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Highway Costruction Cost Estimation Based on Kalman Filter

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***Abstract*—In order to analyze the highway construction cost trend, and improve cost management level, putting forward using the Kalman filter to estimate the construction cost. Regarding the ratio between actual cost and responsibility cost as the system variable, and demonstrating the feasibility of Kalman filter by contrastive analysis. After giving the initial state, calculating the estimation value by simulation. The simulation result shows the Kalman filter is reasonable for smoothing the actual data, and reflecting the actual trend of construction management level, then helping the enterprise to control its construction cost.**

Keywords-highway construction; cost estimation; Kalman filter; cost management

I. INTRODUCTION

A large number of highway construction projects are being carried out in China, and the highway construction cost control is a key link in the process of highway construction. In order to control cost effectively, the whole process cost management theory of construction project has been widely used [1]. And to determine the optimal scheme of the project construction, Liu Yan applied the theory of value-engineering into the whole process cost management and established the cost evaluation model [2]. Ke Hong took the cost management of highway construction as the main line and established the performance evaluation index system of highway engineering cost management at each highway construction stage [3]. In order to improve the efficiency of project cost management, the information platform based on computer and internet is applied extensively [4] [5]. In all these research results, the ultimate goal is to improve the investment benefits of investor based on economic theory. However, to the construction enterprise, the most important is to control the construction cost. In order to control the construction cost, the construction enterprise need to know the cost management level of the very construction unit, and to estimate the construction cost management level of every statistic period, then to make management strategy correspondingly.

Kalman Filter is the most widely utilized data assimilation technique[6][7], the key advantage of Kalman Filter based state estimation approaches is that it can provide a convenient and principled approach to recursively correct state estimates by balancing the errors (uncertainties) in the process and observation model and in the data[8]. This paper built a construction cost estimation model based on Kalman Filter theory and field data of construction enterprise.

II. CONSTRUCTION COST MANAGEMENT METHOD

A. *Construction cost Management Process*

Generally, when a construction enterprise gets a construction project by biding, the overall construction cost will be confirmed, at the same time, the construction enterprise will work out interior control cost, which we call it responsibility cost. The difference between the overall construction cost during biding and the responsibility cost is the profit expectedly. During the construction progress, there is another cost, which is the actual cost. The actual cost means the cost which is spent on the construction project entity, including labor cost, material cost, machine cost and other necessary cost. The actual cost is fluctuant actually, if the actual cost exceeds the responsibility cost, the profit will be decreased. So, it is very important for construction enterprise to make different management strategies control the actual cost.

In order to make different management strategy, the manager of enterprise must know not only the actual cost but also the cost management level in current month. However, Highway construction cost is very complex, including different subdivisional works, such as pavement engineering, subgrade engineering, bridge engineering and tunnel engineering to name a few. The cost in every month is different because of the different proportion of subdivisional work, to measure the management level of very month, the enterprise generally takes relative index, such as the ratio of actual cost and responsibility cost. The construction cost management flow chart is as in Figure I.

In Figure I, X_k depicts the ration of actual cost and the responsibility cost in the k month. $\hat{X}_k$ is the optimal estimation value of the ration of actual cost and the responsibility in the k month. If $\hat{X}_k > 1$, which means the profit will be decreased, the manager must pay close attention to the construction method, construction technology and construction organization design, and make the strict management strategy correct the cost management problem. And if $\hat{X}_k < 1$, the current management level is reasonable. The construction enterprise will go on monitoring the construction progress until the project ends.

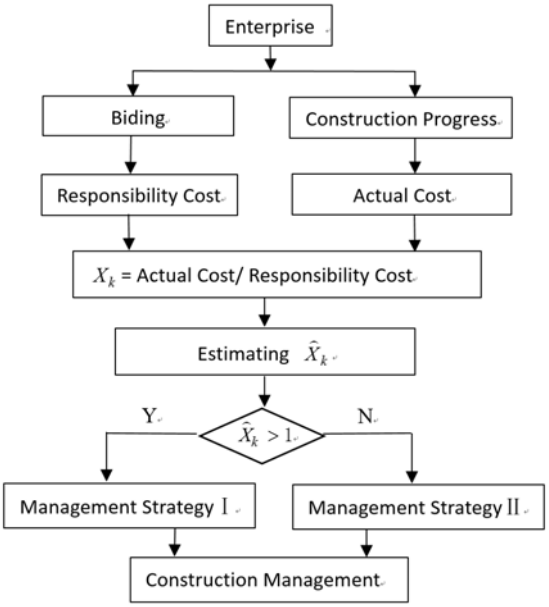

FIGURE I. CONSTRUCTION COST MANAGEMENT FLOW CHART

B. *Construction Cost Data Flow*

In the Figure I, the core is how to estimate the value of $\hat{X}_k$. Before estimating the value, we must understand the construction cost data flow. The construction management process has its special characteristics. First, it has the development inertia, which means the cost management method of last period influences the cost of next period. Second, it has the transitivity, which means the management problem of last period must be solved at the next several periods. So, the actual cost of this period contains the information of last period, even implies the information of next period. Then the construction cost data flow can be illustrated in figure II.

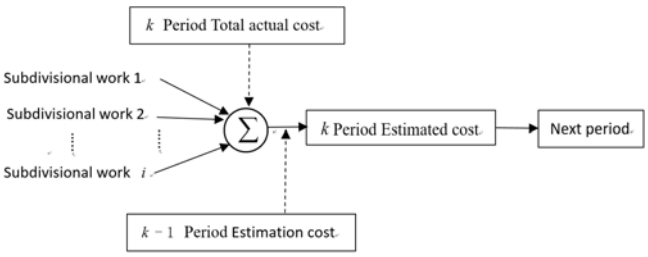

FIGURE II. CONSTRUCTION COST DATA FLOW

From Figure II, we can see that the total actual cost is made from the cost of different subdivisional works, these different subdivisional works have different management levels, so the cost data is affected by many kinds of factors, we can called them noise. In order to estimate the cost precisely, we estimate the actual cost based on Kalman Filter.

III. KALMAN FILTER ESTIMATION MODEL FOR COST

A. *Theoretical Model Comparison*

Kalman filter for construction cost estimation uses the fact that the cost can be expressed in state-space form, that is

$$X_k = f(X_{k-1}, U_k) + W_k \tag{1}$$

$$Y_k = h(X_k) + V_K \tag{2}$$

In (1) X_k depicts the system state at time k, X_{k-1} depicts the system state at time $k-1$, in this paper, the time period is 1 month. Equation (1) depicts the process equation also known as state-transition equation, which describes the dynamics of state X_k (e.g. construction cost) as a function of X_{k-1} and external disturbances U_k plus an error term W_k which reflects errors in the process model (e.g. model misspecification, process noises). Equation (2) depicts the observation equation also known as measurement equation h which relates the system state to measurements Y_k. The error term V_k depicts errors in either the measurement model h and/or the measures themselves.

If the above equations represent a linear dynamic system, f and h are the linear operators that can be expressed by matrices F_k and H_k respectively. As a result, the following equations can be derived:

$$X_k = F_k X_{k-1} + B_k U_k + W_k \tag{3}$$

$$Y_k = H_k X_k + V_k \tag{4}$$

Where W_K is assumed to be drawn from a zero mean multivariate normal distribution with covariance Q_k:

$$W_k \sim N(0, Q_k) \tag{5}$$

And V_K is assumed to be a zero mean Gaussian white noise with covariance R_K:

$$V_k \sim N(0, R_k) \tag{6}$$

After calibration, equation (4) can be used to estimate the construction cost.

B. Construction Cost Estimation Process

The initial state, and the noise vectors at each step $\{X_0, W_1, \ldots W_k, V_1, \ldots V_k\}$ are all assumed to be mutually independent.

In what follows, let the notation $\hat{X}_{k|k}$ represent the posteriori state estimate at time k given observations up to and including at time k; $\hat{X}_{k|k-1}$ represents the state estimate at time k according to the state at $k-1$; $\hat{X}_{k-1|k-1}$ represents the optimizing state estimate at time $k-1$; $\hat{P}_{k-1|k-1}$ represents the error covariance matrix for the state estimate at time $k-1$; $\hat{P}_{k|k-1}$ represents the error covariance matrix for estimating $\hat{X}_{k|k-1}$. So a Kalman filter is iteratively executed in the five distinct steps:

1) state estimation

$$\hat{X}_{k|k-1} = F_k \hat{X}_{k-1|k-1} + B_k U_k \tag{7}$$

2) error covariance matrix $\hat{P}_{k|k-1}$

$$\hat{P}_{k|k-1} = F_k \hat{P}_{k-1|k-1} F_k^T + Q_{k-1} \tag{8}$$

Where T represents transposition.

3) posteriori state estimate

$$\hat{X}_{k|k} = \hat{X}_{k|k-1} + K_k (Y_k - H_k \hat{X}_{k|k-1}) \tag{9}$$

Where K_k represents Kalman Gain.

4) Kalman gain estimate

$$K_k = \hat{P}_{k|k-1} H_k^T / (H_k \hat{P}_{k|k-1} H_k^T + R_k) \tag{10}$$

5) error covariance matrix $\hat{P}_{k|k}$

$$\hat{P}_{k|k} = (I - K_k H) \hat{P}_{k|k-1} \tag{11}$$

Where I is a matrix of 1, for single model system I =0.

According to the equation (7) to (11), we can estimate the value of construction cost.

IV. KALMAN FILTER MODEL APPLICATION

A. Theoretical Model Simplification

According part II, we take the highway construction cost as a system, so the system is regarded as a single model system. And we hypothesize the construction cost management level at time k same as that at time $k-1$, so we define $F_k = 1$. The estimation value is same as the actual data, so we define $H_k = 1$. And In this paper, we regards U_k =0, regard Q_k and R_k as constants. Then the equation (7) to (11) can be changed into:

$$\hat{X}_{k|k-1} = \hat{X}_{k-1|k-1} \tag{12}$$

$$\hat{P}_{k|k-1} = \hat{P}_{k-1|k-1} + Q \tag{13}$$

$$\hat{X}_{k|k} = \hat{X}_{k|k-1} + K_k (Y_k - \hat{X}_{k|k-1}) \tag{14}$$

$$K_k = \hat{P}_{k|k-1} / (\hat{P}_{k|k-1} + R) \tag{15}$$

$$\hat{P}_{k|k} = (1 - K_k) \hat{P}_{k|k-1} \tag{16}$$

If the initial conditions are given as in

$$\hat{X}_{0|0} = \hat{X}_0, \hat{P}_{0|0} = \hat{P}_0, \tag{17}$$

We can estimate the construction cost.

B. Original Data Processing

According to the original data, we can get highway construction responsibility cost and actual cost, and can calculate the ratio between actual cost and responsibility cost. The data in Table Iis an example, it is a part of data we got to illustrate the method of data processing. These data came from only one subdivisional works, an enterprise generally manages hundreds of subdivisional works, so there are a lot of data like these data per month.

When the ratio between actual cost and responsibility cost is 1, we consider the profit of the enterprise is balanced, this is the critical state, so we can hypothesize the initial state of the parameters as follows:

$\hat{X}_{0|0} = 1$, $\hat{P}_{0|0} = 10$, and because we think $\hat{X}_{k|k-1} = \hat{X}_{k-1|k-1}$, then $Q = 0.01$. R can be calculated by empirical data, in this paper $R = 0.15$.

TABLE I. ACTUAL COST AND RESPONSIBILITY COST INITIAL DATA

Responsibility cost	**Actual cost**	②/①
①	②	
10659839.60	13973805.28	1.3109
22531493.43	23055551.97	1.0420
27493812.73	24380823.35	0.8739
41938517.88	40653367.34	0.9694
43429151.34	43002604.59	0.9902
12714676.00	12686128.25	0.9978
50582900.25	50035328.63	1.0270
50551095.60	51486886.95	1.0517
47551558.45	45171964.24	0.8855
49688374.17	49128640.00	0.9887

C. Simulation Results

Figure III gives an example to show the performance of Kalman filter. It can be found that the results become smoother than before. It also show that estimation data can reflect the actual management level.

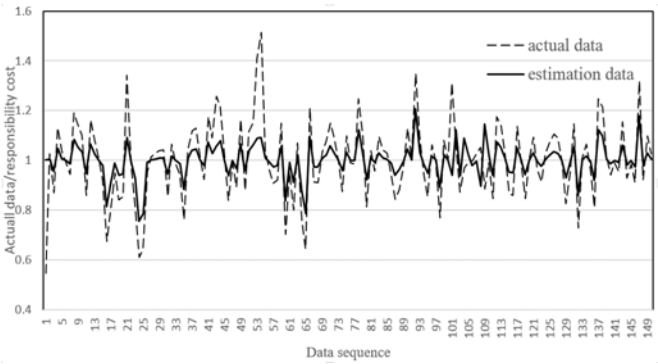

FIGURE III. COMPARISON BETWEEN THE ESTIMATION RESULT AND ACTUAL DATA

V. CONCLUSION

Kalman filter is a method used as the data assimilation technique in many research fields. We demonstrated the Kalman filter is fit for estimating the highway construction cost based on the comparison analysis. After giving the initial state, calculating estimation value of the construction cost, the estimation result shows the Kalman filter is reasonable for smoothing the actual data, and reflecting the actual trend of construction management level, and helping the enterprise to control its construction cost.

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REFERENCES

[1] Ma yong. “Research on the cost management and its application in the whole life cycle”, Doctoral dissertation, Southwest Jiaotong University, 2006.

[2] Liu Yan.. “Research on the evaluation method of the whole process cost control scheme of highway construction project ”, (Doctoral dissertation, Central South University), 2010.

[3] Hong, K. E., & Zhou, F. “Research on performance evaluation index system of highway construction cost management”, Journal of Highway & Transportation Research & Development. 2012 .

[4] Jia Ming Ding, Zhang zhihui,&Li-Xing Ding. “Research of Cost Management Informationization in the Whole Process of Road Engineering”, Journal of Engineering Management, 2013, (3), 62-65.

[5] Hai Jian Li, Tian yuexin, & Li wenjie. “Internet thinking and traditional enterprise reengineering”, China Industrial Economy, 2014, (10), 135-146.

[6] Speyer, J. L. and Chung, W. H. “Stochastic processes, estimation, and control”. Philadelphia:Society for Industrial and Applied Mathematics, 2008.

[7] Simon, D. “Optimal State Estimation: Kalman, H-infinity, and Nonlinear Approaches”. John Wiley & Sons, New York, 2006.

[8] Lee E B , Markus L. “Foundations of optimal control theory”. New York : Wiley , 1967