IMPROVED CALIBRATION FOR HDM-4 IMPLEMENTATION: A LESSON FROM KOREAN EXPERIENCES

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1. Introduction

Many developing countries have been requested to use HDM-4 (Highway Development & Management-4) model by World Bank to get a loan of budget for their infrastructures. In addition, developed countries are also now using HDM-4 model for their various objectives. Even though HDM-4 is well grounded powerful program, many users have been often confronted with difficulty on handling and calibrating HDM-4. That is way HDM-4 contains extremely many variables and functions for road asset management field. Obviously, it is strength, however, this characteristic sometimes considered as a critical weakness to HDM-4 users. Many users now are undergoing difficulty for implementation, especially developing country because they do not have enough fundamental data such as, pavement performance history data, vehicle characteristic, unit cost and so on. In addition, HDM-4 has several critical problems in deterioration model. However they never suspect HDM-4 model itself.

The problem is started from 'Network calibration approach'. Under this structure, only one calibration coefficient set is applied to explain all network sections. If HDM-4 user knows well about characteristic of deterioration characteristic of pavement, he can easily understand or expect its problems. One more thing is fixed estimation function. HDM-4 hired specific estimation shape for each deterioration index. Function of calibration factor *'K'* is only limited to adjust deterioration speed not the process. It should be treated as an important issue. To solve the main problem, this research mainly treated three things; 1) first is defining characteristic and problem of HDM-4 deterioration model. 2) Next is suggestion of section based calibration method. 3) Last will be suggestion of new concept to adjust fixed estimation function in HDM-4 deterioration model using Korea national highway pavement data.

2. Current status of HDM-4 implementation

Report from PIARC (World Road Association) noted that 769 registrations in 109 countries already use HDM-4 model, in addition, its application have been lively applied all over the world. We can easily find many case studies of Thailand, Vietnam, Russia, Tonga, Estonia, Sweden, U.S, Swaziland, Korea, India, Malaysia, and South Africa and so on. A main objective of their researches are a) Network level maintenance strategy, b) Effect of climate difference, c) Feasibility of specific maintenance method, d) Introduction of new pavement material, e) Research on pavement design, f) Comparison of existing (applied) model, g) Optimal maintenance timing, h) Road user effect, i) Socio-environmental effect.

Most countries (or case studies) expressed positive opinion about application of HDM-4 model to their specific objectives. However, they often pointed out problem on handling HDM-4 and limitation of calibration. They usually had performed 1st level of calibration. Even some studies relied on estimation value and only desk study for their calibration. Like this, most of countries did not have reliable calibration of deterioration model. One of important reason is that they tried to find one representative calibration coefficient set for entire network. Even though they applied a road network as a small matrix defined by condition under level of traffic volume, pavement material (or strength), climate, they properly cannot have precision of an analysis. It is impossible to apply one set of calibration factors to the entire network. When we consider uncertainty of road pavement field, the each section requires unique calibration coefficient in accordance with their deterioration characteristic.

Most of reference (even tutorials) did not treated with detail instruction on calibration procedure and its result, especially method of finding calibration factor *'K'*. In our expectation, many parts of calibration were relied on default value suggested by HDM-4 model because most of methodology to find calibration factor *'K'* are based on field data (for higher calibration level) which is

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* Keywords: pavement management, HDM-4 calibration, section base calibration, multi-function approach

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difficult to inspect in a practical manner such as, time-series data, initiation timing of crack, pothole, ravelling and so on. Lastly, there is few paper or report treating HDM-4 itself. Maybe many HDM-4 users already find many problems and critical issues of HDM-4. HDM-4 is now widely applied to all over the world. Even though scientific value is not so high, related information should be shared to an interested party regardless of good or bad practice.

3. Problems and application issues

(1) Difficulty and incorrect of current calibration

It is needless to say importance of calibration of deterioration. Estimation result becomes totally different whether calibration is performed or not. Nevertheless, sometimes case study neglected calibration procedure about deterioration model due to lack of data. That is way they usually tried to apply for 'Network base calibration approach' suggested by HDM-4 manual. Its methodology is a little bit unrealistic. In addition, it is impossible to explain entire network by using one set of calibration factor. In conclusion, 'section base calibration structure' is essential for much correct and practical implementation of HDM-4.

(2) Problem of calibration structure

Most countries are now inspecting crack, rutting and IRI respectively. Usually, they do not consider IRI as a dependence variable. In HDM-4 model, IRI has a role of total index representing all kinds of deterioration indexes. It means HDM-4 user do not have to calibrate and even inspect the other deterioration indexes. In order to solve the problem, estimation model should introduce 'weighting factor' for each calibration factor.

(3) Problem of fixed estimation function

Pavement deterioration process is usually differed by each country, regional condition and even individual section because every road section is in a different circumstance affecting road condition such as, climate, pavement design, traffic volume, material and so on. For these reasons, deterioration model should be flexible against these variables. To consider it, HDM-4 model introduced calibration factor, however, the factor *'K'* can adjust only deterioration speed. Even if HDM-4 user has enough time-series data, they cannot adjust estimation process to match with actual process. Under current system, it can be solved by assigning multi section connecting every 2 time points. However, it is very time consuming work. It is possible only project level application.

(4) Systematic errors

There are several systematic errors in HDM-4. Firstly, condition recovery is sometimes happened without any maintenance option. In addition, Traffic load (MESAL;YE_4) is included in crack progression model as a condition parameter, however, it has no sensitivity to crack progression. Once crack happen, it reaches the final level (100%) after almost same years regardless of condition parameter (most case is taken around 9 years). In addition, HDM-4 default crack estimation model is very sensitive to SNP. In this simulation using default '*K*', crack was never happened where section has more than 4.53 SNP value for 30 years. It means if road agency designs SNP to more than specific level, crack will be never happen in HDM-4 default model.

(5) Representative value of annual pavement condition

HDM-4 model has year based structure. It is calculated by average of beginning and end of the year condition. Under this concept, two kinds of errors are happen. Firstly, when maintenance option is applied, its effect is generated throughout the multi year. Second one is that gap of reset condition is increased as time goes by. This phenomenon is especially serious where section has fast deterioration speed, also long-term analysis period. In this case, it finally makes annual maintenance work. It is critical problem making biased life cycle cost. Above all, if this phenomenon is series, it is impossible to apply practical application.

(6) Scale and proportion of life cycle cost

Many HDM-4 users point out the scale and proportion of life cycle cost. This problem is caused by too much road user cost (vehicle operating cost + travel time cost). One research result[1)] pointed that user cost is occupied around 99.67% of total life cycle cost. Even though the research added socio-environmental cost (air pollutant + workzone + accident cost), proportion of user cost was still more than 95%. We can easily expect that economic result is very sensitive to maintenance standard.

4. Suggestion of HDM-4 calibration method

(1) Section base calibration method

Objective of section based approach is to suggest much easier and correct calibration method. Its concept is shown at **Fig. 1**.

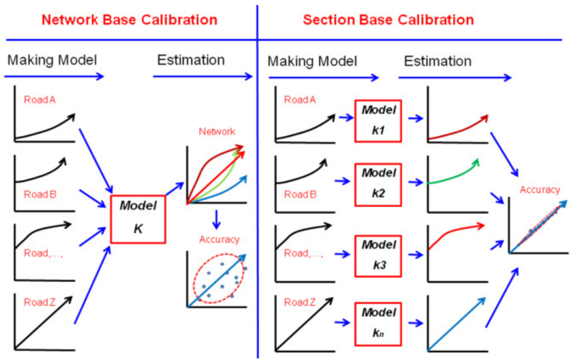

Figure 1: Difference between network and section base calibration

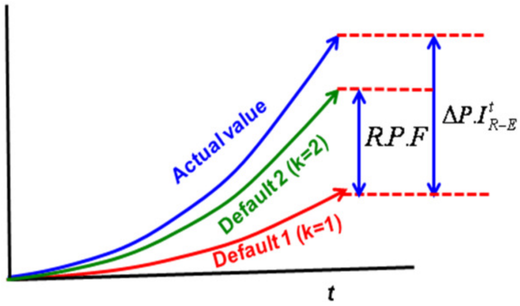

Figure 2: Calculating 'Fitting coefficient'

Section base calibration has much strength. Since this method considers deterioration characteristic of every individual section, naturally it has high precision. Therefore, it does not need to apply probabilistic approach if all sections are possible to apply this approach. Secondly, it does not demand much data. Only one or two inspection data are enough. In addition, calibration coefficient is easily calculated. Lastly, this methodology can be extended to network & matrix level analysis.

Important procedure should be focused on finding calibration coefficient *'K'* of each deterioration index. To find it, understanding of *'Fitting Coefficient'* using Relative Performance Factor (*R.P.F.*) is essential. In this research, 'K_{ci} , K_{cp}'(for crack initiation & progression), 'K_{rpd}'(for plastic deformation of rutting), 'K_{gp}'(for IRI progression) were applied for calibration because it is enough to adjust three deterioration indexes using only calibration factors. The others were leaved as default value which has very small sensitivity to deterioration speed. Concept of fitting method and equation are shown at **Fig. 2** and **Eq. (1)** .

$$K_{prog.} = \frac{\Delta P.I^t}{R.P.F} + 1 \tag{1}$$

$K_{prog.}$ which is calibration factor for progression of each index is determined by using relative performance factor ($R.P.F$) and difference value between inspection and estimation value of HDM-4 default model at time *t* denoted as $\Delta P.I^t$ (see **Fig.2**). Here, $R.P.F$ is unit value estimated by adjusting calibration coefficient. Above equations are only for progression. Therefore, rutting and IRI which are continuously increased from the first year can be directly applied. However, deterioration index having calibration factor for initiation point, like crack, must apply different method. If information about initiation point is secured, of course, it can be estimated by adjusting hypothetical value defined by user. However, such type of data is unusual. In case of crack, HDM-4 model assumed that crack initiation calibration factor 'K_{ci}' is in an inverse relationship with 'K_{cp}'[2]. That is, two calibration factors for crack should be taken as the *'pair type'* which has inverse relationship. If road condition has normal deterioration process against condition variables, its accuracy can be reach to $R^2 = 1.00$. **Fig.3a** (the best case) and **Fig.3b** (the worst case) show the precision of section base calibration approach.

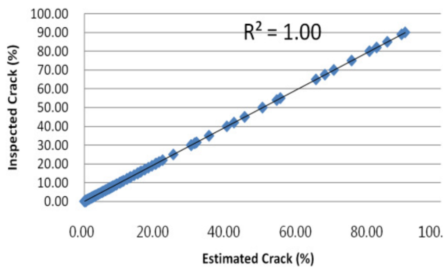

Figure 3a: Accuracy of fitting method (crack)

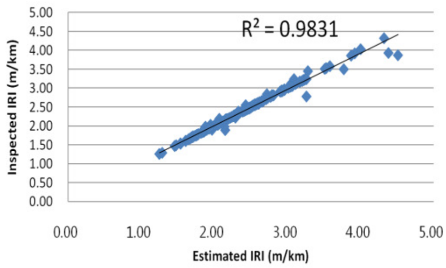

Figure 3b: Accuracy of fitting method (IRI)

Under concept of section based approach using fitting method, representative calibration coefficient for network can be estimated. This methodology has two important meanings; first one is the calibration coefficient represents network characteristic considering traffic volume, pavement strength, environment and pavement deterioration. Next is that it can be applied for no data or error data included section which is impossible to apply section base calibration approach. It is useful for excluded section due to various errors or newly open road. **Fig. 4** shows procedure of network level analysis using 'Section K', with 'Network K', and 'Matrix K'

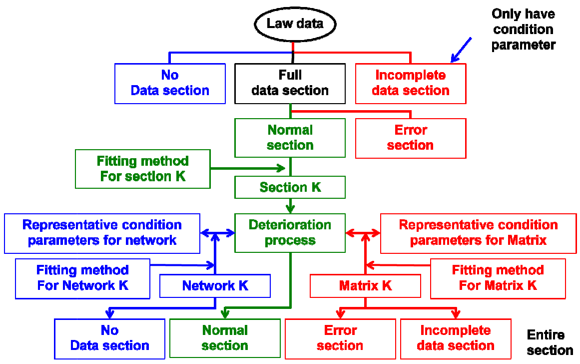

Figure 4: Concept of methodology for whole network analysis by using 'Section K, network K and matrix K'

One of weakness of section base calibration method is that it is a little bit time consuming work. If one country manages road section by every unit kilometer, it will be very hard work. In addition, it cannot consider multi-inspection point to explain much complex deterioration process due to current fixed estimation function of HDM-4.

(2) Suggestion of flexible estimation structure

A main objective of this approach is to suggest new concept for flexible estimate structure. It will be denoted as 'Multi-Function model (or M.F. model)'. That is why this paper called it as a 'Model' because it is possible to forecast deterioration process independently. M.F. model is based on multi condition data without condition parameter. Structure of M.F. model are very easy to understand and easy to apply. In addition, update is also easy. Its basic concept was contrived from '*fitting method*'. However, concept of M.F model is much flexible. Since HDM-4 model has fixed estimation process, calibration is just relied on difference value between two conditions. Properly, estimation result sometimes has over or under estimation value. To solve this problem, M.F. model hires various forecasting functions. Its detail procedures are composed of law data filtering, benchmarking, forecasting, judgment and final decision. Its concept and procedures are explained at **Fig.5** and **Fig.6**.

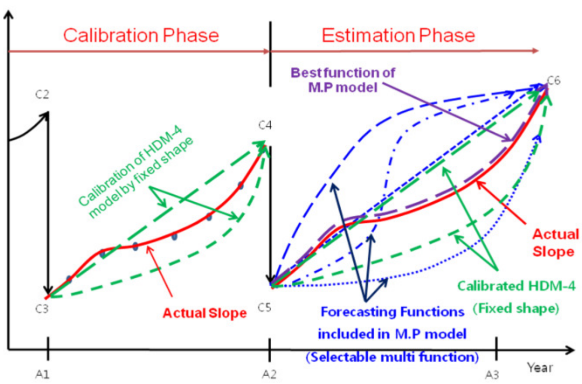

Figure 5: Concept of M.F. model

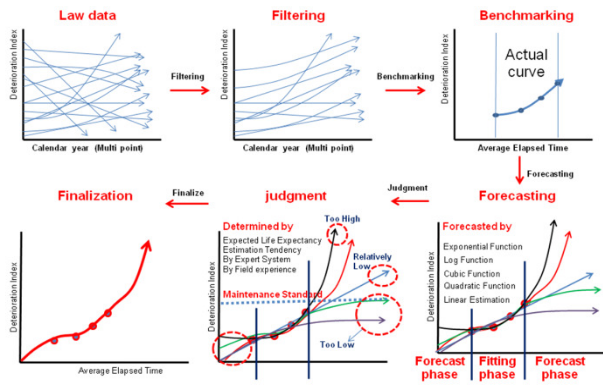

Figure 6: Procedure of M.F. model

5. Empirical study

(1) Application data

Applied data for this research is from Korea Institute of Construction Technology (KICT) who is maintaining Korea national highway. Secured sample scale are 2316 sections having 4 years time-series inspection record from 2003~2006 with many kind of road related data. However, it has many kinds of error. Filtering procedure is essential.

(2) Section base calibration approach

Since objective of this paper is only for deterioration model, estimation of life cycle cost analysis is not included. Application of HDM-4 model will be addressed by dividing into 'Basic calibration' and 'Full calibration'. First one can be defined as calibration on domestic level which is usually called as 'level 1'calibration. Its calibration target is usually vehicle fleet, physical characteristic of each section, unit cost. Last one is adding calibration procedure of deterioration model using section based calibration approach with basic calibration procedure. Based on result of section base calibration method, representative calibration factor and matrix approach also can be applied. Comparison of benchmark process which is estimated by each approach is showing at **Fig. 7**.

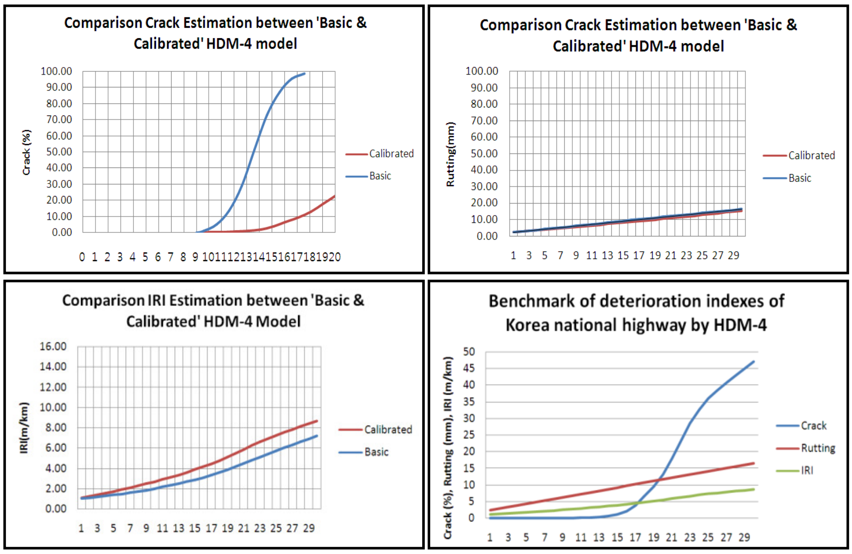

Figure 7: Comparison of benchmark line of basic and full calibration result

In **Fig. 7,** HDM-4 default deterioration model relatively well explained characteristic of rutting and IRI. However, crack has huge difference with full-calibration approach. That is why we need calibration procedure of deterioration model.

(3) Multi function approach

After filtering procedure, sample size was sharply decreased to 272 sections for crack, 339 sections for rutting and 208 sections for IRI respectively. Usually, longer time series data makes less survival probability due to inversed condition which is being better condition without any maintenance activity. To apply multi function approach, benchmark point representing average of elapsed time (X axis) and deterioration level (Y axis) should be firstly estimated. It is easily calculated by average. By using benchmark information, we can forecast past and future deterioration process with precision (R-square) by using various functions (Linear, Quadratic, Cubic, Exponential and Logarithmic Function were applied). If period of collected time series data is shorter, its judgment should be much more depended upon precondition than R-square. It become longer, on the contrary, R-square value has much stronger meaning. Example of crack is shown at **Fig.8**. and **Table. 1**

Table 1: Estimation functions of M.F. model (case: crack)

Function	Estimation function	R^2
Cub.	$f(x) = 0.121x^3 - 2.530x^2 + 19.92x - 47.74$	1.000
Quad.	$f(x) = 0.167x^2 - 0.777x - 0.381$	0.998
Linear	$f(x) = 1.697x - 9.324$	0.990
Log.	$f(x) = 12.28\ln(x) - 21.21$	0.976
Exp.	$f(x) = 0.021^{e^{0.647x}}$	0.953

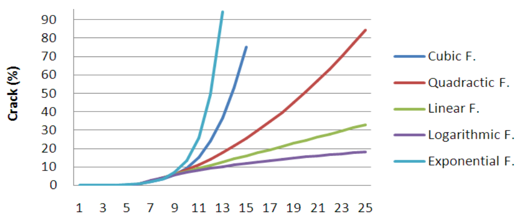

Figure 8: Comparison of forecasting progress (case: crack)

By referring the information of life expectancy of a rating and R-square value, we cannot easily determine best estimation function. Because its time series period was not so It is only possible under several preconditions for judgment. Important thing is that applied standard must be match with pavement deterioration characteristic of each country. As a precondition, life expectancy, deterioration process after maintenance level was applied. As a result, quadratic (crack), exponential (rutting) and linear (IRI) function was determined as a forecasting function. As a matter of fact, last step should be checking accuracy of suggested model. However, there is no way to check its reliability because this paper did not have reliable deterioration process to match with it. Hence, this paper tried to compare M.F model with Markov hazard model[3] using same data. Its deterioration process is compared in **Fig.9a** and **Fig.9b.**

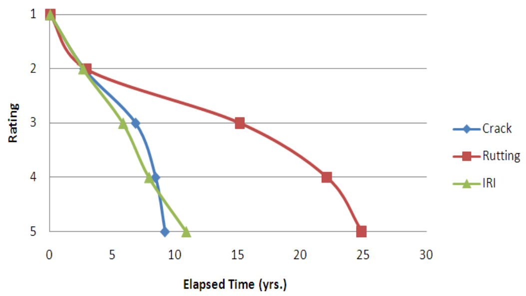

Figure 9a: Benchmark of Markov hazard model

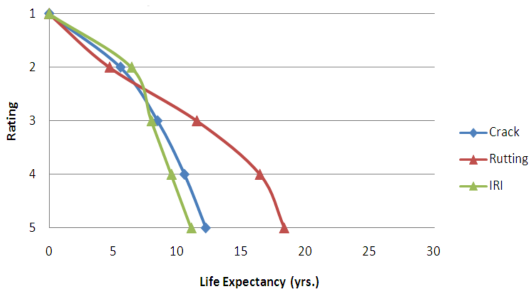

Figure 9b: Benchmark of M.F. model

6. Conclusion

Until now, many case studies of the world are often confronted with difficulty on handling HDM-4 and limitation of calibration because application of HDM-4 model is demanded for too many data and difficult calibration procedures. For that reason, this paper tried to improve calibration method and to define characteristic or problem of HDM-4 deterioration model with case study of Korea national highway. This paper firstly defined main problems of HDM-4 model as; 1) Network based calibration approach, 2) Many structural problem and systematic error in deterioration model and 3) Fixed estimation function. To solve the problems, 'Section base calibration method' and 'Multi function approach' were suggested as main solution.

Suggested 'Section base calibration method' by using 'fitting method' was very easy to apply using minimum calibration data. Although this method is a little bit time consuming work, its calibration precision is very high. Moreover, this method has a wide range of application, such as multi project aggregate method, finding network or matrix base calibration coefficient (Matrix K, Network K) for incomplete data section. Above all, it can be applied right now.

Multi function approach was suggested as a countermeasure of problem on fixed estimation function of HDM-4. In addition, it is possible to directly apply as a forecast model independently. Suggest method is useful when analyzer has more than two inspection point to fit much close to real deterioration process. Since concept of M.F. model can be extended to both 'section base' and 'network base' forecasting, its possibility is very high. The most important strength of M.F model is flexibility on estimation or forecasting. However, its flexibility also can be interpreted as 'Subjectivity'.

Just word in conclusion, one of the most important problems is that HDM-4 is 'Black box'. Even though user found error, they cannot check the problem and modify it. Developer should open the source code to user for better reliable system.

Reference

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