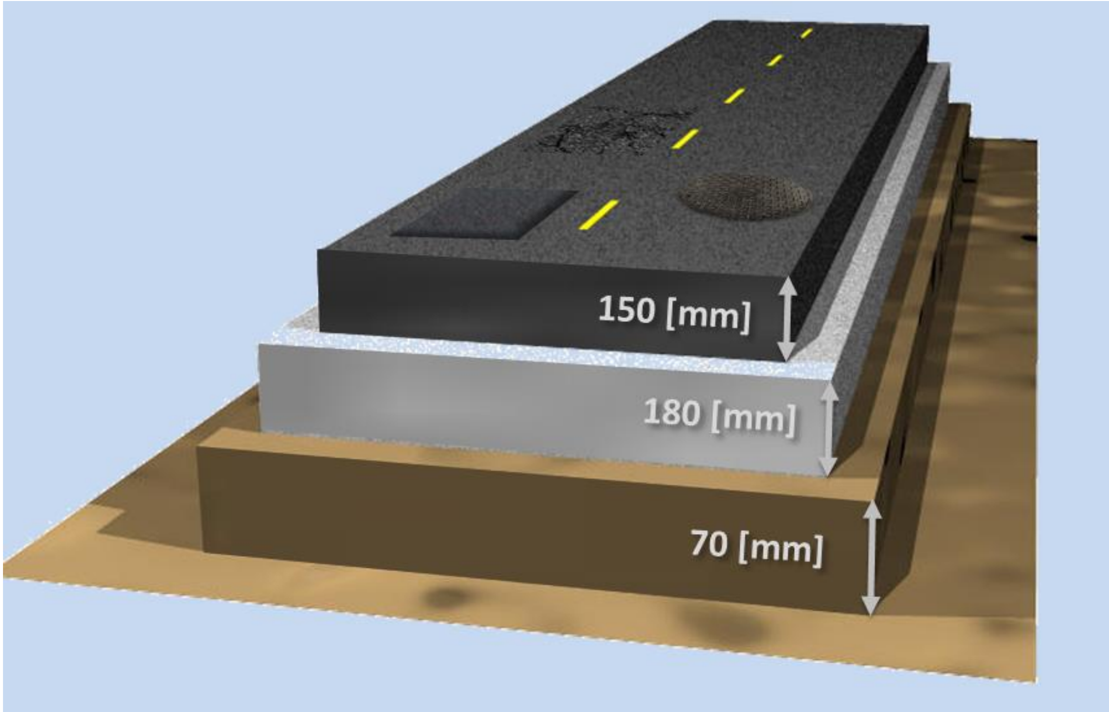


Fig. 7-19 PCI Obtained Through Dynamic Driving Simulation

3. SN Visualization

PT data were analyzed using a laser tracker and stacked to form a 3D image, enabling users to rapidly view the PT conditions of various sections using this module. Users can select a layer of the pavement in the 3D image to view the SN value of the layer. The 3D information was used to develop a driving APP, as illustrated in Fig. 7-20.

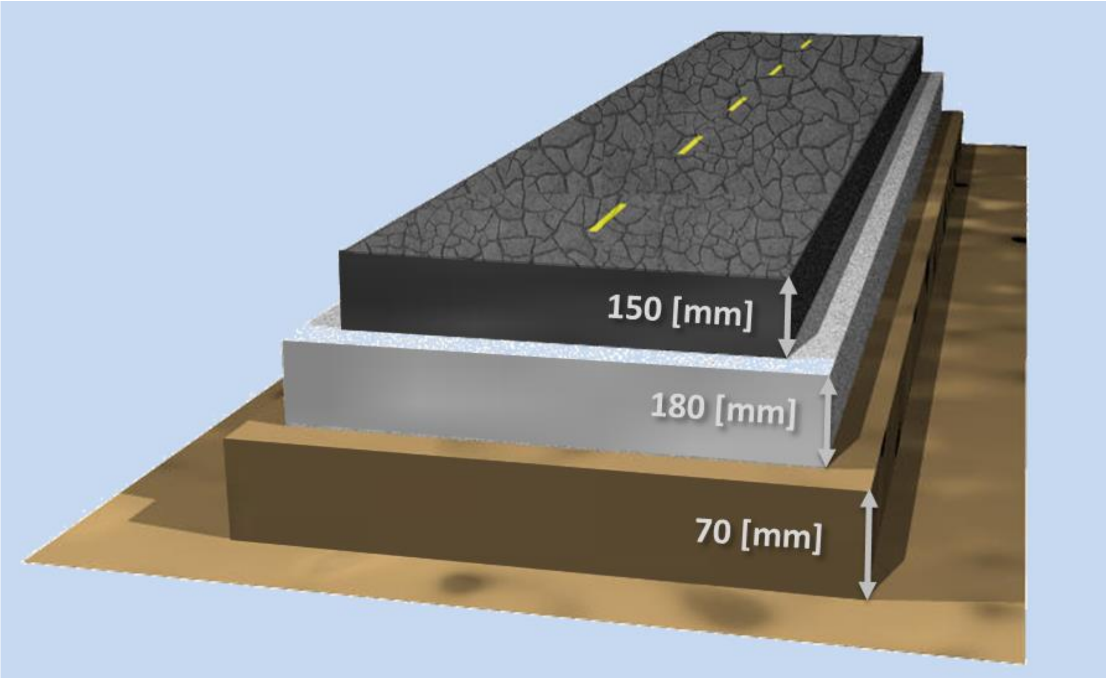


Fig. 7-20 PT Obtained Through Dynamic Driving Simulation

7.3 National Freeway Pavement Graphical Management Through APP Development and Application

Amidst the global prevalence of mobile APPs, this paper endeavored to develop an APP specifically for pavement management. Through graphical representation, the APP transforms pavement maintenance into a national movement, thereby achieving sustainable operations.

This paper aimed to mobilize the National Freeway Pavement Management System and develop a multifunctional APP to create an integrated platform centered on the National Freeway Pavement Management System. This APP can then be used to enhance pavement management performance. It can be applied to pavement inspections to automatically organize test data and upload the data to the National Freeway Pavement Management System.

1. First, the functions of smart inspection vehicles were analyzed. These functions were incorporated into the APP. The APP was then applied to a field survey to test its functions. The test data were uploaded to the National Freeway National Freeway Pavement Management System and cross-referenced with historical data.

2. The functions of previous inspection APPs were reviewed. Functions with favorable utility were retained and incorporated into the National Freeway National Freeway Pavement Management System for recommending maintenance methods and estimating maintenance costs and developing a multifunctional inspection APP.

3. The module functions of the National Freeway Pavement Management System were improved, and the integrity of historical road data was ensured. The sorting and analysis module of the National Freeway Pavement Management System was used to analyze the IRI, PCI, and ESALs indices to generate a comprehensive index. This index was coupled with GPS navigation to develop an APP that plans routes based on road comfort.

7.3.1 Development and Application of the Graphics System for the Road Users' Driving APP

To design an inspection APP different from existing APPs used by the various city and country governments, two interfaces were designed for the proposed driving APP, the one for road users and the other for competent authorities. Extant inspection APPs largely focus on capturing the images of distress points. A review of the success of Pokémon Go indicated that expanding the system to include general users can enhance the effectiveness of pavement management. Functions relating to PCI were developed based on road user application. The driving interface is illustrated in Fig. 7-21.

Fig.7-21 Pavement Condition Management Interface of the Road Users' Driving APP

The GPS points are updated while driving, and the APP functions change, accordingly. The type and distance data of the distress ahead are presented on the left of the interface. The distance of the distress point is updated as the vehicle continues to approach the distress point, as illustrated in Fig. 7-22.

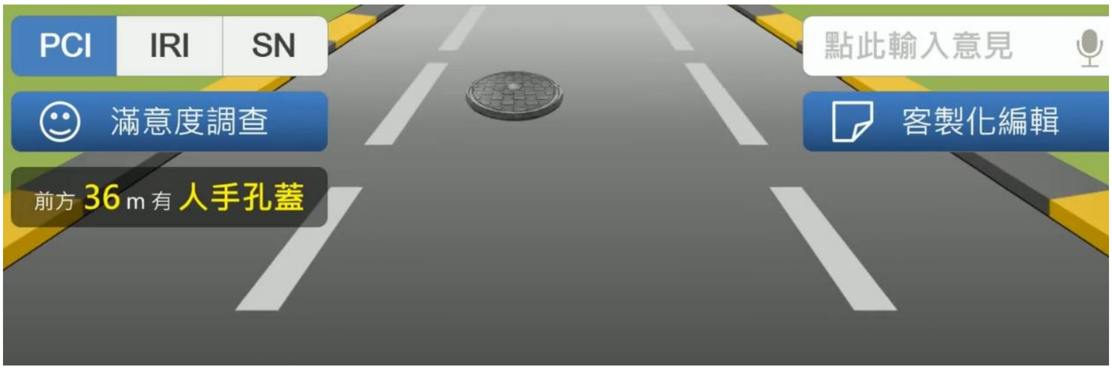


Fig. 7-22 Pavement Distress Notification of the Road Users' Driving APP

Customized settings enable the passenger or driver to select the distress point. Once a distress point is selected, the user can set the distress type and severity. The distress data of the road section is then instantaneously updated, providing the next road user with updated pavement condition, as illustrated in Fig. 7-23.

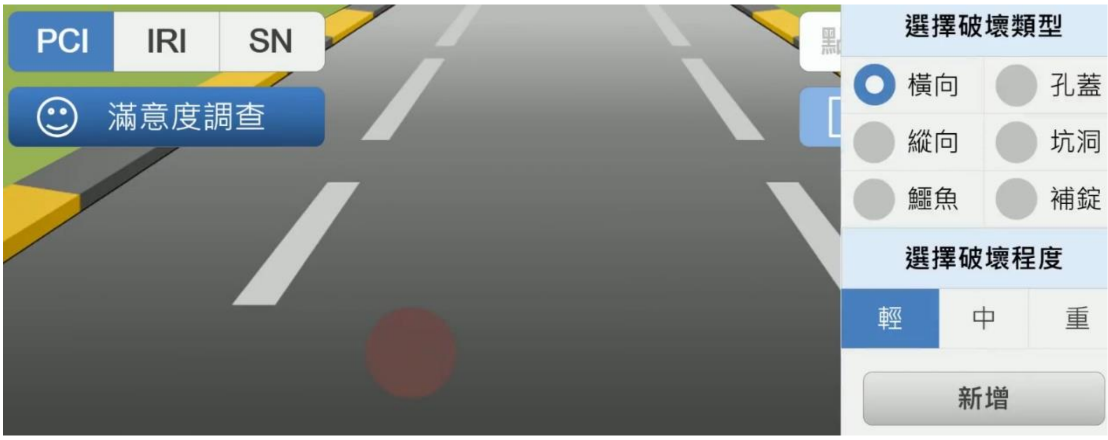


Fig. 7-23 Pavement Condition Customization of the Road Users' Driving APP

The APP also provides a satisfaction survey for the pavement recommendations. Currently, the user is able to choose between "satisfied" and "unsatisfied." In future, this paper will perform an AHP analysis to examine different scoring intervals and create a comprehensive satisfaction scale. The current satisfaction options are illustrated in Fig. 7-24.

Fig. 7-24 Satisfaction Survey on the Pavement Conditions Using the Road Users' Driving APP

7.3.2 Competent Authority's Driving APP Graphics System Development and Application

The functionalities of the competent authority's driving APP primarily center on management. It uses the latest information updated by road users for statistical analysis and presents information pertaining to the main distress in the current month, overall maintenance cost in the current month, average maintenance time, PCI values, and the proportion and severity of different distress types (Fig. 7-25).

Fig. 7-25 Pavement Condition Image Presented in the Competent Authority's Driving APP

When driving, the passenger selects the distress points to obtain the distress information. Using the below figure as an example, tapping the manhole cover presents the distress information, date of distress, maintenance vendor, maintenance time, and maintenance cost.

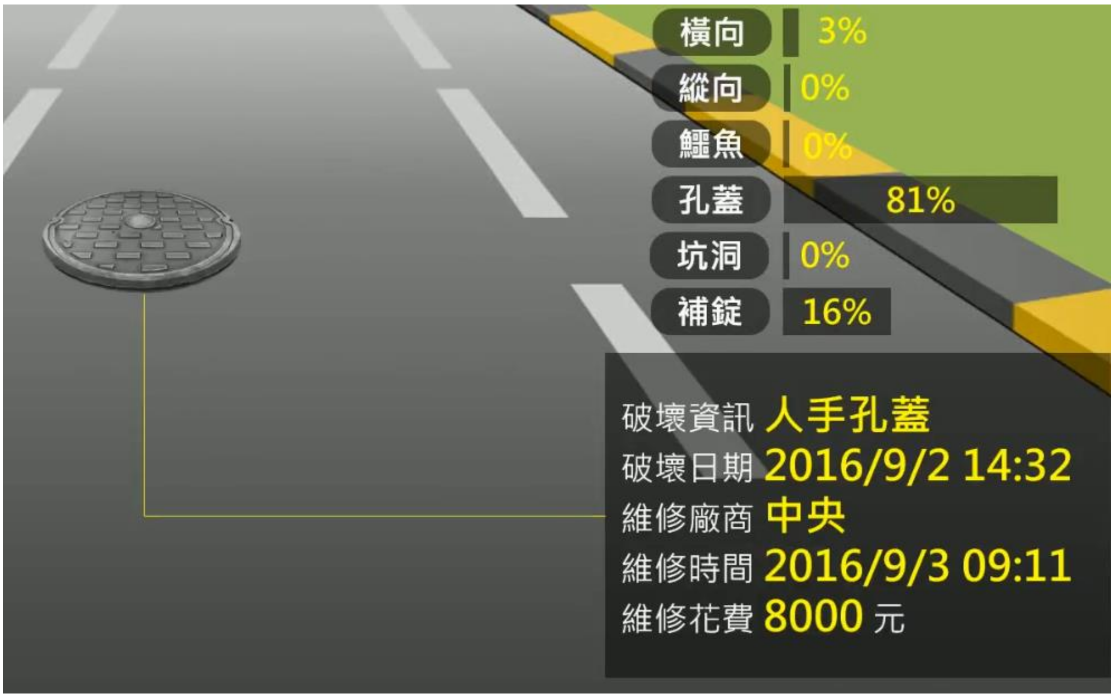


Fig. 7-26 Pavement Distress Information Displayed in the Competent Authority's Driving APP

7.4 Software operation

Kingsu PIS can explain the destruction information in detail every day according to the desired date as shown below. We can find out from different manufactures and various machines, and will be displayed the number of serious damage, potholes, and destruction of the manufacture.

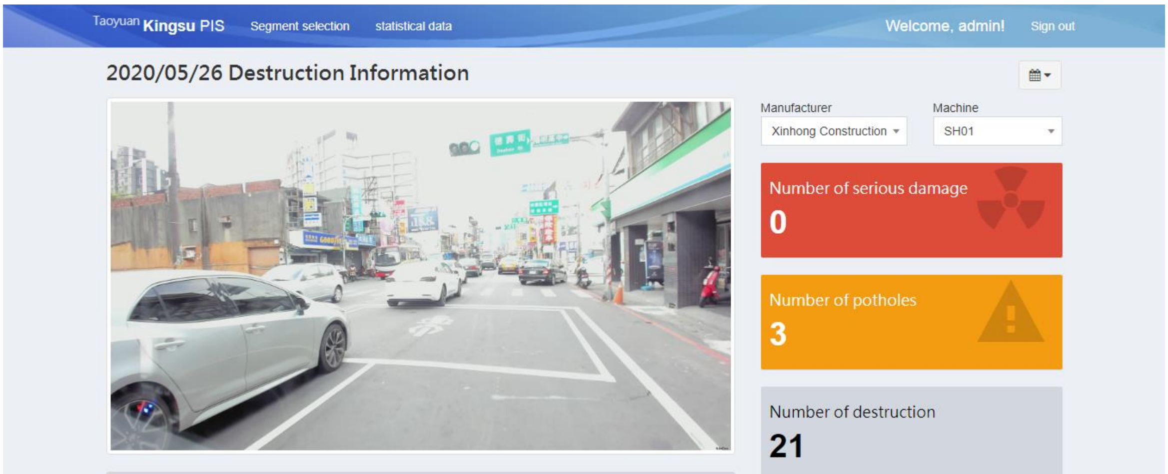


Figure 7-27 Display of Destrcution Information in Region

From the destruction of information above according to one of the manufactures that you want to know, below it also explains the last update position on that day, as well as the location in the form of maps that can be seen clearly.

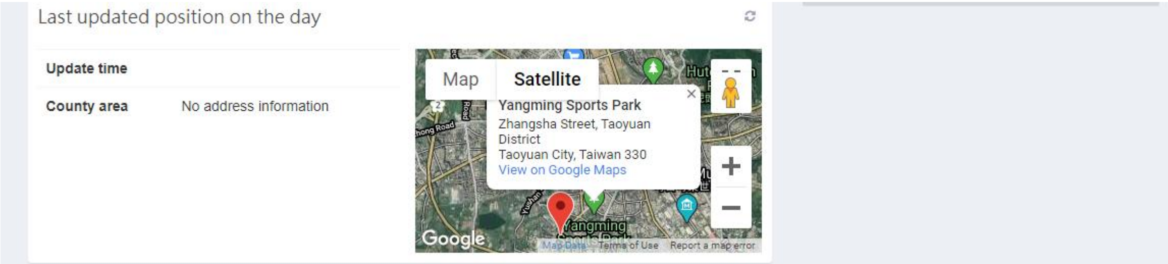
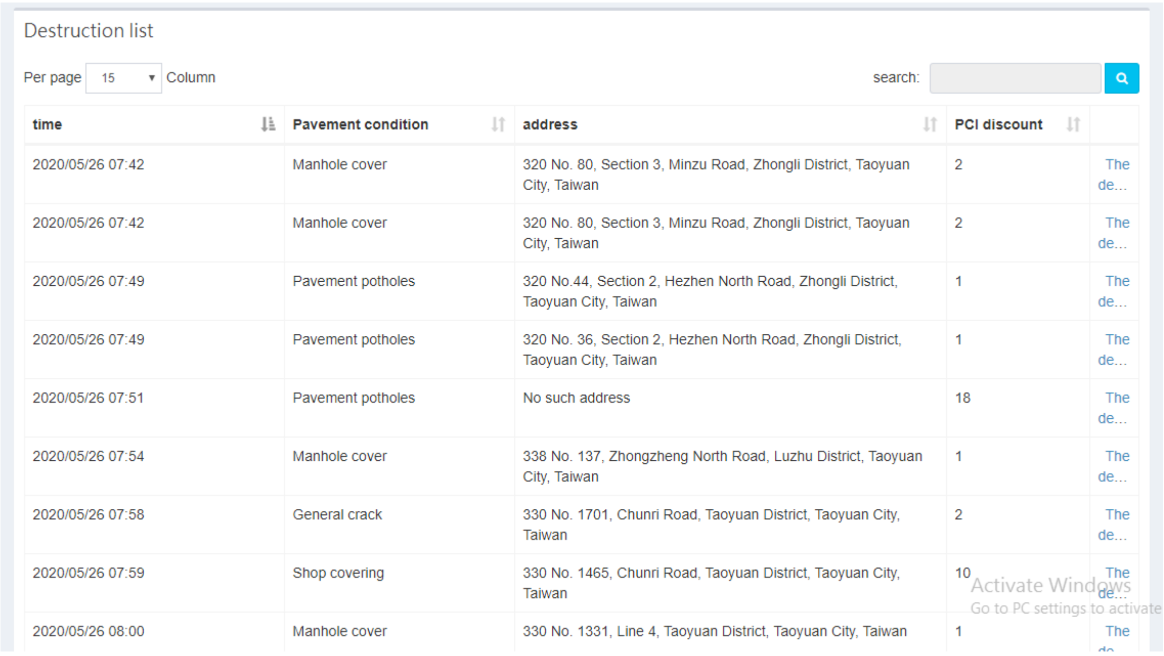


Figure 7-28 Map of choosen area

There is a destructive list that explains the time, pavement condition, address, and PCI discount. Several types of pavement conditions described include manhole covers, pavement potholes, general cracks, and shop covering.


Destruction list

Per page 15 Column search:

time	Pavement condition	address	PCI discount	
2020/05/26 07:42	Manhole cover	320 No. 80, Section 3, Minzu Road, Zhongli District, Taoyuan City, Taiwan	2	The de...
2020/05/26 07:42	Manhole cover	320 No. 80, Section 3, Minzu Road, Zhongli District, Taoyuan City, Taiwan	2	The de...
2020/05/26 07:49	Pavement potholes	320 No.44, Section 2, Hezhen North Road, Zhongli District, Taoyuan City, Taiwan	1	The de...
2020/05/26 07:49	Pavement potholes	320 No. 36, Section 2, Hezhen North Road, Zhongli District, Taoyuan City, Taiwan	1	The de...
2020/05/26 07:51	Pavement potholes	No such address	18	The de...
2020/05/26 07:54	Manhole cover	338 No. 137, Zhongzheng North Road, Luzhu District, Taoyuan City, Taiwan	1	The de...
2020/05/26 07:58	General crack	330 No. 1701, Chunri Road, Taoyuan District, Taoyuan City, Taiwan	2	The de...
2020/05/26 07:59	Shop covering	330 No. 1465, Chunri Road, Taoyuan District, Taoyuan City, Taiwan	10	The de...
2020/05/26 08:00	Manhole cover	330 No. 1331, Line 4, Taoyuan District, Taoyuan City, Taiwan	1	The

Figure 7-29 Destructive list of pavement condition

According to the destructive list below, a detailed material explanation can also be obtained, equipped with maps of the exact location, location pictures, and real conditions in the form of photos, as well as more complete information.

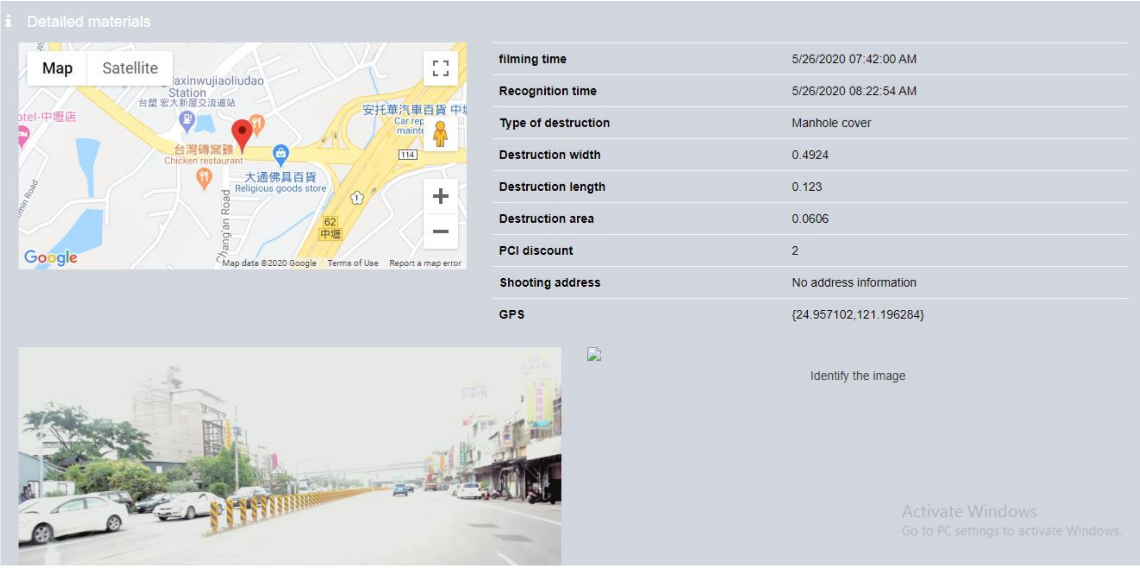


Figure 7-30 Detail material and picture

The user can also access in the form of maps that can show details of what road works are taking place in figure 7-31 such as pedestrian underpasses or land bridge entrance, road patrol, danger sign, etc. at one location throughout Taiwan and all destruction or just want to know the damage to the pavement from which points can be selected in the figure 7-32, and accurate position can also be detected and known in figure 7-33.

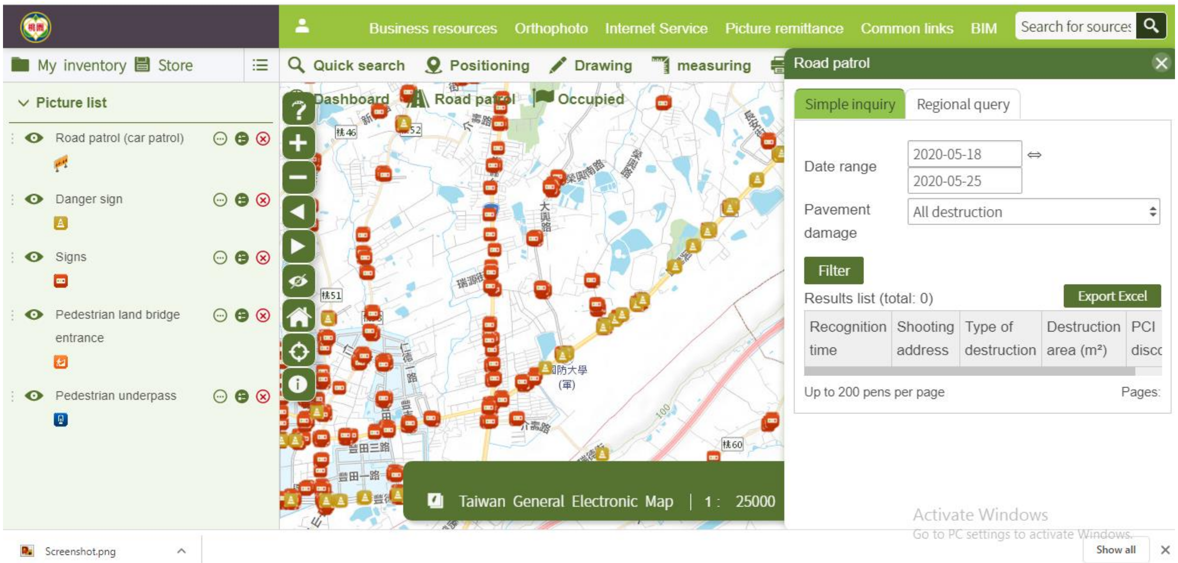


Figure 7-31 The display of maps with road sign

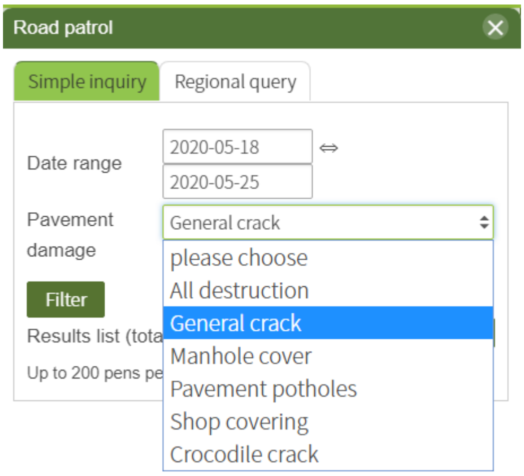


Figure 7-32 Pavement damage

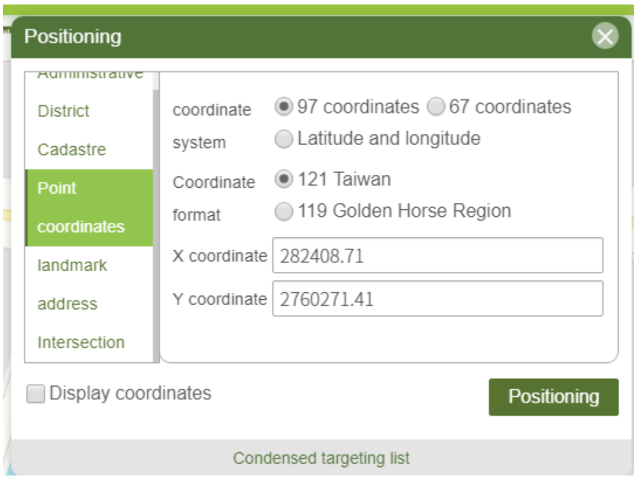


Figure 7-33 Position of choosen location

Chapter 8. Conclusion

1. The present study estimated pavement performance indicators (i.e., the IRI, ESALs, SN, and PCI) employing the SCSV method. Each parameter was entered one by one and brought together using seven different models. This resulted in a predictably high success rate to the value of the IRI. Many highway agencies have the equipment necessary to take IRI readings but are unable to afford the personnel that such readings require. The proposed model allows the state of pavement to be estimated at present and in the near future in assisting scheduling maintenance projects. The proposed scheme is designed to minimize CO_2 emissions for a set quantity of repair materials. Likewise, the proposed scheme can be used to extend the length of road that could be repaired for a given amount of CO_2 emissions. Decision makers can determine whether to enhance the efficiency of road work or to lower CO_2 emissions according to the results of the analysis. The proposed model could be generalized to a wider range of situations by including a wider range of traffic data, pavement structural properties, and roughness indices.
2. The study collected all raw material carbon emission factors from all over the world within a range, a reasonable inference is that due to different carbon emission factors used throughout countries. Cement concrete products carbon emissions maximum impact factor is a product of cement material, if the proportion of the same design under the intensity of the nature of their works, if you can increase the volume of cement material is replaced with the highest minus carbon benefits.
3. Concrete itself in the production must be on to use more attachment, but differences can cause the resin itself less carbon effects and therefore to a larger overall product carbon emissions, 280kgf/cm2 concrete per ton of carbon emissions reduced 384.73 kg Co2-e/m3 to 311.73 kgco2e/m3 about 72.99 kgco2e/m3 of approximately 18.97%.
4. The game comprises nine asphalt vendors and the terms and conditions of their contracts. They were Zhong Jian, Da Shan, He Feng, Wei Yong, Sheng Gong, Lu Sheng, Zhi Sheng, Xin Dao, and Ying Tai. Although Ying Tai was the closest vendor to the construction site, Zhi Sheng achieved the most favorable strategy selection performance, with a competitive total construction cost of NT $50.34 million.
5. Technological research and development, innovative civil engineering

The original intention of the R & D team is to cooperate with the organizer of the happy road leading you, through the application of innovative technology to achieve the most immediate and effective service and management.

In addition to the original application of conservation functions, this technology will provide additional value-added services in APP development, after capturing the image data provided by the vehicles inspected daily in all work areas and the acceleration and deceleration speeds, the data will be available for use in smart transportation around the island, including:

A. Route:

Integrate the query data of inspection vehicles across Taiwan into comprehensive census data and integrate monthly data updates, the latest route information will be available to cooperate with the county and city government traffic bottleneck plans.

B. Road network:

Road network information will cooperate with the inspection system build with different base maps such as GIS, Google, etc. Different layers of systematic information data updates in real-time, and queried and applied by the corresponding unit.

C. Attractions:

Attractions services will be complemented by the inspection track route of each inspection vehicle, carry out planning for daily attractions, traffic flow, and personnel flow, enter data into APP module for reference applications, and plan to integrate with the Tourism Bureau for the rapid delivery of scenic materials, the efficiency will be comparable to Uber Eats.

D. Traffic guidance:

Traffic flow dredging function will cooperate with the traffic bureau and police department's network monitoring system interface, feedback on real-time road conditions and driving speed data, provide dredging plans to reduce traffic load.

E. Management:

In the management of roads, it has always been a pain of the organizer, therefore, the real-time management of this system will greatly reduce the number of engineers on the field, replaced by real-time functions and dispatch processing on the management system, each government employee will save hours of time and resources every day on average.

F. Facilities:

The direction of subsequent research will be introduced into the application of asset management, to save the annual budget by taking the content of the asset management application as the resource management of the road and its auxiliary facilities, and conduct real-time surveys and establish a database of infrastructure status.

6. Less impact on existing systems:

   The content project developed by this plan is to develop a complete set of software and hardware systems and opening inspect contracts of various units to cooperate with the existing annual plan of each road authority, the main purpose is to reduce the impact of using the interface. Field inspectors should understand the gap of their institutional and practicals during the process of education and training, to achieve the quality of civil engineering construction and supervision staff.

7. Information communication, engineering integration:

   Integrated management system, database, responsive website, and other systems to overcome and deal with in the information side. The hardware part integrates GPS, WIFI, charge-coupled device image, wireless communication, and other functions into a single system through the latest 5G communication application. In this way, the advantages of lightness and easy operation will be achieved in civil engineering, which has not applied a number of technology products yet.

8. Business units, manpower lean:

   Business units will no longer manage a large number of acceptance record forms, status information of all damage patterns, locations, sizes, lengths, areas, PCIs, etc. will be queried at the database, provide data, analysis report downloads in need. This will effectively save time for business units to organize data, the management of the acceptance record will also be more objective, faster.

9. Inspection vendors and improvement of performance:

Inspection vendors will no longer be the original inspection model, originally co-pilot do paperwork of status records, now transferred to be office staff and lesser worker required, the rest of the workers will be dedicated to the rest of the project work to enhance the overall corporate image and performance management, to achieve the goal of lean management.

10. System functions and expansion applications:

    In addition to the damage of the original road image recognition system, markings, sidewalk trees, sidewalk damage, and road ancillary facilities are added for AI operation training, to achieve comprehensive infrastructure maintenance management, its functions and database are reserved for reference and application expansion.

11. Savings budgets:

    The application of this system can save a total of more than 1.5 million NT dollars per year in one working area. There is about 200 working area in Taiwan, this can save up to 300 million NT dollars of public budgets. Therefore, the effective introduction of information technology in civil engineering will be the direction of development in the years to come, achieve the goal of smart road, smooth road, and safe road.

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