Framework for Evaluating Sensitivity on Domestic Energy Consumption

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ABSTRACT

This paper presents a framework for evaluating sensitivity on domestic energy consumption and its experimental simulation. Recently, analyzing the domestic energy consumption and comprehending the influence of life environmental changes are required. However, while the monitored data for energy consumption are indispensable for evaluation, it is difficult to collect a volume of samples. Therefore, this paper presents how to generate artificial data from the limited number of sample data. To generate the artificial data, there are two steps: frequency analysis by data segmentation and goodness of fit test for identifying probability distribution. Then the required data are generated according to the probability distribution. Moreover, according to the probability distribution and the frequency of each segment, Monte Carlo simulation for what-if analysis works for sensitive analysis. The example simulation shows how to resolve the complexity and what kinds of analysis are possible.

Keywords: Evaluation for energy consumption, complex system, what-if analysis, sensitivity analysis, Monte Carlo Simulation

1. INTRODUCTION

Recently, the concern about environmental problems including global warming has increased because the Kyoto Protocol comes into effect. On the other hand, in the residential sector, demand for energy is in increasing tendency by the improvement of the life style and the shift to the service industry [1]. In these circumstance, we should conserve the energy and resources, and develop environmentally-friendly new technologies such as heat pump and co-generation system have developed [2]. Moreover, the evaluation for energy consumption is attracted the attention.

There are some studies with domestic energy consumption. For example, non-instrusive electric appliances load monitoring system [3] and the method for identifying the rate of the measured data by end-use purpose [4][5] have been poposed, and the analysis of energy demand in actual home life has also been disucussed [6]. In fact, collecting and analyzing monitored data are necessary to evaluate the energy consumption. However, at the moment, it is cost-consuming task to set up data collection devices at home [3]. Therefore, it is difficult to to get wealth of data.

Besides, the domestic energy consumption is affected by various factors such as its location, family structure, and wether. In these years, energy consumption patterns have been diversified because of spreading of the nuclear family, dual income, searching for a more comfortable life and so on [2]. It becomes important to understand the influence exerted by change of life environment.

In this paper, we propose the technique for generating artificial data from the limited monitored data. Moreover, we also propose the method of sensivity analysis for domestic energy consumption which uses the probability distribution and frequency obtained from frequency analysis and goodness of fit test. Then example simulation shows Monte Carlo simulation for "what if analysis" works for sensitive analysis.

2. OVERVIEW OF SAMPLE DATA

In this research, we use monitored data of four houses in Kansai area. Table 1 shows property of monitor houses. Two houses (E1, E2) have electricity based energy system, and the another houses (G1, G2) have gas based energy system. The monitor period is one year: June 1th, 2000 to May 31th, 2001. The observed contents include consumption of the amount of hot-water, electricity, gas for every hour, and water temperature for every four hours.

In this paper, we focus hot-water supply for the first step. We have the idea that if we analyze the data of hot-water supply or kitchen which existing electricity

Table 1. Property of Monitor Home

Home	Type of Hot-water Supply System	Address	Family Size (Composition)	Age
E1	Electricity	Sanda, Hyogo	4 (Adult 2, Child 2)	48, 42, 19, 15
E2	Electricity	Ohtsu, Shiga	5 (Adult 2, Child 3)	46, 45, 20, 18, 15
G1	Gas	Toyono, Osaka	4 (Adult 2, Child 2)	37, 33, 8, 4
G2	Gas	Osaka, Osaka	6 (Adult 4, Child 2)	77, 73, 43, 42, 14, 12

consumption data and gas consumption data, the sensitivity analysis of changing energy supply system becomes possible. Then, we had two ideas: analyzing the data of hot-water supply or analyzing the data of kitchen.

The reasons for choosing hot-water supply are as follows:

(1) In general, energy consumption for hot-water supply occupies the largest rate of domestic energy consumption [4],

(2) While the hot-water supply has explicit output which is amount of hot water, there is not definite output for the kitchen,

(3) It is difficult to identify the energy consumption used by stove burner.

3. MODEL FOR ENERGY CONSUMPTION AND ORIENTATION OF THIS RESEARCH

Figure.1 shows the energy consumption model and its relationship with this research. The upper part is the energy consumption model and the lower part is the proposed part.

First, let us explain the energy consumption model. The monitored data are stored in the database. As described in the preceding chapter, each record exists for every an hour or every four hours. Therefore, they are aggregated to daily, weekly data and monthly data.

The inputs of energy consumption model are electrical consumption and gas consumption, and the output is amount of hot-water supply. In our model, inputs are transformed into energy, cost, and CO2 as intermediates. Then the intermediates are transformed into hot water.

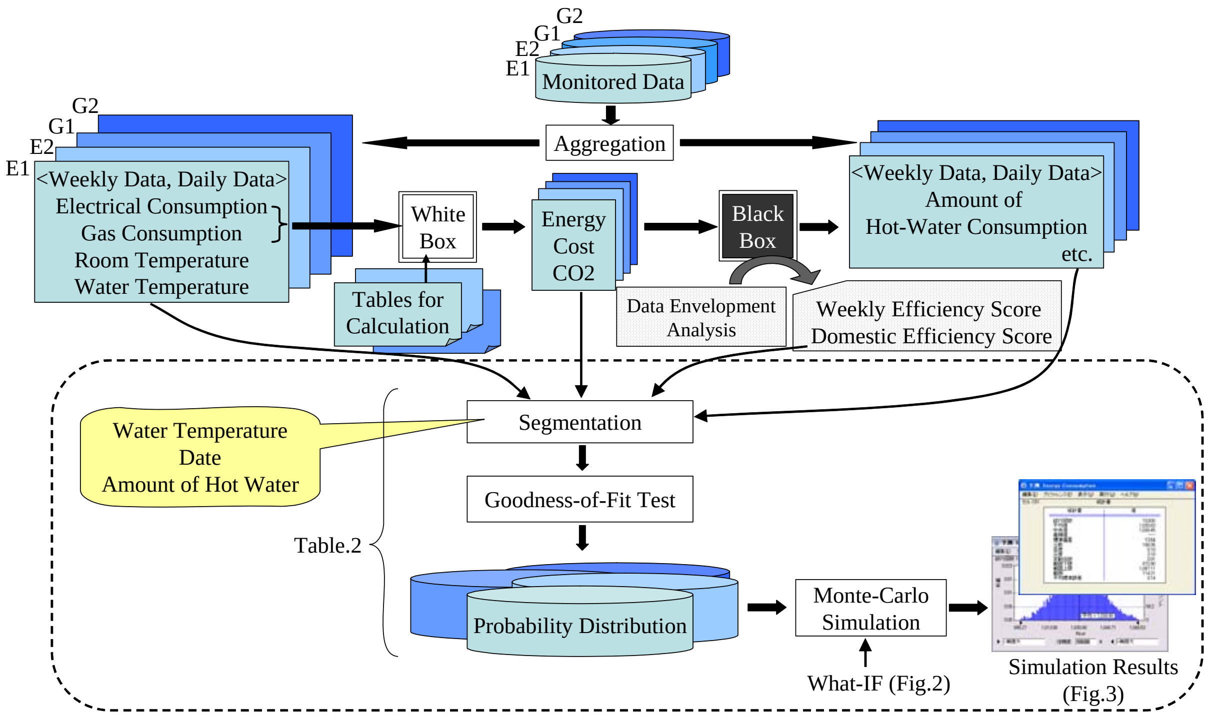

Fig.1 Energy Consumption Model and Orientation of This Research

Generally, the former transformation is a white box which is formulated definitely and the latter is a black box which can not be formulated because the system is complex and the conversion efficiency is affected by uncertainties such as seasonality, amount of hot-water consumption and technical progress.

For the black box, there is research [2] which evaluates the conversion efficiency by DEA (Data Envelopment Analysis) [7]. In this model, there are efficiency scores which are calculated by DEA.

Next, let us describe the lower part. This is the proposed part. The purpose of this research is to propose the method of generating the artificial data from the limited monitored data and of analyzing sensitivity for domestic energy consumption. First, we segment the data of inputs, outputs, intermediates and efficiency scores by adequate axes such as water temperature, date and amount of hot water. Next, we set probability distribution for each segment by the best fit algorithms.

Then the artificial data are generated from the probability distribution. Iterating the what-if analysis based on the probability distribution and frequency, the sensitivity analysis can be done.

4. GENERATING THE ARTIFICIAL DATA

4.1. Segmentation of Monitored Data

As mentioned in the previous chapter, the artificial data are generated from the probability distribution. Then it is important to enhance goodness of fit to increase the reliability. In order not to set one probability distribution to all the data, we segment the data by some axes and give a probability distribution to each segment. In addition, to select adequate axes has important task. If we select an improper axe, it may disserve the data forcibly although the data follow certain distribution.

In this case, we examine six axes as follows:

(1) Date: It divides based on data such as every one month, every season and so on.
(2) Amount of hot-water: It divides based on amount of hot-water consumption such as not over 200 liters, between 200 liters and 400 liters and so on.
(3) Water temperature: It divides based on water temperature such as not over 5 degree Celsius, between 5 degree Celsius and 10 degree Celsius and so on.
(4) Day of the week: It divides based on whether the day is weekday or weekend.
(5) Air temperature: It divides based on air temperature such as not over 10 degree Celsius, between 10 degree Celsius and 15 degree Celsius, and so on.
(6) Air temperature continuity: it divides based on whether the hot day or the cold day continues.

Examining these axes, for the first step, we select amount of hot water and water temperature because they have a great effect on energy consumption of hot-water supply.

4.2. Frequency Analysis and Probability Distribution Fitting

After segmenting the monitored data, we analyze the number of data in each segment and identify probability distributions to them (Table.2). In this research, the numbers of data are assumed to be frequency which each segment occurs.

The probability distribution of each segment is defined by goodness-of-fit tests such as chi-square test, Kolmogorov and Smirnov test and Anderson and Darling Test [8]. These goodness-of-fit tests are done by commercial software such as Crystal Ball [9].

Setting probability distributions to all segments, we statistically verify the relevance of them. Then there are some segments that are identified they are not statistically appropriate. Consequently, we make a hypothesis that disregarding the daily variance may make goodness of fit low. In order to reduce the daily variance, we apply moving average (computation period: 2days and 7 days) to the monitored data [10]. However, the goodness of fit was not improved. Moreover, we have tried to fit probability distribution to the data which are combined monitored data and data done moving average. Though, it did not improve goodness of fit either.

From these results, the reason why the goodness of fit has not improved might be choosing improper axes. Then, for the future work, we will investigate the monitored data and examine the segmenting axes again. However, the purpose of this paper is to propose the methodology. Although there is some question as to the degree of reliability, let us proceed to a discussion based on amount of hot water and water temperature as the segmenting axes.

Table.2 Probability Distribution and Frequency of Energy Consumption for E1

			Water Temperature (degrees Celsius)				
Amount of Hot-Water Consumption (liter)			<10	10-15	15-20	20-25	>25
	<300	Probability Distribution	Extreme-value Distribution	Extreme-value Distribution	Logistic Distribution	Uniform Distribution	Logistic Distribution
		Frequency	6	12	16	19	25
	300-399	Probability Distribution	Extreme-value Distribution	Extreme-value Distribution	Gamma Distribution	Triangular Distribution	Weibull Distribution
		Frequency	34	33	33	28	49
	400-499	Probability Distribution	Extreme-value Distribution	Log-normal Distribution	Extreme-value Distribution	Logistic Distribution	Logistic Distribution
		Frequency	27	21	10	9	9
	>500	Probability Distribution	Extreme-value Distribution	Beta Distribution	Logistic Distribution	Exponential Distribution	Extreme-value Distribution
		Frequency	8	3	1	2	2

4.3. Generating the Artificial Data

After setting a probability distribution to all segments, the artificial data are generated based on the probability distribution. For example, when we generate the artificial data of the house like E1 for one year, we make the hypothesis that the frequency of each segment occurs is equal to E1, and then generate the stochastic variables based on the probability distributions and frequency as shown in table.2. To put it simply, six stochastic variables are generated from extreme-value distribution in the segment which amount of hot-water supply is less than 300 liters and water temperature is less than 10 degree Celsius. Thus, we can get the artificial data.

Additionally, it is possible to generate the artificial data of changing life environment by shifting the frequency. How to change the frequency will be described in next chapter.

5. SENSITIVITY ANALYSIS BY MONTE CARLO SIMULATION

5.1. Monte Carlo Simulation

The idea of Monte Carlo simulation was originally developed for the Manhattan Project during World War II [11]. It randomly generates values for uncertain variables over and over to simulate a model [9]. Monte Carlo simulation can be implemented in spreadsheet.

If there are random elements in the problem, the problem is often solved by Monte Carlo simulation. It is also applied to business area to evaluate the risk which involved in decision making and the effect of changing the policy. The authors have proposed the method to analyze the risk in a supply chain by Monte Carlo simulation [12].

5.2. Sensitivity Analysis

In this paper, the simulation for sensitivity analysis is done based on What-IF analysis [9]. What-IF analysis is the method that examines the all possibilities to be thought. Simulating the change of life environment or family composition based on What-IF analysis, we can investigate in the change of energy consumption as not the fixed value but the range of value such as:

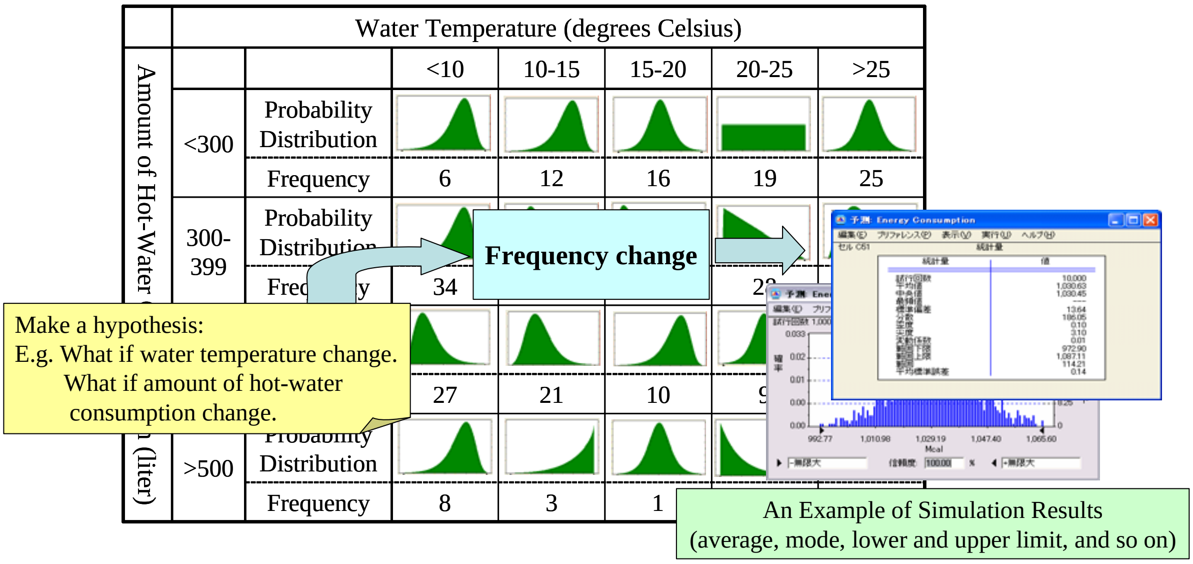

Fig.2 An Example Scenario of Monte Carlo Simulation

(1)What if we consider it on an average?
(2)Which is the most common case?
(3)When is the maximum value taken?
(4)When is the minimum value taken?
(5)How large the variation of forecasted values?

Figure.2 is an example scenario of Monte Carlo simulation for sensitivity analysis on domestic energy consumption by CB. First, we segment the monitored data and analyze the number of data in each segment which shows frequency in one year. Then, we get the probability distribution for each segment by best fit algorithms.

According to the hypothesis that the life environment changes or number of family composition varies, let us change the frequency. For example, when we make the hypothesis that water temperature falls at 5 degree Celsius, the frequencies that hot-water supply is less than 300 liters are change from (6, 12, 16, 19, 25) to (18, 16, 19, 25, 0). This is the crosswise direction frequency change in Figure.2.

Additionally, when we make the hypothesis that the number of family increase by one, the frequencies that water temperature is less than 10 degree Celsius are change from (6, 34, 27, 8) to (1, 20, 39, 15). This is the vertical direction frequency change in Figure.2.

Changing the frequency based on the hypothesis, we do the Monte Carlo simulation based on the probability distribution and the new frequency. For example, after changing the frequency based on the hypothesis that water temperature falls at 5 degree Celsius, the frequency of the segment which amount of hot-water supply is less than 300 liters and water temperature is less than 10 degree Celsius is 18. Then the 18 random variables are generated from the probability distribution which is a set at the segment. Therefore, we can understand the energy consumption when the life environment changes, and by analyzing the simulation results, we can analyze sensitivity on domestic energy consumption.

5.3. Analyze the Simulation Example

In this section, let us show the two simulation results as examples: what if the water temperature falls at 5 degrees Celsius and what if the number of family increases by one. As described in section 4.2, there are some probability distributions which are not statistically appropriate. Then we notice that there is some doubt in the simulation results again.

The Figure.3 shows the screen image of parameter setting and simulation results. First, let us describe the simulation what if the water temperature falls at 5 degree Celsius. Before shifting the frequency, the amount of energy consumption of the segment which amount of hot-water supply is less than 300 liters is 821 Mcal. On the other hand, shifting the frequency based on the hypothesis, the simulation result is 1030 Mcal at the average. Therefore, if the water temperature falls at 5 degree Celsius, the amount of energy consumption increase 209 Mcal at the average thought the amount of hot-water supply is same.

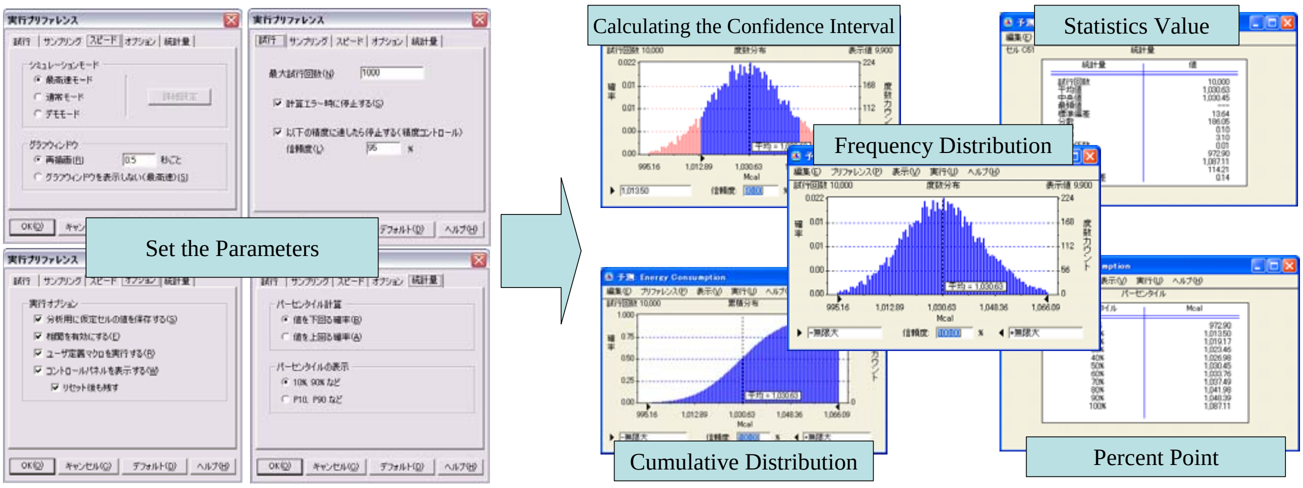

Fig.3 An Example of Simulation Results.

Next, let us show the simulation what if the number of family increase by one. Before shifting the frequency, the amount of energy consumption of the segment which water temperature is less than 10 is 1502 Mcal. On the other hand, the simulation result shows that the amount of energy consumption of the segment becomes 1651 Mcal. That is, if the number of family increases by one, the amount of energy consumption is increase 149 Mcal at the average.

Additionally, as shown in Figure.3, doing the Monte-Carlo simulation, we can know not only the average but also the medium, variance, upper limit, lower limit and so on. It is the advantage of Monte-Carlo simulation.

6. CONCLUSION

We have proposed the technique for generating artificial data from the limited monitored data and the framework for analyzing the sensitivity on domestic energy consumption.

First, we have explained the energy consumption model and described the relation between the model and this research. Then we have shown that by segmenting the monitored data and setting the probability distribution to each segment, it is possible to generate the artificial data from the probability distribution. Moreover, we also have shown that shifting the frequency of each segment based on hypotheses and using the frequency and probability distribution, we can analyze the effect of life environment changing.

Then we have described the two simulations as example: what if the water temperature falls at 5 degrees Celsius and what if the number of family increases by one. These have shown that the simulations can analyze the effect of life environment change. Moreover, doing this simulation, it has been possible to know not only the average but also the medium, variance, upper limit, lower limit and so on.

For the future works, we will investigate the monitored data and segmenting axes to improve the goodness of fit. Additionally, we will develop the method of evaluating the whole domestic energy consumption which is includes air-conditioner, kitchen and so on. Moreover, we will examine the evaluating method which is considering not only cost and CO2 but also comfort and risk.

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