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Application of Information Management System Approach in Airport Pavement Maintenance Strategy Selection

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ABSTRACT

The modern airport applied the airport pavement management system（APMS） to enhance efficiency of maintenance. Selection of repair strategy is one of the most important tasks in APMS and a suitable repairing strategy would once for all guarantee that needed repairs to be carried out at the right time. Normally the repairman would follow the advice of the expert and execute a set plan designed previously based on the past experience and know-how acquired by those experts and some on-site situations. Nevertheless, it is not rare in practical situations that the repaired pavement becomes damaged again soon and it says the former strategy is not adequate to solving the problem or material is definitely called for. This study also has taken advantage of a machine learning theory of neural network, by means of an expert questionnaire, and through special case study and integration to accumulate relevant knowledge to facilitate the making of better than ever proper strategies when the need presenting itself in the future to make repair suggestions. One part of this study we have added a feedback learning function to the system concerning repair materials. This will enable the system to keep a non-stop upgrading process to assure the optimal suitability of those materials.

Keywords: airport pavement management system, neural networks, maintenance strategy

運用資訊管理系統於機場鋪面維修策略選擇之研究

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摘　　要

現代化機場已逐步採用機場鋪面管理系統(APMS)，其維修策略的選擇是一個重要的部分，以確保維修成效的保證。通常鋪面維護人員會依照專家的經驗與知識，並根據現地現況，找出造成鋪面破損的原因和提出建議維修破損的策略；然而，在實務上常看到維修後再破損的例子，顯示先前選擇的維修策略不能有效修補鋪面。機器學習在土木工程專家系統之應用深具研究價值，可以解決知識獲取不易的問題。本文利用類神經網路機器學習的方式，藉由成功或失敗的案例，經由案例的學習與歸納，累積知識，以期日後針對現地破損進行建議維修時，更能選擇出適合的策略，確保鋪面服務績效。

關鍵字：機場鋪面管理系統、類神經網路、維護策略

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I. INTRODUCTION

With emergence of e-commerce, global logistics management came into being, air transportation has its fast and convenient property, and in particular has indispensable role in management of supply chain and rapid response, while airport air transportation node, safe and efficient operation of airplane on airport taxiway and runway and parking apron, shall be an element modern airport resource planning management; although Taiwan has fewer rigid pavements than flexible pavements, most of them were distributed in crucial traffic locations such as airport, highway toll station, tunnel, playing very important and crucial role in traffic transportation [1]; but prolonged usage of rigid pavement would inevitably lead to damage, if such damage were not repaired in time, and allowed to deteriorate, it would lead to increased difficulty and repair cost of later repair, or even airport airplane operation shutdown, and further affect logistics smoothness, and reduce realtime function of supply chain. Therefore how to repair damaged pavement rapidly and efficiently is a very important issue of pavement maintenance personnel.

Selection of repair strategy is an important element of airport pavement management system; appropriate repair strategy is guarantee of repair effect. Usually pavement maintenance staff will find out of expert experience and knowledge, and based on field status, the cause of pavement damage and recommend damage repair strategy; nevertheless, it is often seen in practical situations that the repaired pavement becomes damaged again, indicating that pavement cannot be well repaired by means of previously selected maintenance strategy, it has to be repaired in other method or with other material, to ensure service effect of repaired pavement. This paper used artificial neural network machine learning theory and expert questionnaire investigation approach to learn from and generalize cases, build up knowledge, so as to select more appropriate strategy to guarantee pavement service effect, in case of recommending repair of field damage later. Taking account of repair material creativity and fittability, this paper established repair material feedback learning function so that the system can keep learning with time to ensure repair material fittability.

II. STUDY OF ARTIFICIAL NEURAL NETWORK IN TAIWAN AIRPORT RIGID PAVEMENT REPAIR

Oversea studies of artificial neural network in pavement repair had resulted well, artificial neural network model was successfully applied to recommend pavement repair method, but recommended repair strategy shall in fact include recommended method and material, while current artificial neural network model based pavement repair system only recommended repair method, not recommended appropriate repair material [2-8], if pavement field engineering staff use inappropriate material, even in correct method, failed cases will be frequent, therefore this study considers method and material in combination, conducts machine learning of method and material,in order that constructed system will help field pavement staff more.

Although conventional expert system has transparent knowledge, tough issue often occurs when adding or changing knowledge, hence this paper collects knowledge by means of machine learning. While in Taiwan pavement repair industry, there is not many types of pavement repair methods, and over several decades, repair methods pavement maintenance staff choose change little, it is predicted that, in next decade, optional methods for engineering staff will not change much; contrarily in the case of repair material, due to furious development of material, as well as material performance and repair staff application skill, and environment, various region or experts have different comments on each kind of material. Therefore this study also considers variable of repair material, in order to feedback training artificial neural network model for repair material construction, not only keep feedback training neural networks, but can add new material to network training.

This paper adopted artificial neural network machine learning model to construct a prototype expert system suitable for Taiwan airport rigid pavement repair, and adopted the most popular and representative reverse-transmission artificial neural network for learning; when recommending repair

strategy in this paper, there were primarily two parts, recommended repair method and recommended optional repair material, thus expert systems constructed by means of artificial neural network were also divided into two models, the first model was to recommend appropriate repair method to user, after user chooses a repair method, the system would recommend, according to inference of the second model, appropriate repair material under such method to user. Flow chart of artificial neural network recommended repair strategy module was shown in Fig. 1.

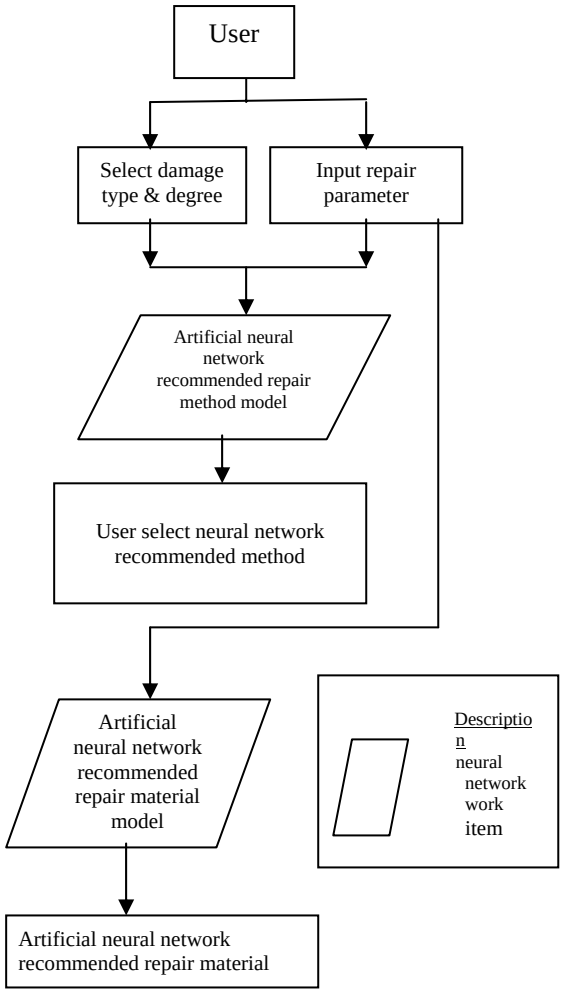

Fig. 1. Flow chart of artificial neural network recommend repair strategy module

III. CONSTRUCTION OF ARTIFICIAL NEURAL NETWORK OPTIONAL REPAIR STRATEGY MODEL

Recommended repair module in this paper were divided into two models, recommended method and recommended repair material, the former has less principal change in selection method in next several years due to less variation of repair method with time; but repair material is in rapid development, new material are successfully developed from time to time, or even the same material would keep changing applicable scope and region due to repair effect, for example, some material have significant repair effect in foreign countries, yet after imported into Taiwan pavement engineering maintenance, its repair effect decreased, because of environment conditions such as varied weather, underdeveloped technology, but after continuous trying and testing in past years, technology upgrade or application scope change improves repair effect. Therefore this paper constructed appropriate neural network model for characteristics of two models.

3.1 Artificial neural network recommend repair method model

In case of rigid pavement damage, airport pavement engineers would consider multiple factors in recommending method, after literature review and expert interview, this paper generalized a few factors: damage type, damage level, damage cause, repair type (normal or urgent), weather or budget; as more factors to consider would lead to more questionnaire work, thus, provided that human expert considering factors and expert filling out questionnaire can be simulated, this paper first collects weight of each factor about pavement repair given by multiple expert by means of hierarchy analysis, then after consistency test and obtaining characteristic vector, estimates weight of each factor, as summarized in Table 1, therefore this paper selects higher weight factor as neural network variable, or [repair type (normal or urgent)], [damage type], [damage level], simulates human

expert logic of considering repair method, and would take these factors as inputparameter(Input) of artificial neural network model, while output parameter is mainly recommended repair method. The schematic of artificial neural network recommend repair method model was shown in Fig. 2.

Table 1 Hierarchy analysis weight of expert factors on pavement repair

No	Factor considered	Weight	Order
1	Damage type	0.217	2
2	Damage level	0.352	1
3	Damage cause	0.157	4
4	Repair type (normal, urgent or temporary)	0.199	3
5	Weather	0.048	5
6	Budget	0.027	6

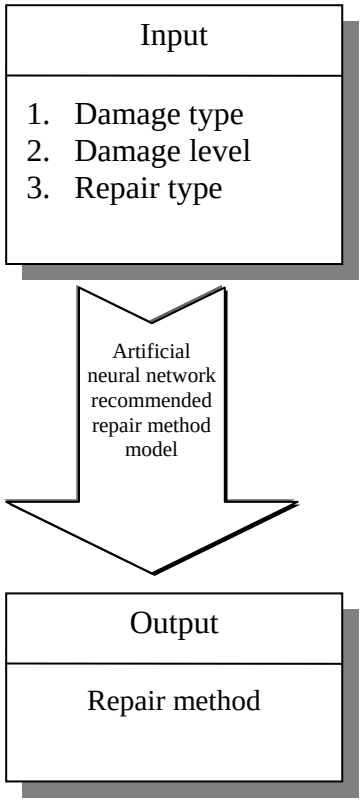

Fig. 2. Schematic of artificial neural network recommended repair method model

As to input and output items of aforesaid artificial neural network, selection of these items was based on their independence, necessity, abundance and availability; as artificial neural network uses digital means to obtain network weight to represent knowledge in case, so one has to transform case data into digital data. This paper used nodes of input and output (processing unit node) to denote status of each symbol data, classifying data as contradicting status; take "edge damage" for example, damage type can be divided into three nodes, low, intermediate and high according to damage level (processing unit):

Node #1 = edge damage "low" level damage
Node #2 = edge damage "intermediate" level damage
Node #3 = edge damage "high" level damage

Other input or output items were processed likely, e.g., divide repair type into two nodes, normal, temporary or urgent repair, artificial neural network input node was constructed according to this model; while this model output node is repair method, first summarize common repair methods used in Taiwan airports: temporary no repair, joint filling method, partial depth patching, partial slab full-depth repair, full-slab renovation, grouting stabilization base or temporary blanket treatment, and use the same construct input node to convert Taiwan airport rigid pavement repair method to seven nodes (processing unit), but different from the former, repair method recommended is not singular, variable repair methods were available for user to select at the same time, thus output nodes were non-expulsive, and shall be detailed in example format:

Output processing unit
Node #1 = temporary no repair
Node #2 = joint filling method
Node #3 = partial depth patching
Node #4 = partial slab full-depth repair
Node #5 = full slab renovation
Node #6 = grouting stabilization base
Node #7 = temporary blanket treatment

Artificial neural network uses node input and output to conduct neural network Train and Test, and just input parameters of input node later, then the trained neural network will execute Recall programme, obtain output variable estimated from input variable, indicating that, after inputting

damage type, level and repair demand, then recommended repair method(non-singular) can be estimated.

3.2 Artificial neural network recommended repair material model

Current oversea studies on recommending pavement repair strategy by artificial neural network were primarily repair method, while it was often urgent or temporary repair for Taiwan airports, there's less cases of common repair method, but it's often the case that damage occurs again after repair, the cause was presumed to be improper selection of repair material, appropriate repair method has to be coupled with appropriate repair material to result in good repair effect, therefore this study tried to use artificial neural network means to recommend repair material likely. Appropriate repair material artificial neural network model was constructed for factors airport pavement engineer considered in choosing repair material. After literature review and expert interview, we could generalize preferential factors such as repair method, repair type (normal or urgent) or repair effect, when repair engineer selected repair material, as optional material varied with different repair methods, so this study constructed appropriate model for each repair method, meanwhile considered mechanism of repair effect ongoing learning and feedback, and thereby put forward the idea of [satisfaction], defined as below:

"For specific repair method with various repair material, make comprehensive assessment of material fittability. Such comprehensive consideration includes material availability, cost, workability, repair speed, effect and durability, or other related experience."

This paper constructed artificial neural network recommended repair material models, based on four repair methods: joint filling method, partial depth patching, partial slab full-depth repair and full slab renovation, the artificial neural network model for each method was established; and interviewed Taiwan pavement maintenance staff and repair suppliers about each method, collected a broad spectrum of condition such as brand, commercial name of repair material normally used by each method in Taiwan, and thereby constructed artificial neural network from above data, as shown in Fig. 3.

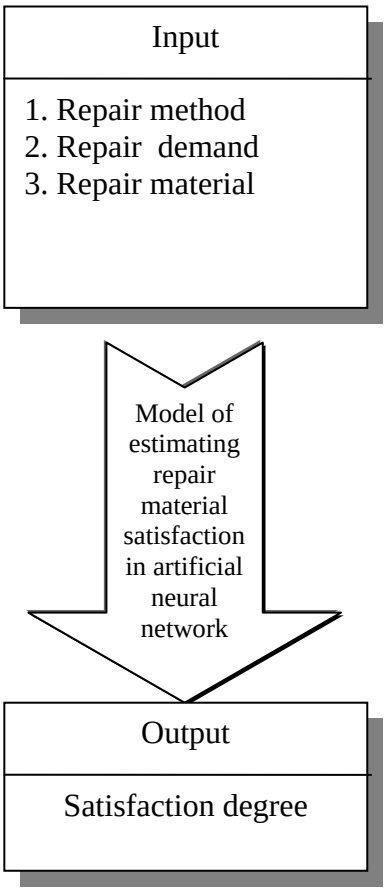

Fig. 3. Schematic of artificial neural network recommended repair material model

Like artificial neural network recommend repair method model, we used node input and output to conduct neural network Train and Test, and just input parameters of input node, then the trained neural network can execute Recall programme, and obtain output variable estimated from input variable, indicating that, after inputting damage method, repair demand and selected repair material, one can estimate satisfaction value (singular) of this selected repair material. To note, this model predicted satisfaction of such repair material with respect to repair method and demand, hence in building expert system later, according to satisfaction sequence of each repair material, the system will rate the repair material with higher satisfaction, so that repair effect can be secured.

System recommended repair material would

not necessarily have certain satisfaction, human, material or weather defects such as improper construction and bad quality of repair material, would often give rise to second damage of repaired location, resulted in not high satisfaction after repair, thus such repair material case could be deemed as fail case; under similar repair condition later, the system will recommend this repair material, too, and hence repair failure case will happen again. Or system recommended repair material, after user repair and long time observation, indeed provided good repair effect, even higher satisfaction, such repair case would be deemed as pass case. if such fail or pass case can be added to system for auto-learning, then under similar repair condition in future, higher satisfaction repair material would be easier to be rated by system, while low satisfaction repair material would be replaced by high satisfaction repair material with time, such feedback auto-learning was another key point of this paper about repair material module.

This paper tried to put repair material in feedback training, as artificial neural network has incremental learning capability, or loading training example one by one, and correct knowledge gradually [9], thereby the system recommends repair material to user, and the user will provide satisfaction of repairing with such material to system in future, so as to enable system auto-learning, automatically correcting knowledge library, so that the system can withstand time test.

IV. EXAMPLE FORMATION

The most critical factor of artificial neural network success was data, but Taiwan airport history repair records were incomplete, so data acquisition was not easy, according to literature, artificial neural network cases came from the following sources: (1) programme simulation manufacturing example (2) record data (3) expert questionnaire [10].

As to rigid pavement repair, there were no related finite element programme to simulate field damage and its repair at home and abroad right now, or not able to fully simulate field damage and repair from laboratory test, thus it was not easy to acquire data from two above methods. Therefore this paper acquired examples by means of questionnaire, coupled with learning in artificial neural network model, so that the user can choose appropriate repair strategy from this model.

Various repair methods would have different applicable repair material, and in order to attain continuous learning and feedback, this paper constructed an artificial neural network model for each repair method, and incorporated “satisfaction” idea, pavement experts just need to, according to damage repair method, repair type and repair material selected, input satisfaction of human expert about repair effect. And repair effect was very associated with time, usually repair effect satisfaction would go down with time, so a fixed period has to be added, as warranty period of pavement maintenance contract was normally one year, so when inputting satisfaction, it called for human expert satisfaction after one year performance of repair contract.

Just like phrase variable transformation, usually human expert has no numeric idea, while artificial neural network was digital data operation, hence in designing questionnaire, convenience and friendliness of phrase variable completion should be taken into account, so expert interview was done by means of phrase variable digitization, satisfaction was classified as seven satisfactions of varied degrees, ranging from very unsatisfied, unsatisfied, slightly unsatisfied, not clear, slightly satisfied, satisfied and very satisfied, for experts to choose from; while satisfaction phrase degree was transformed into definite number in the same way as that of previous module fuzzy phrase transformation, by using Hwang’s [11] phrase transformation and left-right-point method, one can obtain every satisfaction and its corresponding value.

V. SYSTEM PRACTICE

This system belongs to numeric operation, thus this system adopted powerful computation form Excel to perform numeric operation, in Excel 2000 there were over three hundred functions, which can help knowledge engineer process various types of operations, besides, Visual Basic links easily with Excel, coupled with macros (Visual Basic for Application, VBA), stronger function will be generated.

The next part was numeric estimate of

related artificial neural network, this study adopted PCNeuron programme provided in "*Artificial Neural Network Model and Application* –the 7th edition" written by Prof. Ye Yi-cheng from Chung-Hua University as network construction tool, to conduct neural network training and test, as it was a programme executed under DOS environment, so data processing by Excel and format transformation have to be done before combining Visual Basic. Structure chart of recommended repair method and material module in this paper was shown in Fig. 4.

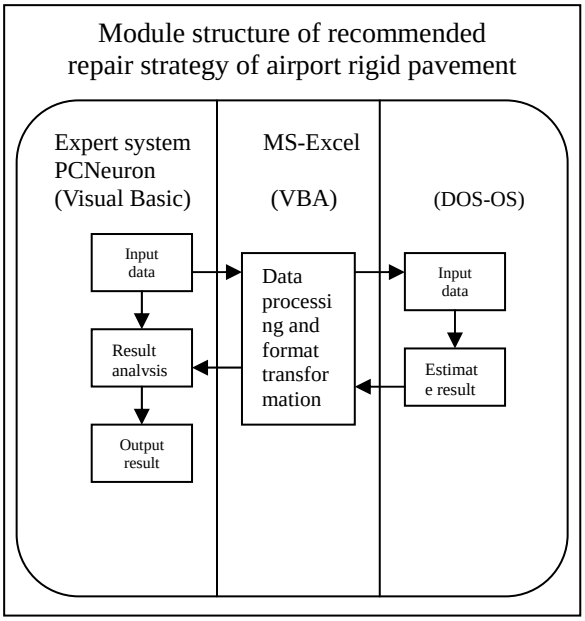

Fig. 4. Module structure of airport rigid pavement recommended repair strategy

In the part of artificial neural network recommended repair method, artificial neural network mainly executed Recall programme, meaning that after construction of network with satisfactory accuracy, then one could input such cases with only known input vector but with unknown output vector into trained network, thereby estimated output of each processing unit could be obtained. Therefore, after user input associated repair condition through user interface built in this system, VB would conduct data processing and format transformation via Excel, transform into parameter file PCNeuron needs, when artificial neural network finished recall programme, its output data could likely feed back through Excel data transformation to VB programme, sort and select the top three recommended values, then the user can get artificial neural network recommended repair method and its recommended value.

When artificial neural network recommended repair material, it also executed Recall programme to seek appropriate repair material, but its difference from recommended repair method was that output vector of this model was a processing unit-satisfaction, hence system recommended material shall be repair material with highest satisfaction. Therefore after user input repair condition, this system would put repair material into artificial neural network to recall one by one, find satisfaction value of each repair material under repair condition input by user, and sort these satisfaction values, select the top three kinds of material, this was the appropriate repair material recommended to user by system.

Another objective of this model was auto-learning, feedback training was added to keep continuous machine learning of repair material, or after system recommended user repair method and material, the user could be told from this module that satisfaction value of this repair material in system. If repairing of a repair material failed to reach expected effect, after frequent later feedback training, eventually this repair material would not be selected by users; and vice versa, after frequent feedback training, good repair material would be easier to be chosen by system later, so that repair effect could be more secured. Therefore this study added feedback training module, user searched repair data and verified, put forward appropriate satisfaction phrase variables for damage repairing effect, regarded it as a new case and trained artificial neural network again, generated a new weighted matrix file, so when system will execute recall programme in future, from new weights and threshold, appropriate repair material can be selected.

VI. SYSTEM VALIDATION

During constructing prototype system in this paper, experts of this system were invited one after another to examine system structure and validate execution result, then make system correction based on expert comments. As to validation of this expert system, apart from actual expert validation, in order to confirm system analysis result and compare variation of logic of

airport rigid pavement experts in solving pavement repair problems, take repair method, selection for example, take questionnaire result of previous 10 experts to make statistic analysis under the same conditions, if all experts select the same method, then this method score is 1, if 9 experts select the same method, then this method score is 0.9, and pro rata, then take 0.5 as threshold, method score greater than 0.5(including 0.5) was regarded as 1, if less than 0.5 then it was regarded as 0, this result would be deemed as the most correct and finally integrated target; then compare questionnaire of each expert and system estimated result with final integrated target, under the same condition, for each repair method, compare expert or system estimates and selected method of final integrated target, when expert or system estimated method was the same as that of final integrated target, then score 1, otherwise, score 0, in the end, compare estimated scores of each expert and system, in order to evaluate difference of prototype system built in this study and expert logic model in solving pavement repair problem.

According to above validation analysis method, for all pavement damage condition and various repair demands, compare each expert questionnaire and system estimated result and final integrated target, resulted in Table 2.

From result of Table 2, two points could be obtained as follows:

1. Table 2 showed that, system estimated scores were all higher than those of all experts, indicating that system estimated result was more approximate to final integrated target; being nearer final integrated target implies that system estimation was more objective and rational, proving that this system's selection of airport rigid pavement repair strategy would be more objective and rational and effective.

2.Though system estimated scores were higher than those of all experts, they varied not much, indicating that system analysis result was very similar to logic model of airport rigid pavement experts in solving pavement repair problems, it was validated that this system has function of estimating and providing appropriate repair strategy.

Table 2 Statistics of comparison points of expert questionnaire and system estimate with final integrated target

Object	Score
System estimate	1795
Expert 1	1633
Expert 2	1392
Expert 3	1635
Expert 4	1389
Expert 5	1690
Expert 6	1499
Expert 7	1648
Expert 8	1678
Expert 9	1656
Expert 10	1684

VII. CONCLUSIONS AND SUGGESTIONS

It was empirically proved that repair strategy screening system built in this paper has function of estimating and providing appropriate repair strategy; and repair material had been incorporated into artificial neural network training, the system not only recommends appropriate repair material to user, but also provides feedback training module, so that the system keeps auto-learning and updated with time, aiding in later selection of appropriate or newly developed repair material, and ensuring repair material fittability.

As related Taiwan airport pavement repair effect data were difficult to collect, the artificial neural repair strategy screening model built in this paper, was to train artificial neural network with expert questionnaire, a little different from actual airport repair status; the future recommended airport pavement maintenance provider shall be able to record and maintain repair data to facilitate later continuous training of artificial neural network, let network corrected continuously from actual examples, so that it not only provides appropriate repair strategy but also indirectly trains human expert

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