Uncertainty Considered LCC Evaluation For Property Investment By Using Probability Distribution Function

Case study of energy-saving condominium refurbishment

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Keywords: Uncertainty, Probability Function, LCC, Decision Making

1. Introduction

In Japan, extending life-span of existing housing have become the prior principles of residential policy. However, the value of existing housing on market, is underestimated by depreciation even the properties remains in good physical conditions. Therefore, many researches attempted to develop assessment tools which could inspect the physical condition and estimate the utility value of existing housing properly. However, users still have difficulty to decide when or how to invest on their property because the market lacks support tool which could help them find out suitable solutions under uncertainty.

Although LCC (Life-Cycle Cost) analysis is an effective tool which helps us presume the future cost for long-term maintenance plan, it might be possible that simulation result falls short of original prediction after many years because it lacks discussion about the fluctuating parameter and uncertainty. That is, existing method is not reliable enough for decision makers who want to conduct a long term investment so that LCC is not prevalent among personal users.

In short, LCC analysis as a decision-making method needs to consider more about future risk and probability. Thus, this research focuses on improving the serviceability of LCC analysis, in order to support users making decisions.

1.1 Purpose of Research

The main purpose is to propose a LCC model which estimates the whole cost using different alternatives in the planning period with uncertainty analysis. Appraisal model assumes the changeable situations, and incorporates uncertainty factors, such as interest rate into LCC equation in order to analyze the probability distribution of future cost. The results of LCC simulation could help users manage their properties and make decisions at each step of housing life cycle (fig 1).

On the other hand, this research as a decision making support tool attempts to contribute to existing housing market in terms of ideal circulation mechanism of existing housing market (fig 2).

2. Literature Review

Mostly, user's decision making on property investment or maintenance plan depends on the expected return after a long-term planning period. LCC analysis is an useful tool to review users' strategy of housing property management from the point of view of economic life. However, so far it is not prevalent among personal users, which means there is still room for improvement. In order to find out the reason, this research reviewed literatures relating to: 1) Application of LCC analysis on housing research, and 2) Asset management study concerned with flexibility and uncertainty.

2.1 Application of LCC Analysis on Housing Research

There are lots of studies discussing about LCC of housing from different perspectives: Moriya. K focused on examining

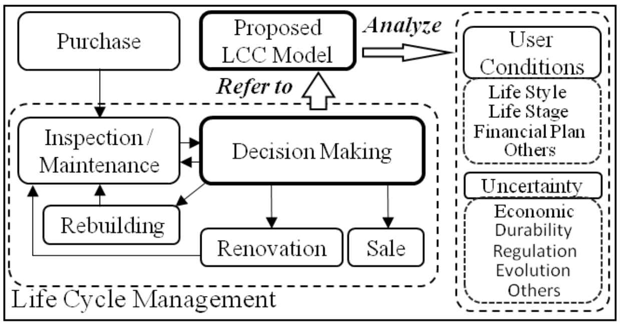


Fig. 1 Decision Making Flow Applying LCC Model

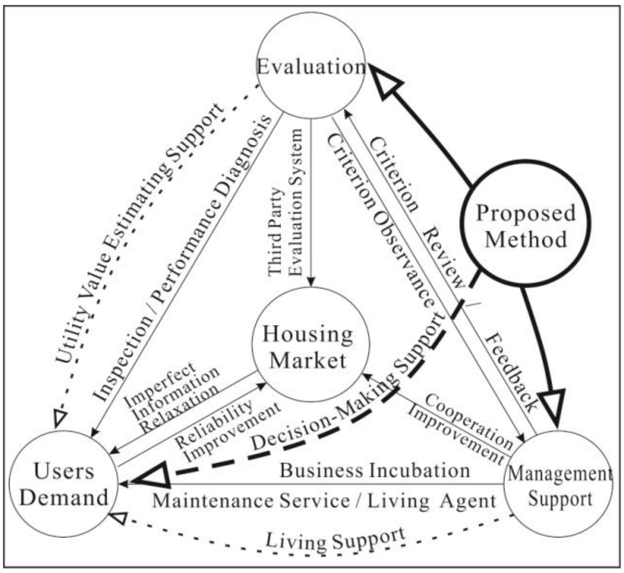


Fig. 2 Ideal Mechanism of Housing Market

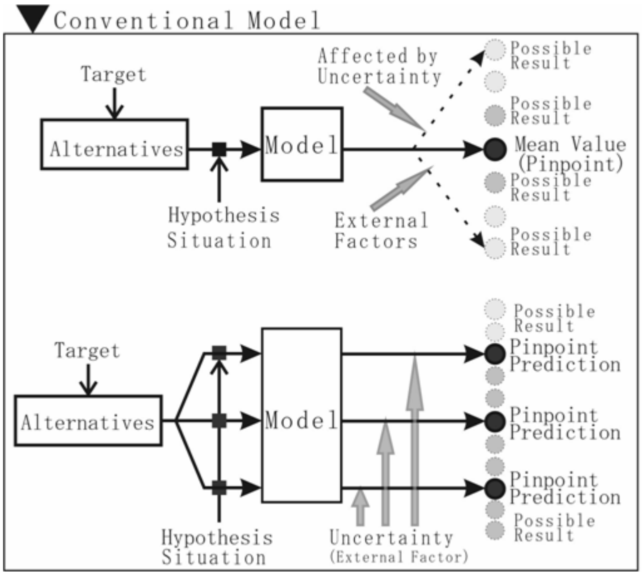


Fig. 3-1 Concept of Existing LCC Model

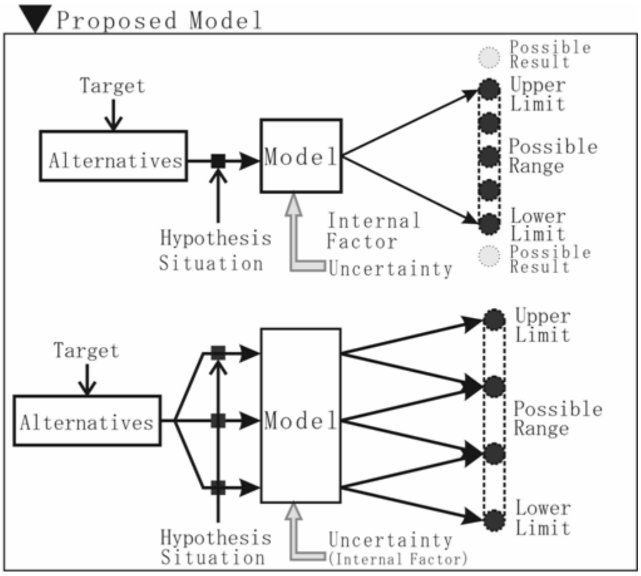


Fig. 3-2 Concept of Proposed LCC Mode

the durable years of components in order to propose an appropriate maintenance cycle (Moriya. K et al, 2000). Igarashi (Igarashi et al, 2004) tried to test the feasibility of layout planning for variable living space which would meet different demands for every stage of users' lifestyle. Kubota. T scrutinized the economical advantage of sustainable housing which was designed in circulative and longevous resource. (Kubota. T et al, 2004).

Most of these researches have generally concluded that LCC prediction is limited by hypothetical conditions critically. Therefore, results are applicable only under particular situations. Dud to the inadequacy of previous approaches, LCC simulation results should be more flexible to include any unexpected situation in the future.

2.2 Asset Management Study Concerned with Flexibility and Uncertainty

Most of the researches in Japan applied DCF (discount cash flow) method to calculate the LCC present value. Under many circumstances, asset value is underestimated in practice by using DCF method. The reason is that in most cases, discount rate is set constant while it is inconstant in reality for a long term. That is, how to adjust management plans or reallocate budgets, is not usually included in the conception of DCF method, (Copeland et al, 2002)

Differing from conventional financial options, ROA (Real Options Approach) provides more flexible options to undertake business initiatives and helps decision makers have a good insight into, explicit the assumptions under their projections. In order to simulate the future risks and possibilities, volatility is presumed by applying binomial distribution to reflect the uncertain fluctuation. Thus, projections associated with uncertainty and probability become more similar to real-life rather than prediction with pinpoint value(Mun,2003).

2.3 Research Contributions

This research adopted both LCC and ROA to estimated LCC present value by using various hypothetical situations rather than limited, and simplified conditions. This model also took the uncertain factors into account in order to illustrate the mean value and possible range of LCC prediction by applying binomial distribution.

3. LCC Analytical Method

3.1 Main Conception of Proposed LCC Model

Most of the LCC studies in housing management are considered with simplified conditions. Parameters which might fluctuate in the future are set as constant value. Also, the result of LCC prediction only shows the pinpoint value under specific hypothetical situation (fig.3-1). It is very possible that the LCC result falls short of original prediction after many years. Analysis by conventional method is not reliable enough for decision makers who want to conduct a long term investment.

Differing from conventional models, parameters with uncertainty (such as fluctuating interest rate) are set as fluctuant values that change with time (fig.3-2) in proposed model. Prediction shows the possible range of LCC in the future under different hypothesis situations rather than pinpoint values. Users with different risk appetites could make decision easier by referring to the probability of upper limit, lower limit and mean value.

3.2 LCC Model by Using Probability Distribution

LCC appraisal model is established as flow below

a)step1: Making LCC Probability Tree by Applying Binomial Distribution (fig.4):

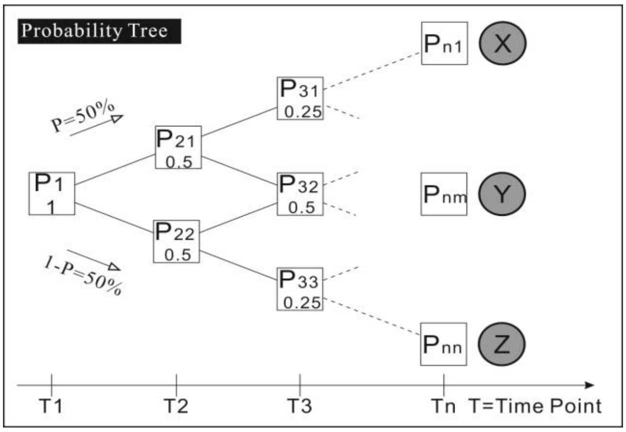


Fig. 4 Making Probability Tree

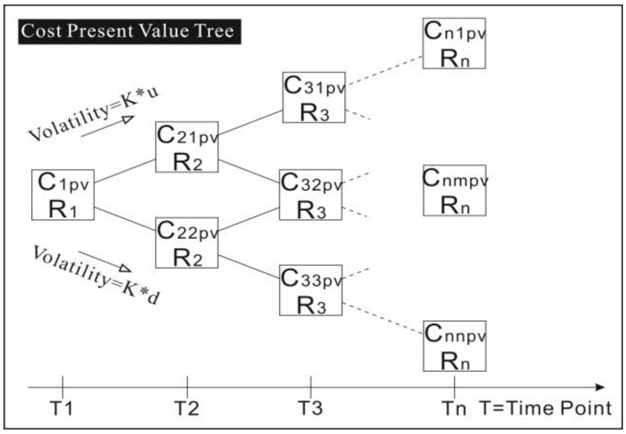


Fig. 5 Making Cost Present Value Tree

Set up first planning period from T1 to Tn which depends on user's plan. Assume the event's probability such as fluctuation of interest rate. In fig4, we set probability=50% to describe the possible trend under uncertainty. Then X, Y, Z represent the final results derived from probability tree after n years. We used the equation (1) below to calculate the probability of each node at each time point:

P_{nm} =probability of events X, Y and Z

$$= C_{m-1}^{n-1} p^{n-m} (1-p)^{m-1} \qquad (1 \leq m \leq n) \qquad ...(1)$$

b)step2: Making Cost Present Value Tree

Apply binomial distribution and probability tree above to estimate possible future cost of each node on possible tree, then apply DCF method to discount them into present value tree by equation (2) below. Then we can draw Cost Present Value Tree as shown in fig 5.

$$C_{nmpv} = \frac{C_{nm}}{R_n} = \text{ present value at node m, time point Tn } ...(2)$$

$$C_{nm} = AW(Ku)^{n-m}(Kd)^{m-1} \qquad (1 \leq m \leq n)$$

Rn: discount rate at time point Tn

A: Cost at T1 W: energy-saving rate (ESR)

K: inflation rate u & d: volatility

The discount rate Rn takes into account not just not just the time value of money, but also the uncertainty of future cash flow; the greater the uncertainty, the higher the Rn. The energy-saving rate (ESR) represents the percentage of consumption change of a plan. It saves more energy and utility cost with lower ESR. Volatility u and d are reciprocal of each other which are the degree of variation of inflation rate K; the greater the uncertainty, the higher the u and d.

c)step3: Estimating the Distribution of LCC Prediction

At time-point Tn, there are n kinds of possible LCC result, and also several routes from T1 to Tn. Possible LCC of specific node at time-point Tn can be calculated by adding up all the cost through the routes. Hence, the distribution of LCC prediction can be figured out (fig 6). Further, the weighted average of all possible LCC is the mean value. We could know how possible the cost-reduction could be by cumulating probability of route which LCC mean is lower than benchmark, the alternative without energy-saving renovation. Take fig 7 as an example, a1 to a21 are the end nodes of each branch which show 21 possibilities of renovation project after 21 years. Among them, 10 (a1 to a10) predictions have lower LCC than benchmark which means they are possible to save cost if project be conducted. Since we know the value of benchmark is between a11 and a10, we could use the cumulative probability of a11 and a10 to proximate the cost-reduction probability of whole alternative.

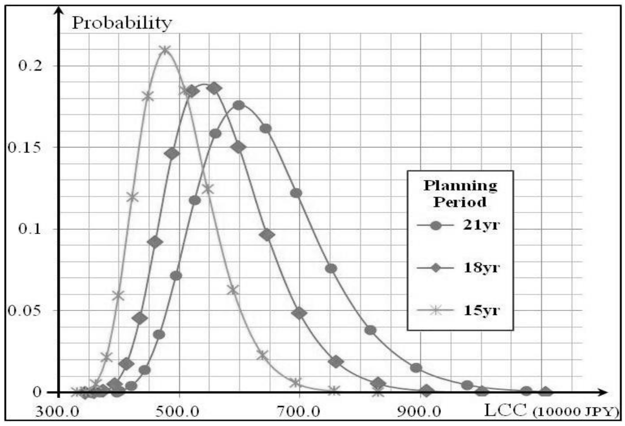


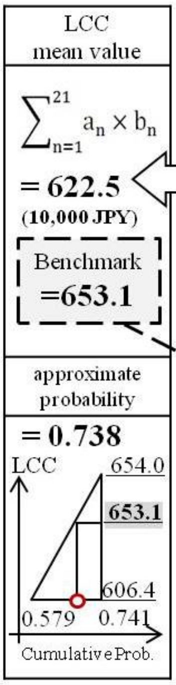
Fig. 6 Distribution of LCC

4. Case Study

We assume a household who attempts to reduce LCC by renovate their condominium with energy-saving equipment. We calculate the LCC (Utilities) in 15, 18 and 21 years based on the yearly expenditures with 314 thousand Japanese Yen.[1] Only utility cost is considered while others are omitted in this case. Three renovation alternatives with different energy-saving rate (ESR) are proposed as simulation objects (table 1) by referring to the setting of ESR of previous

1 estimated by referring the statistical data from Bureau of Statistics of Japan: http://www.stat.go.jp/data/kakei/longtime/index.htm

research (Liao, 2015)[2].



a	LCC of node Tn	b	Probability	Cumulative Probability
a1	1545.3	b1	0.000001	1.000000
a2	1383.5	b2	0.000021	0.999999
a3	1243.5	b3	0.000195	0.999978
a4	1121.7	b4	0.001162	0.999783
a5	1015.6	b5	0.004891	0.998621
a6	923.0	b6	0.015503	0.993730
a7	842.0	b7	0.038391	0.978226
a8	771.1	b8	0.076054	0.939835
a9	708.8	b9	0.122417	0.863781
a10	654.0	b10	0.161675	0.741364
a11	606.4	b11	0.176157	0.579689
a12	563.2	b12	0.158625	0.403532
a13	525.5	b13	0.117841	0.244907
a14	492.2	b14	0.071830	0.127066
a15	462.4	b15	0.035575	0.055236
a16	436.0	b16	0.014095	0.019661
a17	412.4	b17	0.004363	0.005566
a18	391.2	b18	0.001017	0.001203
a19	385.2	b19	0.000168	0.000186
a20	355.4	b20	0.000018	0.000018
a21	340.7	b21	0.000001	0.000001

Fig. 7 The Way to Calculate LCC Mean and Probability

We assumed ESR of different equipments which could reduce running cost by referring to previous research and merchandise catalogue. Please note that the ESR changes in different projects so that it should be revised case by case.

In order to estimate LCC under different uncertainties in the future, we assumed three patterns of hypothetical situation by referring to the historical interest rate trends (table 2). During the planning period, interest rate R(n) has been set as variable parameter rather than fixed value. Pattern X represents a stable economic environment where interest rate and inflation rate rarely change in the near future while Pattern Z describes a unstable future with violent fluctuation. It is allowed to assume various scenarios according to any sort of reliable information, or based on personal experience. By using the proposed LCC appraisal model, the LCC mean value of each alternatives can be estimated as table 3 shown.

Table.1 Three Alternatives with Different ERS

Energy-Saving Renovation Alternative		case A		case B		case C		Benchmark	
		ESR	¥	ESR	¥	ESR	¥	ESR	¥
Electricity	window insulation	85%	57	90%	46	92%	38	100%	0
	eco air-conditioner	40%	30	40%	30	40%	30	100%	0
	LED lighting	40%	6	40%	6	40%	6	100%	0
Water	water-saving toilet	30%	28	40%	18	100%	0	100%	0
	water-saving faucet	50%	1	50%	1	50%	1	100%	0
Gas	high efficiency gas heater	60%	25	80%	15	80%	15	100%	0
Total Cost		147		116		90		0	
Total ESR		72%		78%		81%		100%	

Benchmark : case without energy renovation　¥: 10,000 JPY

ESR(energy-saving rate) = $\frac{\text{energy consumption (before)}}{\text{energy consumption (after)}}$

Benchmark is the LCC mean value of the alternative without energy-saving renovation. Compare to the benchmark, approximate probability represents how possible the cost-reduction could be when the project is conducted.

The result shows that renovation could save utility cost with higher probability when the future fluctuation is comparatively stable in pattern X while the probability is lower in pattern Z. Long-term planning period could also raise the probability of return on investment. Users can make decision by referring to Table 3 in four aspects:

a)Comparing the LCC mean Value and Benchmark:

Alternative is regarded as feasible if LCC mean value is lower than benchmark without probability consideration. This is the most general way to evaluate alternative in existing LCC studies.

b)Referring to the Approximate Probability:

Even with the same alternative, there might be several possible LCCs under different situations (review fig 6 , fig 7).All the possible LCCs of one alternative are compared to the benchmark respectively, in order to estimate how possible

Table. 2 Three Pattern of Hypothetical Situation

parameters		pattern X			pattern Y			pattern Z		
		yr-1	yr-7	yr-13	yr-1	yr-7	yr-13	yr-1	yr-7	yr-13
interest rate	R(n)	0.50%	0.50%	0.50%	0.50%	2.50%	2.50%	0.50%	6.00%	4.00%
inflation rate	K	100.5%			101.5%			102.5%		
rising volatility	u	1.05			1.10			1.15		
falling volatility	d	0.952381			0.91			0.87		
rising probability	P	50%			50%			50%		
falling probability	1-P	50%			50%			50%		

yr-1, yr-7, yr-13: interest rate at first year, 7th year and 13th year

2 In previous research, the ESR and cost of several housing equipments and renovating methods are gatherd and summarized from catalog of different makers. By referring to the statisticl data from Agency of Natural Resources and Energy, the total ESR is estimated by following equation: $W_m = 0.44 \times E_e + 0.2 \times E_w + 0.36E_g$ (Ee=electricity, Ew=water, Eg=gasoline).

Table. 3　LCC Simulation Result of Each Alternatives

alternative	case A	case B	case C	case A	Case B	case C	case A	Case B	case C
LCC mean value	493.4	492.2	483.0	564.8	569.7	564.0	635.0	645.9	643.6
benchmark	485.2			585.0			683.1		
approximate probability	52%	54%	64%	77%	74%	76%	87%	81%	77%
Pattern Y	planning period15yrs			planning period18yrs			planning period21yrs		
alternative	case A	Case B	case C	case A	Case B	case C	case A	Case B	case C
LCC mean value	484.2	482.2	472.7	549.5	553.0	546.6	613.5	622.5	619.2
benchmark	472.4			563.6			653.0		
approximate probability	57%	59%	64%	71%	67%	69%	81%	74%	74%
Pattern Z	planning period15yrs			planning period18yrs			planning period21yrs		
alternative	case A	Case B	case C	case A	Case B	case C	case A	Case B	case C
LCC mean value	462.1	458.2	447.5	520.4	521.5	513.7	580.8	587.1	582.2
benchmark	441.4			523.0			607.4		
approximate probability	56%	59%	64%	64%	66%	72%	73%	71%	72%
Unit: 10000 Japanese Yen									

the LCC can be reduced. Users with different risk appetites can easily decide whether they want to take the risk by referring to probability rather than pinpoint mean value.

c)Comparing the Planning Period:

The most beneficial planning period for user could be figured out by simulating various cases. However, prediction of project longer than 30 years is unreliable (Fawcett, 2001).

d)Comparing the Possibility Under Various Hypothesis Situations:

Because analyzing and verifying the feasibility is quite essential, it is recommended to consider different scenarios as more as possible.

5. Conclusion

In Japan,　in order to smooth the circulation of existing housing market, decision making support tools for personal user need to be improved. Although LCC analysis is useful to estimate housing's LCC present value, there is still room for improvement because it lacks discussions about the fluctuating parameter and uncertainty.

This research proposed a new way to calculate LCC which attempted to estimate the effect of uncertain factors by applying binomial distribution. Differing from conventional models, parameters with uncertainty are set as fluctuant values that change with time so that prediction could shows the possible range of LCC in the future under different hypothesis situations rather than pinpoint values.

By referring the simulation results in four aspects, decision makers with different risk appetites can easily grasps how risky the investment will be under various kinds of hypothetical situations. The applicability of proposed appraisal model has been verified as well.

However, only two uncertain factors, namely interest rate and inflation rate have been taken into account in this case study. How to quantify the rest of uncertain factors relating to LCC calculation such as technology improvement is suggested to be clarified. Also, to demonstrate the practicality through real project is essential for further research.

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不確実性を考慮した確率関数型LCC手法に関する研究
集合住宅の省エネルギー改修を題材として

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キーワード：　不確実性　確率関数　ライフサイクルコスト　意思決定

LCC手法は住宅の生涯費用を積算するために有効なツールであるが、将来の変動や不確実性に対する議論が不足しているため、住宅市場において個人ユーザーの利用が普及しているとは言えない。流通の円滑化には個人ユーザー指向の意思決定ツールが不可欠であるため、本研究では、住宅資産に関する投資問題に直面する意思決定者をサポートするためのLCC評価モデルを提案した。

既存手法により、計算にかかわる不確実要素が外部要素として固定値に設定された結果、予測極めて限られた範囲の予測値しか示さないことが分かった。それに対して、本研究は不確実要素を内部要素とし、二項格子分布(binomial distribution)確率分布を用い、不確実要素の変動の数量化を試みた。その結果、LCCの期待値のみならず、分布範囲とその確率も提示できるようになった。

ケーススタディを通じ、提案モデルにより確率付きの分析結果における応用性を確認した。その結果により、意思決定者のリスク設定によって、異なる予想条件下の投資のフィージビリティーを評価することが容易になることが分かった。なお、今後の課題として、本研究では扱わなかったLCC計算にかかわる不確実要素をさらに検証する必要があると考えられる。

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