A Flexible Software Framework for Transportation Maintenance Scheduling

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***Abstract*—This paper presents a general-purpose software framework dedicated to the evolutionary transportation scheduling, which is one of the most challenging areas in transportation engineering. Against evolution, the most popular approach is manual process. Manual process in here is to describe the system business using the most appropriate modeling language(s) at the most appropriate level(s) of abstraction. To demonstrate the applicability of the framework, we report our experience in using the software to generate pavement maintenance report under manual business model.**

***Index Terms*—Maintenance Scheduling, Transportation, Manual Process**

I. Introduction

A. Motivation

Transportation is essential for regional economies. However, heavy traffic loads and environmental impact can cause damage such as cracking in pavement structure, which can impair their performance. To keep transportation in good repair, it is very necessary for government to maintain transportation facilities. Unfortunately, the transport facilities are varied and numerous, so it must be a challenging problem for government to make the optimum maintenance schedule timely and effective according to the situation.

Transportation maintenance scheduling (TMS) is the process of deciding how to maintain transportation facility with limited resources. With the development of society, transportation has become more and more complicated. The traditional scheduling method can't satisfy the requirement of transportation maintenance. As a result, software technology is introduced to TMS and makes a great contribution.

B. Limitation of Existing Systems

Although software has made a great contribution to TMS, they are still imperfect. Evolution is inevitable over the course of the life-cycle of complex software-intensive systems. And this problem becomes extremely prominent because of the variety of transportation facilities.

In China, the government will have the routine inspection of transportation facilities every year. Take pavement inspection for example. The factors contain Rutting Depth (RD), International Roughness Index (IRI), Side-way Force Coefficient (SFC) and Structure Strength Coefficient (SSI) etc. Measuring precision of RD is 10 meters. Supposed that the length of highway in province is 3000 kilometers, and the quantity of single tracking data must have about 3 million. And the government is required to sum up all these factors and come up with a maintenance report. Such process may happen to bridge and tunnel maintenance scheduling. Consequently, government is subject to the variety of software, which may lead to a big resource wasting.

C. Our Contributions

According to the surveys and the essays of TMS, we can summarize the three stages of the maintenance scheduling. The first stage is raw data collection. There are many inspections every year, which collect the information from facilities. The second stage is row data transformation and evaluation. Because of the variety of factors, data evaluation becomes extremely difficult. Then we figure out a solution that the values of factors should be transformed into hundred-mark system value. In this way, the evaluation will be easier and more feasible. The third stage is data analysis and maintenance scheduling report generation. After evaluation, the levels represent the state of the facility. And we decide which activity should be taken to maintain the facility by analyzing the related situations. Finally, we can work out a maintenance scheduling report.

Considering the software users, such as the boffins of Communications Research Institute, may pretty much understand transportation maintenance, we propose an approach, manual process, for TMS.

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II. APPROACH AND OVERVIEW

A. Manual Process Framework

Manual Process Framework (MPF) is a software framework that allows user to define some process of software at specific level, which is suitable for different transportation facilities. MPF needs three models, Raw Data Conversion Model (RDCM), Optimal Mapping Model (OMM) and Predictive Model (PM), to function correctly. RDCM is for data conversion and evaluation. It converts the raw data to hundred-mark system value and divides it into five levels. OMM builds the relationship between the levels of the data and the maintenance activities. It will tell the decision-maker which is the optimal maintenance activity for the facility. PM is used to predict the condition of the facility in few years.

As the evolution of transportation and research, the models will be changed while MPF remain the same, which can reduce the cost and increase efficiency.

B. Framework Architecture

The framework is mainly divided into four modules: input module, manual process module, parser module and Report generation module. The input module receives the data from device, files or input text, and then stores them into database. The manual process module allows user to model the business process. Parser module is for data parsing and equation calculation. The report generation module is to produce scheduling report according to business model and data.

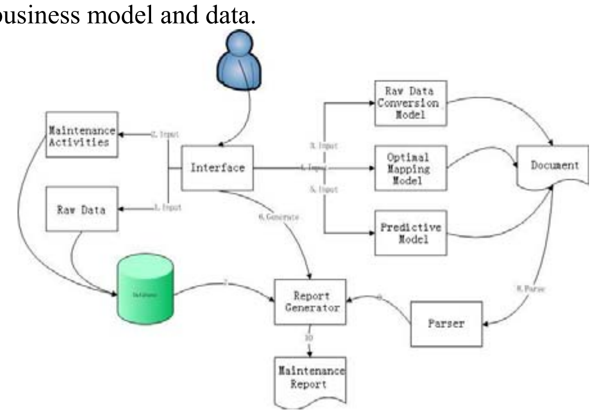

Figure 1. the architecture of the software framework

III. THREE PHASES

A. Raw Data Import

Raw data import is the first step of the software, which provides basic data for further calculation. The acceptable data format contains Excel document and SQLite database file. Once the data format is determined, the importer begins data classification and storage.

B. Business Process Modeling

Business process modeling is to build business model for the framework using modeling language. Inspired by the programming language, we define an easy-to-use language whose expression is similar to mathematical equation. To let the framework understand business model, we still need to build a parser to parse the structure of business model. The parser consists of two parts: process Syntactic analysis and Equational semantics analysis.

- **Process Syntactic Analysis**

The purpose of syntactic analysis is to determine the structure of the input text. This structure consists of a hierarchy of phrases, the smallest of which are the basic symbols and the largest of which is the sentence. It can be described by a tree with one node for each phrase. Basic symbols are represented by leaf nodes and other phrases by interior nodes. The root of the tree represents the sentence.

We use Top-down parsing to find the structure of the input text. Top-down parsing is a type of parsing strategy wherein one first looks at the highest level of the parse tree and works down the parse tree by using the rewriting rules of a formal grammar.

The Top-down parsing here have three stages. The first stage is the token generation, or lexical analysis, by which the input character stream is split into meaningful symbols defined by a grammar of regular expressions. For example, our program would look at an input such as "if a<10 then b=10 endif" and split it into the tokens if, a<10, then, b=10, endif, each of which is a meaningful symbol in the context of an arithmetic expression. The next stage is parsing or syntactic analysis, which is checking that the tokens form an allowable expression. The final phase is semantic parsing or analysis, which is working out the parse tree. After that, we can use depth-first traversal to confirm the process of business model.

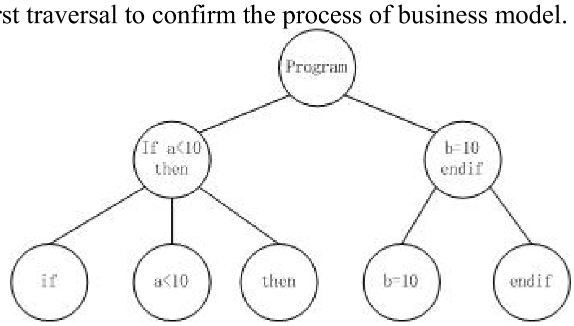

Figure 2. the parse tree of the input text "if a<10 then b=10 endif"

- **Equational Semantics Analysis**

Equational semantics is a way to define the meaning (also called semantics) of syntactical objects in computer science. Equational semantics have three steps. The first step is token generation, or lexical analysis, which is general step of semantics analysis. The second step is operation priority judgment. We use Reverse Polish Notation to determine the priority of operations. Reverse Polish notation (RPN) is a mathematical notation wherein every operator follows all of its operands, in contrast to Polish notation, which puts the operator in the prefix position. The infix expression "a-b*(c+d)" can be written down like this in RPN: "abcd+*-". In order to save the value of variable, we build hash table. Hash table is a data structure that uses a hash function to map identifying values, known as keys to their associated values. The parser read this from left to right. If the text is an identifier, the parser finds its value in hash table then replaces the identifier with its value. After an assignment, the parser will insert a new key-value pair into the hash table or update the hash table.

C. Report Generation

Report generation is combined with the basic data and the business model to generate transportation scheduling report. First, it read the data, the evaluation levels of facility and maintenance activities, from database. Second, the generator call the parsers to predict the next year levels of the facility using predictive model and decide which activity is the best according to optimal mapping model. Finally, the generator sums up all these results and come up with a scheduling report.

VI. PAVEMENT MAINTENANCE EXAMPLE

A. Raw Data Import

In pavement maintenance, the raw data is consist of Rutting Depth(RD), International Roughness Index(IRI), Side-way Force Coefficient(SFC), Structure Strength Coefficient(SSI) and maintenance activities list.

B. Raw Data Conversion Modeling

Every single data element has its own conversion model, so we take IRI conversion for example. The IRI conversion model can be referred to standard. The converted value is known as Riding Quality Index(RQI). xi is the i-th IRI value from a segment.

$$IRI = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$

$$RQI = \frac{100}{1 + a_0 e^{a_1 IRI}} (a_0 = 0.026, a_1 = 0.65) \quad (2)$$

It is difficult for the user to type the formula exactly the same with algebraic expression. Thus, we make the equation typing feel like programming. The two formulas above will be express in this way:

a1 = 0.026; a2=0.65;

RQI = 100/(1+a0*exp(a1*Avg(iri)));

As a rule, the last formula result is final result of the algorithm. After RQI calculation, we should classify the value into five levels. If RQI value is greater than 90, we consider the RQI level of this facility is the top-level. And we can tell the software by entering this text:

"if RQI>90 then RQI_LEVEL='top-level' endif;"

In this way, the software framework can convert the raw data into levels.

C. Optimal Mapping Modeling

After data conversion, we should decide which maintenance activity is the most suitable for the pavement. We use the simplest way, net present value(NPV), to choose the best activity. This method is to compare the present value of activities during their life-cycle and choose the minimum cost activity. Considering the life-cycle of each activity is different, the remaining life can be regard as salvage. So, the net present value can be calculated like this:

$$C_u = \frac{N_e - N}{T_n} \times C_n \quad (3)$$

$$C_r = C_n - C_u \quad (4)$$

C_u : The salvage of activity

T_n : The life-cycle of activity

N : The expected life-cycle of activity

N_e : Analysis cycle

C_n : The net present value of activity

C_r : The final net present value of activity

Finally, we decide to use the minimum cost activity to maintain the pavement.

D. Predictive Modeling

To generate the scheduling report next year, we should use predictive model to describe the future situation of facility. As same as the data conversion, each factor has its own predictive model. For example, we choose negative model to describe the future of RDI.

$$y = a \cdot e^{-bx}$$

First, we generate points with the historical data, and then fit the model to it and calculate variable a and b in Eq.5. After that, we use this model to predict RDI next year.

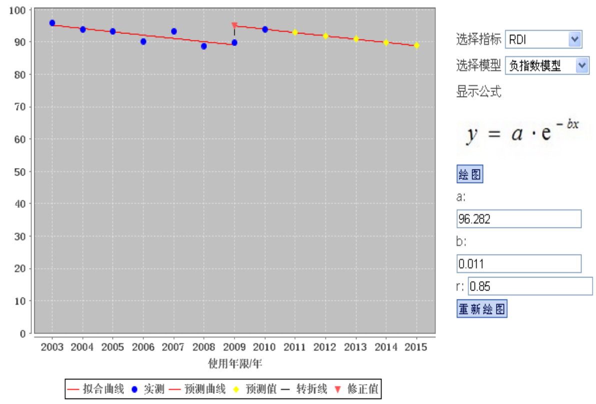

Figure 3. RDI prediction using negative model

E. Report Generation

Two kinds of scheduling report, summary report and detailed report. Summary report sums up all the cost with the same lane and maintenance activity. And each maintenance activity has a subtotal. Detailed report lists all the information of pavement segment such as factors, cost, segment identifier and maintenance activity etc.

V. CONCLUSIONS

From the design idea and implementation of the software framework, we can find that it is different from other software which is on active service. It was built in a flexible way that enable user to define business algorithm personally rather than integrate the algorithm into the software. In this way, the software can not only provide the scheduling report for the department but also benefit the further research of transportation.

位置	维修方案	长度（m）	宽度（m）	工程量（m2）	单价（元/m2）	造价（万元）
上行行车道 1	铣刨 9cm 面层，加铺 5cmAC20+4cmSMA13L	5000	3.75	18750.00	120.0	225.00
下行行车道 1	铣刨 9cm 面层，加铺 5cmAC20+4cmSMA13L	8046	3.75	30172.50	120.0	362.07
小计		13046	3.75	48922.5	120.0	587.07
上行行车道 1	超薄磨耗层	159778	3.75	599167.50	38.0	2276.84
下行行车道 1	超薄磨耗层	85658	3.75	321217.50	38.0	1220.63
上行超车道	超薄磨耗层	2000	3.75	7500.00	38.0	28.50
小计		247436	3.75	927885.0	38.0	3525.96
上行行车道 1	挖除 20cm 基层，铣刨全厚面层，加铺 20cm 水泥稳定碎石基层，加铺 0.5cm 稀浆封层+6cmAC25+5cmAC20+3.5cmSMA13L	7000	3.75	26250.00	202.0	530.25
下行行车道 1	挖除 20cm 基层，铣刨全厚面层，加铺 20cm 水泥稳定碎石基层，加铺 0.5cm 稀浆封层+6cmAC25+5cmAC20+3.5cmSMA13L	3000	3.75	11250.00	202.0	227.25
小计		10000	3.75	37500.0	202.0	757.50
上行行车道 1	微表处填车辙+超薄磨耗层	676	3.75	2535.00	60.0	15.21
下行行车道 1	微表处填车辙+超薄磨耗层	2000	3.75	7500.00	60.0	45.00
上行超车道	微表处填车辙+超薄磨耗层	7676	3.75	28785.00	60.0	172.71
下行超车道	微表处填车辙+超薄磨耗层	2000	3.75	7500.00	60.0	45.00
小计		12352	3.75	46320.0	60.0	277.92
上行行车道 1	微表处填补车辙	31574	3.75	118402.50	22.0	260.49
下行行车道 1	微表处填补车辙	33447	3.75	125426.25	22.0	275.94
上行超车道	微表处填补车辙	5000	3.75	18750.00	22.0	41.25
下行超车道	微表处填补车辙	36401	3.75	136503.75	22.0	300.31
小计		106422	3.75	399082.5	22.0	877.98
合计						6026.43
不可预见费						903.97
设计费、监理费						241.06
工程总造价						7171.46

Figure 4. Summary Report of Shendan-highway of Liaoning Province

车道	起点桩号	终点桩号	长度	PSSI	PCI	RQI	RDI	SRI	养护方案	养护费用（万元）
下行行车道1	K5+000	K6+000	1000	95.00(优)	94.83(优)	94.65(优)	89.73(良)	95.00(优)	微表处填补车辙	8.25
上行行车道2	K5+000	K6+000	1000	91.77(优)	93.13(优)	91.08(优)	90.52(优)	52.15(差)	超薄磨耗层	14.25
下行行车道2	K5+000	K6+000	1000	95.00(优)	94.83(优)	91.19(优)	86.92(良)	54.97(差)	超薄磨耗层	14.25
下行行车道1	K6+000	K7+000	1000	95.00(优)	93.25(优)	95.09(优)	84.65(良)	95.00(优)	微表处填补车辙	8.25
上行行车道1	K6+000	K7+000	1000	95.00(优)	93.33(优)	92.84(优)	77.36(中)	95.00(优)	微表处填车辙+超薄磨耗层	22.50
上行行车道2	K6+000	K7+000	1000	67.73(次)	93.33(优)	86.80(良)	73.70(中)	58.65(差)	稳定碎石基层，加铺0.5	75.75
下行行车道2	K6+000	K7+000	1000	88.69(良)	93.25(优)	90.33(优)	82.58(良)	52.77(差)	超薄磨耗层	14.25
下行行车道1	K7+000	K8+000	1000	95.00(优)	94.53(优)	91.63(优)	87.87(良)	95.00(优)	微表处填补车辙	8.25
上行行车道1	K7+000	K8+000	1000	95.00(优)	94.44(优)	93.15(优)	63.01(次)	95.00(优)	微表处填车辙+超薄磨耗层	22.50
上行行车道2	K7+000	K8+000	1000	62.33(次)	94.44(优)	87.49(良)	53.70(差)	52.57(差)	稳定碎石基层，加铺0.5	75.75
下行行车道2	K7+000	K8+000	1000	93.74(优)	94.53(优)	90.32(优)	85.27(良)	56.06(差)	超薄磨耗层	14.25
下行行车道1	K8+000	K9+000	1000	95.00(优)	95.59(优)	96.15(优)	88.52(良)	95.00(优)	微表处填补车辙	8.25
上行行车道1	K8+000	K9+000	1000	95.00(优)	94.44(优)	93.99(优)	71.12(中)	95.00(优)	微表处填车辙+超薄磨耗层	22.50
上行行车道2	K8+000	K9+000	1000	66.30(次)	94.44(优)	89.53(良)	66.90(次)	59.62(差)	稳定碎石基层，加铺0.5	75.75
下行行车道2	K8+000	K9+000	1000	92.01(优)	95.59(优)	92.63(优)	84.76(良)	56.35(差)	超薄磨耗层	14.25
下行行车道1	K9+000	K10+000	1000	95.00(优)	95.95(优)	96.14(优)	81.16(良)	95.00(优)	微表处填补车辙	8.25
下行行车道2	K9+000	K10+000	1000	86.21(良)	95.95(优)	93.34(优)	78.55(中)	54.74(差)	微表处填车辙+超薄磨耗层	22.50
上行行车道1	K9+000	K10+000	1000	95.00(优)	96.02(优)	92.71(优)	70.84(中)	95.00(优)	微表处填车辙+超薄磨耗层	22.50
上行行车道2	K9+000	K10+000	1000	64.23(次)	96.02(优)	90.83(优)	64.87(次)	61.71(次)	稳定碎石基层，加铺0.5	75.75
下行行车道1	K10+000	K11+000	1000	95.00(优)	94.62(优)	94.74(优)	86.11(良)	95.00(优)	微表处填补车辙	8.25
上行行车道1	K10+000	K11+000	1000	95.00(优)	92.77(优)	92.67(优)	67.29(次)	95.00(优)	微表处填车辙+超薄磨耗层	22.50
上行行车道2	K10+000	K11+000	1000	58.94(差)	92.77(优)	88.91(良)	61.81(次)	64.62(次)	稳定碎石基层，加铺0.5	75.75
下行行车道2	K10+000	K11+000	1000	85.67(良)	94.62(优)	91.49(优)	83.88(良)	54.35(差)	超薄磨耗层	14.25

Figure 5. Detailed report of shendan-highway of liaoning province

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