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ANALYZING DATABASES IN THE TAIWAN BRIDGE MANAGEMENT SYSTEM USING BIG DATA APPROACHES

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This paper describes some preliminary results of this research. Before conducting a comprehensive big data analysis of the whole system of Taiwan Bridge Management System (TBMS), a pilot test was performed to explore possible outcomes. A total number of 34,099 records each having 305 fields of 24 bridges in a specific region were analyzed using the famous R software. The resulting correlations between inventory fields and deterioration of bridge components are categorized in three types: explicable, inexplicable, and irrelevant. For those inexplicable correlations, interviews with experts are found necessary in order to explore useful or meaningful maintenance information. Two more similar tests are also being planned for two groups of bridges that are nearby sea or solely in the mountainous area. In addition to the correlation between a specific deterioration and all existing inventory fields, other maintenance information such as frequently maintained components as well as their maintenance frequencies and costs, and other crucial relationships among fields in the TBMS are highly anticipated in this research in order to establish beneficial suggestions to the bridge maintenance strategies in Taiwan.

Keywords: Bridge inspection, Bridge maintenance, Decision making.

1 INTRODUCTION

The Taiwan Bridge Management System (TBMS) has been online since 2000. Its inventory comprises of 28,365 bridges with 6,524 fields in all tables, and the total amount of data records is 3,457,274 that increases by nearly 1 percent annually. Among these fields, there are 475 containing kernel management information of a bridge such as inventory data, inspection results, and maintenance records. Thus, the databases in the TBMS have met the definition of “Big Data.”

Age distribution of bridges in the TBMS is shown in Table 1. There are more than 5,000 bridges that are over 30 years old aside from 9,365 bridges having unknown built year. Thus, the number of seriously deteriorated bridge components increases drastically every year, even though maintenance activities have been expedited by responsible agencies for many of such components. Due to limited budgets, especially for local governments, prioritization of bridge maintenance is always a challenging task for the bridge management agencies, in addition to determining which option is better between maintaining and rebuilding of a deteriorated bridge. Life-cycle cost analysis is a feasible solution to such problem; however, such technique requires an appropriate deterioration forecast model which is yet to be implemented in the TBMS.

In this research, one of the main anticipated results is to obtain correlative information between the fields of inventory and deterioration of a bridge. Other information is also expected from this research such as actual maintenance frequency, costs, and repairing methods for various bridge components that can be used to establish a more effective maintenance strategy. In addition, since the decision making mechanism between continuing maintenance actions and rebuilding of a new bridge is still not yet clarified, answers to this doubt are expected by digging into the actual inspection results and maintenance records in the TBMS using big data approaches.

Table 1. Age distribution of bridges by management agency.

Bridge's age	**Freeway/Highway**	**Railway**	**City/ County**	**Total**
~10	726	54	1,235	2,015
10~20	2,262	262	3,198	5,722
20~30	1,004	332	4,037	5,373
30~40	971	359	2,752	4,082
40~50	252	408	606	1,266
50~60	61	104	199	364
60~70	18	65	41	124
70~80	9	9	9	27
80~90	6	-	15	21
90~100	-	-	5	5
100~110	-	-	1	1
unknown	16	135	9,214	9,365

2 LITERATURE REVIEW

Lin (2007) successfully established a service life prediction model for expansion joint that obtained a 9% difference between the predicted and the actual service year. He also discovered that horizontal acceleration, number of spans and traffic flow are the most significant factors in determining the service life of an expansion joint. In addition, Su (2003) collected 935 bridge inspection data in Taichung to analyze the relevancy between bridge deterioration and its environment by a logistic regression approach. This study discovered that the age of bridge, the distance to sea, and using of I-type girders are the major factors that caused deterioration.

For both the central and local governments, distribution of bridge maintenance budgets is always a difficult task. Chen (2007) established a model to calculate a danger factor (DF) for a bridge by assigning weights to its major components based on their deterioration ratings multiplied by a traveler's factor determined by level of road that bridge was on; then the component having the highest value was normalized to represent the DF of the bridge. The DF can be used for both prioritization of bridge maintenance and distribution of maintenance budgets. This prioritization model is currently incorporated by the TBMS.

Many researchers have promoted life cycle cost concept for bridge management for many years. However, current practice in most bridge construction bids in Taiwan still not yet consider the maintenance costs. Zhu (2013) established an optimal model for calculating bridge total life cycle cost for RC beam bridges, considering travelers' cost and social cost. Safi (2014) analyzed the Sweden bridge management system to find a total maintenance cost for bridge components. The research results showed that the total maintenance cost is 15% to 25% of life cycle cost of a bridge, while different types of bridges may have more than 50% difference in construction cost.

3 TAIWAN BRIDGE MANAGEMENT SYSTEM (TBMS)

Supported by the Institute of transportation, Ministry of Transportations and Communications, the TBMS was developed by National Central University in 1999 in Taiwan. The TBMS is used by all the governmental agencies that are responsible for bridge management. In the TBMS, relational databases are incorporated in which relations of two or more data records are built on the same attribute. For example, if two databases, termed as “inventory” and “agency” are needed, an attribute named “agency’s id” can be added into both databases to create a relation between the two.

There are 9 modules in the TBMS, such as Inventory, Inspection Data, Maintenance Records, Statistic, Decision Support, etc. There are 30 data tables in total. The official maintenance codes in Taiwan regulate that every bridge needs to be inspected at least for every two years. Hence, this research focuses on data in three modules: Inventory, Inspection Data, and Maintenance.

3.1 Inventory Module

There are 33,275 data records in the inventory module; among which only 28,000 bridges are still in use or under maintenance, the rest were destroyed by natural disasters, closed or demolished due to extreme deterioration. In this module, there are four tables that describe the basic data of a bridge. Bridge main inventory table is the top layer of data structure in this module; below which are abutment, pier, and span tables. The main inventory table consists of six kinds of data such as management, geometry, structure, particular structure, river, and design attributes; the total number of fields is 147 with approximately 33,000 records accumulated since year 2000. The abutment, pier, and span tables have data fields describing detailed geometry and design information with 42, 58, and 39 fields and around 9,700, 24,000, and 90,000 records, respectively.

3.2 Inspection Data Module

The methodology of regular bridge inspections used by the TBMS is called DER&U. In this methodology, four indices are used to evaluate the condition of a bridge component: “D” represents the degree of deterioration; “E” represents the extent of the deterioration; “R” represents the deterioration’s relevancy to bridge safety; and “U” represents the urgency to repairing the deterioration. All these indices are numerically rated on an integer scale from 0 to 4 to describe the status of the deterioration. For a concrete bridge, 21 components need to be inspected, for other types of bridges the number of components may be up to 25.

This inspection data module stores visual inspection results of all bridges. It has three layers of data structure that are recorded on main, overall, spans and piers inspection sheets. These inspection sheets have 21, 69, and 51 fields to record the inspection results and currently they have around 291,000, 292,000, and 2,200,000 records; respectively. Since current regulation requires inspection at least once every two years, these records increase roughly 15,000 per year.

3.3 Maintenance Module

Notably, if deterioration is found during inspection, it is required to input a suggested repairing method by the inspector. Thus, at the bottom of the data structure of inspection, the suggested repairing method is also recorded by 34 fields; it has 521,000 records in the TBMS presently. After the deterioration has been repaired, relevant maintenance information such as contractor, duration, and costs is required to be input into this module.

4 DATA PROCESSING

The TBMS is composed of relational databases; therefore, there are many invalid attributes during data analysis. For example, in the Inspection table, there's an attribute named Inventory ID by which this table relates to the inventory. Such kinds of attributes are not necessary during data analysis and need to be deleted to decrease the amount of adverse data.

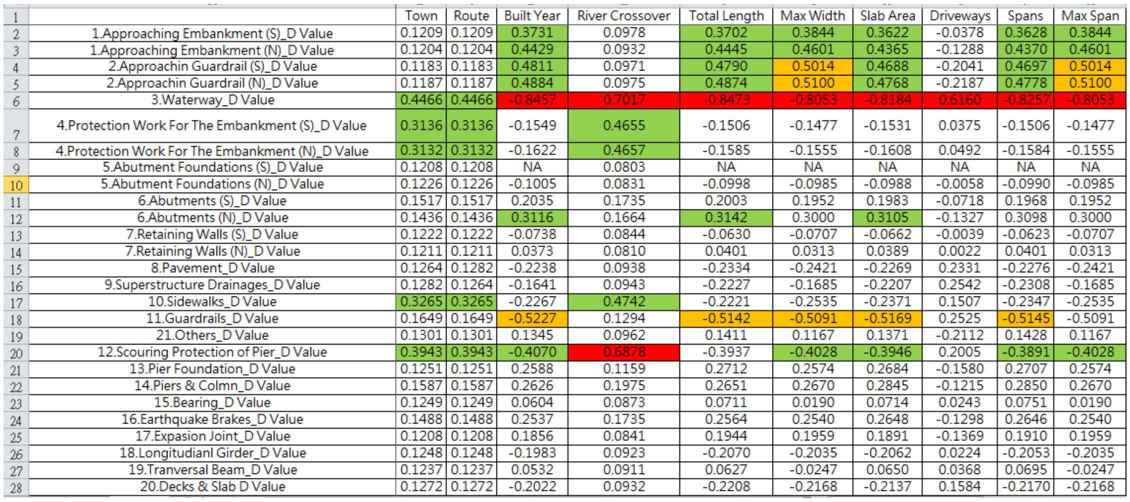
There are about 3 million tuples in inventory, inspect data, and repair work. Some tuples might already have null values in attributes, and some important attributes were left blank. The tuples would make the result inaccurate, and they could affect the result of factor analysis as well. Therefore, such tuples are excluded in this research.

There many attributes in inventory table, inspect table are open fields, such as locational, remark. Users can input any words they want to describe the situation of the bridge. Since the content isn't consistent, so this research excludes these attributes as well. On the other hand, revising the content of fields to ensure correctness of data input is also an important work in this data processing phase.

5 PRELIMINARY RESULT

This research takes Directorate General of Highways (MOTC), Zhongli Section bridges as a regional example, and it filters out 24 bridges with 34,099 data rows. The organized data were analyzed by the software R. R is capable of performing 25 kinds of statistical and numerical analysis functions such as obtaining mean value, standard deviation, plotting of histogram, and executing regression process. Most importantly, the source code of R is available to download freely. Its famous users include Google, Facebook, Bank of America, and New York Times.

This research analyses the relations between bridge inventory and DER&U rating values. The category field adopted Cramer's V while the numerical field adopted Pearson distribution. Due to limitation of pages, only a small portion of the analyzed results is shown in Figure 1.



1		Town	Route	Built Year	River Crossover	Total Length	Max Width	Slab Area	Driveways	Spans	Max Span
2	1.Approaching Embankment (S)_D Value	0.1209	0.1209	0.3731	0.0978	0.3702	0.3844	0.3622	-0.0378	0.3628	0.3844
3	1.Approaching Embankment (N)_D Value	0.1204	0.1204	0.4429	0.0932	0.4445	0.4601	0.4365	-0.1288	0.4370	0.4601
4	2.Approachin Guardrail (S)_D Value	0.1183	0.1183	0.4811	0.0971	0.4790	0.5014	0.4688	-0.2041	0.4697	0.5014
5	2.Approachin Guardrail (N)_D Value	0.1187	0.1187	0.4884	0.0975	0.4874	0.5100	0.4768	-0.2187	0.4778	0.5100
6	3.Waterway_D Value	0.4466	0.4466	-0.8457	0.7017	-0.8473	-0.8053	-0.8184	0.6160	-0.8257	-0.8053
7	4.Protection Work For The Embankment (S)_D Value	0.3136	0.3136	-0.1549	0.4655	-0.1506	-0.1477	-0.1531	0.0375	-0.1506	-0.1477
8	4.Protection Work For The Embankment (N)_D Value	0.3132	0.3132	-0.1622	0.4657	-0.1585	-0.1555	-0.1608	0.0492	-0.1584	-0.1555
9	5.Abutment Foundations (S)_D Value	0.1208	0.1208	NA	0.0803	NA	NA	NA	NA	NA	NA
10	5.Abutment Foundations (N)_D Value	0.1226	0.1226	-0.1005	0.0831	-0.0998	-0.0985	-0.0988	-0.0058	-0.0990	-0.0985
11	6.Abutments (S)_D Value	0.1517	0.1517	0.2035	0.1735	0.2003	0.1952	0.1983	-0.0718	0.1968	0.1952
12	6.Abutments (N)_D Value	0.1436	0.1436	0.3116	0.1664	0.3142	0.3000	0.3105	-0.1327	0.3098	0.3000
13	7.Retaining Walls (S)_D Value	0.1222	0.1222	-0.0738	0.0844	-0.0630	-0.0707	-0.0662	-0.0039	-0.0623	-0.0707
14	7.Retaining Walls (N)_D Value	0.1211	0.1211	0.0373	0.0810	0.0401	0.0313	0.0389	0.0022	0.0401	0.0313
15	8.Pavement_D Value	0.1264	0.1282	-0.2238	0.0938	-0.2334	-0.2421	-0.2269	0.2331	-0.2276	-0.2421
16	9.Superstructure Drainages_D Value	0.1282	0.1264	-0.1641	0.0943	-0.2227	-0.1685	-0.2207	0.2542	-0.2308	-0.1685
17	10.Sidewalks_D Value	0.3265	0.3265	-0.2267	0.4742	-0.2221	-0.2535	-0.2371	0.1507	-0.2347	-0.2535
18	11.Guardrails_D Value	0.1649	0.1649	-0.5227	0.1294	-0.5142	-0.5091	-0.5169	0.2525	-0.5145	-0.5091
19	21.Others_D Value	0.1301	0.1301	0.1345	0.0962	0.1411	0.1167	0.1371	-0.2112	0.1428	0.1167
20	12.Scouring Protection of Pier_D Value	0.3943	0.3943	-0.4070	0.6878	-0.3937	-0.4028	-0.3946	0.2005	-0.3891	-0.4028
21	13.Pier Foundation_D Value	0.1251	0.1251	0.2588	0.1159	0.2712	0.2574	0.2684	-0.1580	0.2707	0.2574
22	14.Piers & Colmn_D Value	0.1587	0.1587	0.2626	0.1975	0.2651	0.2670	0.2845	-0.1215	0.2850	0.2670
23	15.Bearing_D Value	0.1249	0.1249	0.0604	0.0873	0.0711	0.0190	0.0714	0.0243	0.0751	0.0190
24	16.Earthquake Brakes_D Value	0.1488	0.1488	0.2537	0.1735	0.2564	0.2540	0.2648	-0.1298	0.2646	0.2540
25	17.Expasion Joint_D Value	0.1208	0.1208	0.1856	0.0841	0.1944	0.1959	0.1891	-0.1369	0.1910	0.1959
26	18.Longitudianl Girder_D Value	0.1248	0.1248	-0.1983	0.0923	-0.2070	-0.2035	-0.2062	0.0224	-0.2053	-0.2035
27	19.Tranversal Beam_D Value	0.1237	0.1237	0.0532	0.0911	0.0627	-0.0247	0.0650	0.0368	0.0695	-0.0247
28	20.Decks & Slab D Value	0.1272	0.1272	-0.2022	0.0932	-0.2208	-0.2168	-0.2137	0.1584	-0.2170	-0.2168

Figure 1. The obtained coefficients between attributes.

The results obtained from the research are characterized into three categories. Category I demonstrates deteriorations that are related to certain primary inventory fields, which meet general cognition in bridge deterioration and can be reasonably explained. The coefficients of correlation between the category and numeric values were higher than 0.6. Category II depicts a different outlook of high correlation between deterioration of certain bridge components and some primary fields in that the correlation needs to be specially explained; i.e., the physical corrections are not clear even though the correlation coefficients were also higher than 0.6. Category III shows deteriorated bridge components have no significant correlation with the basic inventory fields. The categories of relevance are separately defined subsequently:

(i) Category I: Explicable correlations between inventory fields and deterioration

(a) Correlation of "bridge age" and "deterioration of waterway"

Scouring of riverbed or deteriorating of riverbed protection devices signifies deterioration of waterway; or, river course. The inventory records detailed information of a bridge upon completion, and analysis of such information shows that the built year of a bridge is highly negatively correlated with the deterioration of waterway. In other words, the older a bridge is, the worse the waterway deteriorates.

(b) Correlation of "crossing-river type of bridge" and "deterioration of pier protection"

For crossing-river type of bridges, water current may cause scouring around bridge piers and seriously damage the anti-collision plate around bridge piers. These two fields are highly interrelated.

(c) Negative correlation of "bridge length," "maximum width," "deck area," and "number of spans" with "deterioration of waterway."

The analysis from this study shows that longer bridges obtain a better state of waterway condition; i.e., the river course is less deteriorated for long bridges. This could be due to the fact that most long bridges are located in downstream of river with a gentle slope of waterway and a relatively slower flow where both sides of the river are mostly composed of alluvial phenomena. Bridges located in upstream usually suffer from strong currents caused by steep slopes that accelerate deterioration of bridge piers. Wider bridge width, bigger deck area, and more spans also denote the length of the bridge that usually allow water flow smoothly passing through the bridge. Consequently, these fields have a negative correlation with deterioration of waterway.

(d) Negative correlation of "maximum bridge span" and "deterioration of waterway"

The larger the span of a crossing-river type of bridge, the greater waterway's resistivity to deterioration since larger spans normally ensure a steady water flow; irrespective of whether the bridge is located upstream or downstream. This result is similar to that in (c).

(ii) Category II: Inexplicable correlations between the inventory fields and deterioration

(a) Number of lanes on a bridge is positively correlated with the deterioration of waterway.

(b) Type of transversal beam is positively correlated with the deterioration of waterway.

(c) Bearing type (support type) and deterioration of waterway are positively correlated.

(d) Anti-seismic reinforced facilities are positively correlated with the waterway deterioration.

(e) Type of abutment has a positive correlation with the deterioration of pier protection devices.

(f) Expansion joints and deterioration of pier protection devices are positively correlated.

(g) Material of main beam and girder type have a positive correlation with the deterioration of pier protection devices.

The aforementioned, correlations cannot be directly attributed to explaining the root causes of their relevance, thus, they will be undertaken in subsequent interviews with experts in order to enhance the accuracy of analysis results.

(iii) Category III: Irrelevant correlation between the inventory fields and deterioration of bridge components – (a) Girder; (b) Transverse beam; (c) Bridge deck.

The analysis of this study discovered that the basic information on all the fields for girders, transverse beams, and bridge deck, their deterioration are of no significant correlation with any of the inventory fields. The reason could be that deterioration of these three kinds of bridge components are caused by external forces such as earthquakes or vehicle loads.

6 CONCLUSION

TBMS has been used by all the bridge management agencies in Taiwan for more than 16 years. As a pilot study, this research extracted 34,099 records each having 305 fields of 24 bridges in a specific region from TBMS to form the basic input data to the R software. The preliminary analysis results show that positive and negative correlations between the inventory fields and deterioration of bridge components do exist. These correlations are categorized into three types: explicable, inexplicable, and irrelevant. For those inexplicable relationships, interviews with experts are found necessary in order to explore useful or meaningful maintenance information.

Two more pilot tests are being planned in that bridges with specific location characteristics will be selected as a group. They will be bridges in a region nearby sea and in a mountainous area away from sea. After the aforementioned correlations are obtained, analysis will be continued to countrywide (Taiwan) bridges, i.e., all the bridges in the TBMS excluding railway bridges. Establishment of a more effective maintenance strategy and a decision making mechanism for continuing maintenance actions or rebuilding of a new bridge are highly expected from this research.

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