Proposal of a Quantitative Model for Life Cycle Management of Products and Services Using Utility Function

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ABSTRACT

There are a lot of metrics for evaluating the performance of supply chains. However, they may be aggregated as lead-time, customer service, cost and quality. In this connection the EPA in the United States issued in 2000 a practical guide called "The Lean and Green Supply Chain". The purpose of the guidebook is to demonstrate the opportunities for improving both financial and environmental performance and to briefly review specific tools and methods.

In this paper, we would first extend the range of the supply chain to include re-use and recycling throughout the life cycle of products and services. Using our definition, we propose the multiple attribute utility theory method for assessing a supply chain. We consider this approach to be one of the "The Lean and Green Supply Chain" methods. We can then evaluate the performance of a supply chain not only from a managerial viewpoint but also from an environmental performance viewpoint. Secondly, we apply this technique to the application study and confirm the efficiency of the proposal.

INTRODUCTION

Supply Chain Management is a business term that has emerged in the last few years and is gaining in popularity. The typical definition of the term supply chain management [1] is as follows:

The supply chain refers to all those activities associated with the transformation and flow of goods and services, including their attendant information flows, from the sources of materials to end users. Management refers to integration of all these activities, both internal and external to the firm.

In this definition, the entities of the supply chain are defined as manufacturer and its suppliers, vendors and customers. However, there are some differing definitions for supply chains. For example, literature discussing green supply chain management and green purchasing has been published [2]. The US Environmental

Protection Agency has also published a practical guide [3]. In these approaches, the companies have extensive vendor selection and performance evaluation processes, and tend to leverage staff resources throughout the company to achieve environmental goals. They typically expect their suppliers to go beyond environmental compliance and undertake efficient, green product design and/or life cycle analysis activities. The "UNEP/SETAC Life cycle initiative" was initiated in 2000 by a letter of intent from UNEP and SETAC to cooperate in the pursuit of the formulation of Life-Cycle Economy, and the first workshop took place in Tokyo [4].

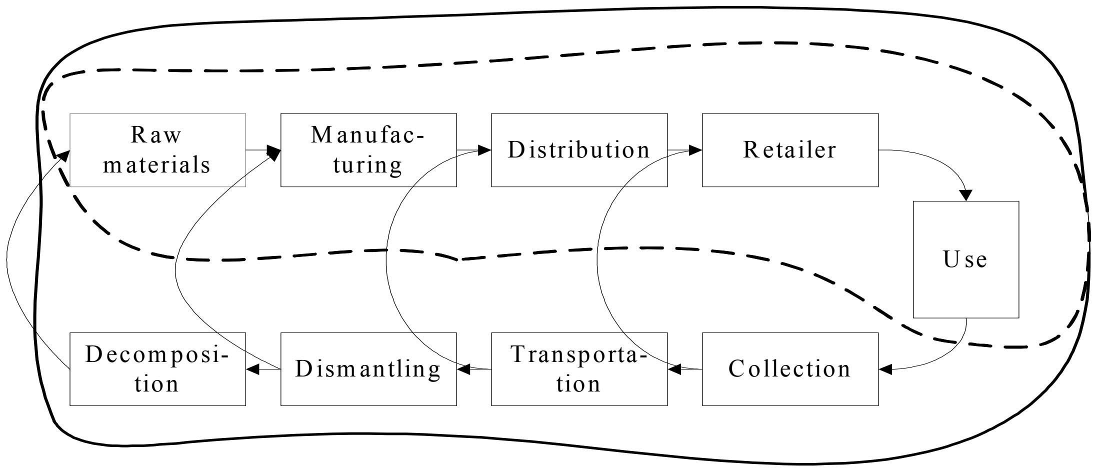

Figure 1 The range of the lean and green supply chain.

In November 2002 another new project called "A Life Cycle Approach to Sustainable Consumption" [5] was created. The aim of these approaches is to reduce CO_2 emission and other environmental loads from a customer viewpoint.

In this paper, we expand the extent of the supply chain to include re-use and recycling throughout the life cycle of products and services. Figure 1 shows the extent of a supply chain which includes dismantling and decomposition. In Figure 1, the range enclosed by a dotted line is the typical supply chain. Using our definition, we propose the new metrics of a supply chain for Lean and Green supply chain management. The metrics are supply chain ROA (return on asset), customer

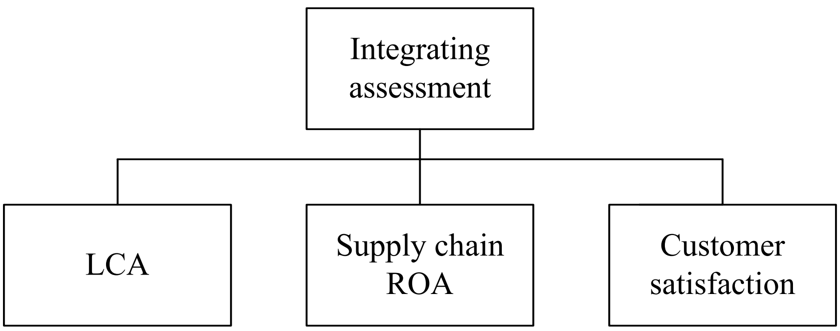

Figure 2 The structure of evaluation of lean and green supply chain.

satisfaction, and Life Cycle Assessment (LCA). We integrate these items by using a multi-attribute utility function.

THE FRAMEWORK OF A MULTIPLE UTILITY FUNCTION APPROACH

Figure 2 illustrates the evaluation structure of the Lean and Green Supply Chain. In the typical supply chain, we can use the metrics from a management viewpoint: Return on Asset and Customer Satisfaction. ROA can be represented by average the stock through a supply chain and Customer Satisfaction can be represented by the out-of-stock ratio. To this we add one more metric, Life Cycle Assessment, which is evaluated from the environmental viewpoint. This approach is called “Lean and Green Supply Chain Management” in this research..

First, in order to analyze the influence of supply chain ROA and customer satisfaction, we make computer simulations by simple two-stage supply chain models. Model-1 follows the traditional pattern and does not provide for information sharing in supply chains. In Model-2 customer demand information is shared in the supply chain, in Model-3 supplier lead-time information is shared, and in Model-4 both demand and lead-time information is shared. From these simulation results can be seen, that customer demand information sharing is beneficial for decreasing the bullwhip effect, and furthermore, that information sharing of customer demand and supplier lead-time is beneficial for the elements that make up a supply chain, such as average stock levels and customer service.

Secondly, in order to quantitatively evaluate the Lean and Green supply chain, we derived the multi-attribute utility function of the supply chain. The multi-attribute utility function is constructed from three single-attribute utility functions: supply chain ROA, customer satisfaction, and LCA. We can evaluate the performance of the supply chain not only from a managerial standpoint but also from environmental aspects, and confirm its efficiency through an application study.

METRICS FROM A MANAGERIAL VIEWPOINT

Many recent studies have indicated that manufacturers tend to share information with their suppliers in order to reduce uncertainty in supply chains [6], [7]. However, the extent of the benefits that can be credited to information sharing among the different entities has not been well quantified.

In this study, as described above, four models are presented. To gain insights into its influence on suppliers and retailers in supply chains this study first probes the impact of demand information sharing using a simple model. Furthermore, the impact of lead-time information and the combination of various kinds of information in the supply chain are investigated.

The research demonstrates that customer demand information sharing is beneficial for decreasing the bullwhip effect, and furthermore, that information sharing of customer demand and supplier lead-time is beneficial for the elements that make up a supply chain, such as average stock levels and customer service.

In this section, the model and the hypothesis are introduced. A supply chain consists of entities with different objectives, all of which are involved in the procurement of raw materials, production and the delivery of products to the customer. Performance of the supply chain is measured by means of cost, lead-time, quality and service [7]. Recent studies have shown that the quick dissemination of relevant information can significantly enhance the performance of a supply chain. Information sharing in one form or another and with few differences occurs between every pair of interacting entities in a supply chain. Suppliers, manufacturers, and retailers tend to reveal information about customer demand, inventory, and supplier lead-time. Currently, the entities within the supply chain are beginning to change their operations. They are beginning to cooperate more, especially with regard to information sharing, which is beneficial for reducing the bullwhip effect and improving the performance of the supply chain.

For the purposes of this study, a supply chain model with a two-stage flow is introduced. The variance in orders may be larger than that of sales, and the distortion tends to increase as they move upstream. This phenomenon is known as the bullwhip effect phenomenon [8], where orders to the manufacturer or the supplier tend to have a larger variance than the demand from the retailer or the manufacturer, and the distortion moves upstream becoming more severe as it advances. Information sharing is generally known for decreasing the variance of the bullwhip effect, and this phenomenon is investigated through simulation by using a simple supply chain model.

Next, the concepts of the model are demonstrated. Figure 3 shows the two-stage supply chain model as an example of a case with no information sharing, whereas Figures 4, 5, and 6 represent three models of information sharing. Figure 4 demonstrates demand information sharing; Figure 5 supplier lead-time information sharing, and Figure 6 both kinds of information sharing. Information sharing could have a beneficial or detrimental effect on an entity depending on the type of

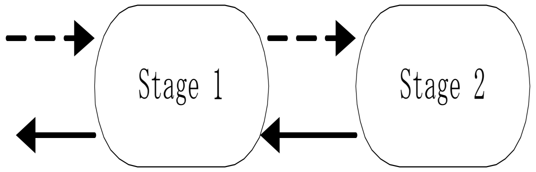

Figure 3 Supply chain model without information sharing; Model-1

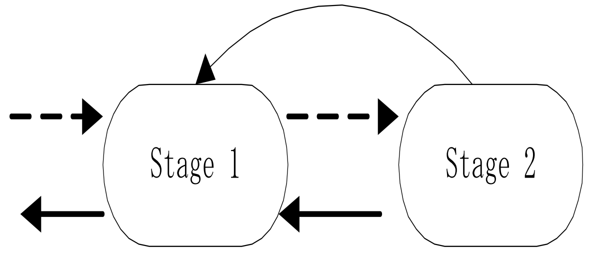

Figure 4 Supply chain model with demand information sharing; Model-2

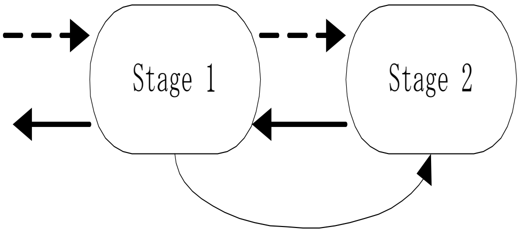

Figure 5 Supply chain model with lead time information sharing; Model-3

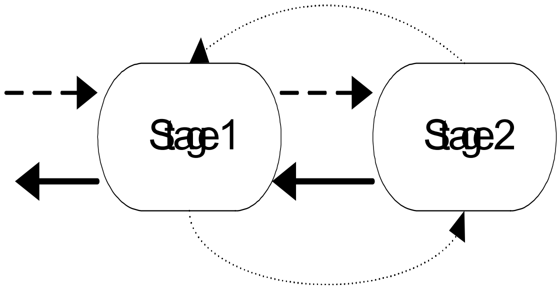

Figure 6 Supply chain model with the both kinds of information sharing; Model-4

information and with whom it is shared [9]. It is especially important to clarify what information is beneficial for an entity in a supply chain.

<Reorder Point>
The ordering system is outlined. Each entity in the supply chain orders goods according to an ordering point system. The sequence of events in the simulation is as follows:
1) Single-item is assumed.
2) Stochastic demand occurs.
3) Customer orders goods to stage one.
4) Unfulfilled demand is lost.
(1) No information sharing: Model-1

In the case of no information sharing between supply chain partners, a reorder point formula is given by equation (1).

$$K_i = \overline{D}_i \cdot T_i + u(\alpha) \cdot \sqrt{T_i}\hat{\sigma}_{D_i} \tag{1}$$

where $K_i =$ reorder point , i-th stage ,

$\overline{D}_i =$ average demand , i-th stage

$T_i =$ lead-time, i-th stage

$u(\alpha) =$ safety coefficient
$\alpha =$ out-of-stock rate

$\sigma_{D_i} =$ demand standard deviation , i-th stage.

(2) Information sharing: Models-2, Model-3, and Model-4

In the case of information sharing between the supply chain partners, the reorder point formula is also given by equation (2).

$$K_i = K_{i-1} + \overline{D}_1 \cdot T_i + u(\alpha) \cdot \sqrt{T_i}\hat{\sigma}_{D_1}, (i \geq 2) \tag{2}$$

In this formula, the reorder point is driven by the sum of the echelon inventory and the existing inventory in the model. This is different from an ordinary reorder point.

<Evaluation>

There are many measurements for evaluating the performance of supply chains. However, they may be aggregated as lead-time, customer service, cost, and quality. In this study, the performance of the supply chain is evaluated from the following measurements:

(1)Sum of ratio of variance

$$\sum_{i=1}^{n} F_i(I) = \frac{V_1(O)}{V(D)} + \frac{V_2(O)}{V(D)} + \cdots\cdots + \frac{V_n(O)}{V(D)} \tag{3}$$

(2) Average stock

Average stock in the supply chain is given by equation (3):

$$\bar{I} = \frac{1}{n}\sum_{i=1}^{n} I_i \tag{4}$$

where I_i = inventory, i-th stage.

(3) Out-of-stock ratio.

The first measurement, the sum of the variance ratio, evaluates the degree of the reduction in the bullwhip effect in supply chains brought about by information sharing. The second, average stock, evaluates the performance of total supply chains. This measurement has the same meaning as the ROA, and this is a measurement that favors business. The third measurement, Out-of-stock ratio, evaluates and favors customer service.

COMPUTATIONAL ANALYSIS

Computational Study

This section is a description of the experimental setup and the results of the computational study. The conditions in the simulation are as follows:

1) Stochastic demand with auto-correlation occurs: $N(10, 5^2)$

2) The order quantity of the first stage is 100, second 200.

3) The lead-time of stage one has variance, and the lead-time of stage two is fixed.

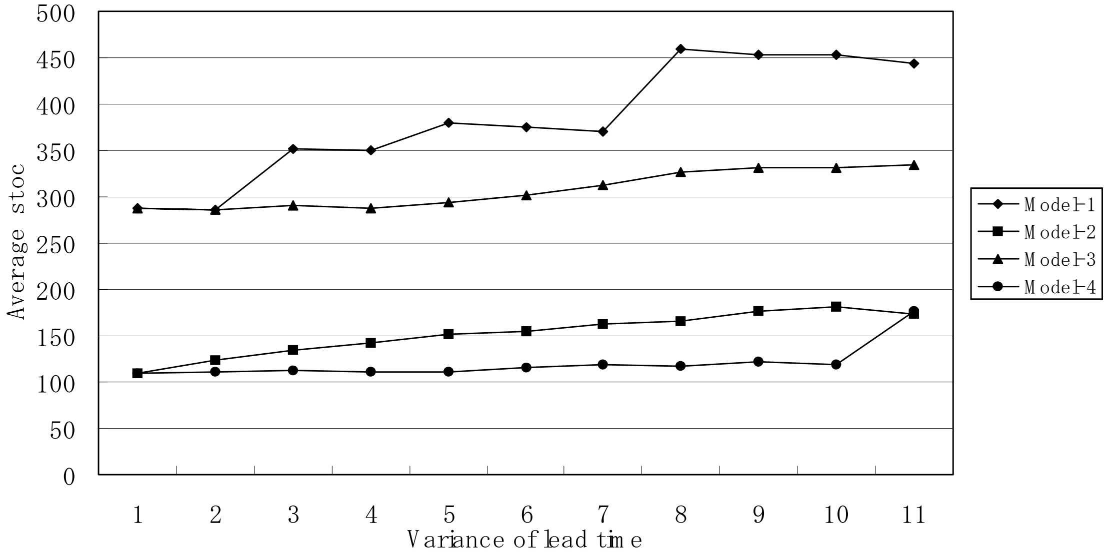

Figure 7 The results of average stock in computational analysis.

4) The lead-time distribution of stage two is assumed to be a Poisson distribution.
5) Out-of-stock rate $\alpha = 0.025$, $u(\alpha) = 1.96$ is assumed.
6) The number of iterations is 1000.

Results and Discussion

Each of the experiments for 1000 periods was conducted. In each experiment, a set of seeds was used for random number generation as demand series. First, we confirmed that information sharing is effective for decreasing the bullwhip effect in the simulations. As a result, Figure 7 shows the average inventory of the supply chain resulting from the simulation. This figure demonstrates that the three kinds of information sharing are useful for a reduction of the average stock, especially, the average stock of Model-3 and Model-4 are low level.

The above results on decreasing bullwhip effect and inventories in supply chains validate our Hypothesis, which states that information sharing is beneficial to all the entities in term of decreasing the bullwhip effect and inventories in supply chains.

METRICS FROM AN ENVIRONMENTAL VIEWPOINT

Lean and Green Supply Chain

We evaluate the expanded supply chain by using the structure in Figure 2. From this structure, we are able to evaluate the supply chain from the supply chain ROA, i.e. average stock, customer satisfaction, out-of-stock ratio, and the Life Cycle Assessment [9]. LCA is a measure of the effect on the environment and the contribution to the social aspect. In order to evaluate the supply chain quantitatively, we derived the multi-attribute utility function based on the structure.

An LCA analysis is a multi-criteria optimization problem, which can be considered in the following form:

$$\max_{x \in X}\{f_1(x), f_2(x),....., f_n(x)\}, \tag{5}$$

where $f_i \in R^1, i = 1,2,.....,n,$ is an objective function of n-dimensional decision variables, and x and X is a set of feasible decisions.
Consider this overall optimization problem (4) in a decomposed form:

$$\max_{x_i \in X} U\{f_1(x_1), f_2(x_2),....., f_n(x_n)\}, \tag{6}$$

where i is a n_1- dimensional decision variable in a subsystem i. The function U in (5) is an overall preference function. The multi-attribute utility theory assesses in a different form as follows:

$$\sup_{x_i \in X} U\{u_1(x_1), u_2(x_2),....., u_n(x_n)\}. \tag{7}$$

In this formulation, x_i denotes the measure of effectiveness of each objective. In addition, $u_i(x_i)$ is a single-attribute utility function, and X is an attribute space, which is constructed $\{x_1, x_2,....., x_n\}$.

The multi-criteria optimization problem is designed to specify the functional form of formulation (6). Along the lines of Keeney and Raiffa [10], under the assumption of preferential and utility independence, the function (6) is assessed in the following way:

Additive utility function:

$$U(x_1, x_2,.....x_n) = \sum_{i=1}^{n} k_i u_i(x_i),\ if\ \sum_{i=1}^{n} k_i = 1 \tag{8}$$

or multiplicative utility function:

$$U(x_1, x_2,.....x_n) = \frac{1}{K}\left[\prod_{i=1}^{n}\{1 + K k_i u_i(x_i)\} - 1\right], \quad if \sum_{i=1}^{n} k_i \neq 1, \tag{9}$$

where

(1) U and u_i are utility functions scaled from 0 to 1,

(2) $0 \prec k_i \prec 1, i = 1,2,.....,n$, and

(3) $if \sum_{i=1}^{n} k_i \neq 1$, then $K \succ -1$ is a nonzero solution

to $\quad 1+K = \prod_{i=1}^{k} (1+Kk_i).$

The type of single-attribute utility function are as follows [10],[11]:

$$u_i(x_i) = a - b\exp(-cx_i) \tag{10}$$

$$u_i(x_i) = a + bx_i \tag{11}$$

Equation (10) is for risk aversion type and risk prone type functions, which except for initial conditions are essentially the same. Equation (11) is identified as the risk neutral utility function.

A case Study

When discussing lean and green supply chain management, it is useful to evaluate the opinions of other researchers in the environmental management field. For this reason, we conducted interviews with researchers as the decision makers. First, single-attribute utility functions were identified using the 50-50-chance lottery technique. The identified single-attribute utility functions for x_1, x_2, x_3 are as follows:

$$u_1(x_1) = -6.919\{1-\exp(0.135\,x_1)\}$$
$$u_2(x_2) = 1.846\{1-\exp(-0.0078\,x_2)\}$$
$$u_3(x_3) = \frac{x_3}{100}$$

Figures 8 to illustrate the single-utility function for x_1, x_2, respectively. Figure 8 shows the utility function is risk prone, and risk averse. From these figures, the attitude of decision maker against the risk can be clarified. Secondly, since trade-off examinations and the p_1-chance lottery technique are conducted, the multi-attribute utility function is derived. The multi-attribute utility function for the overall goal is as follows:

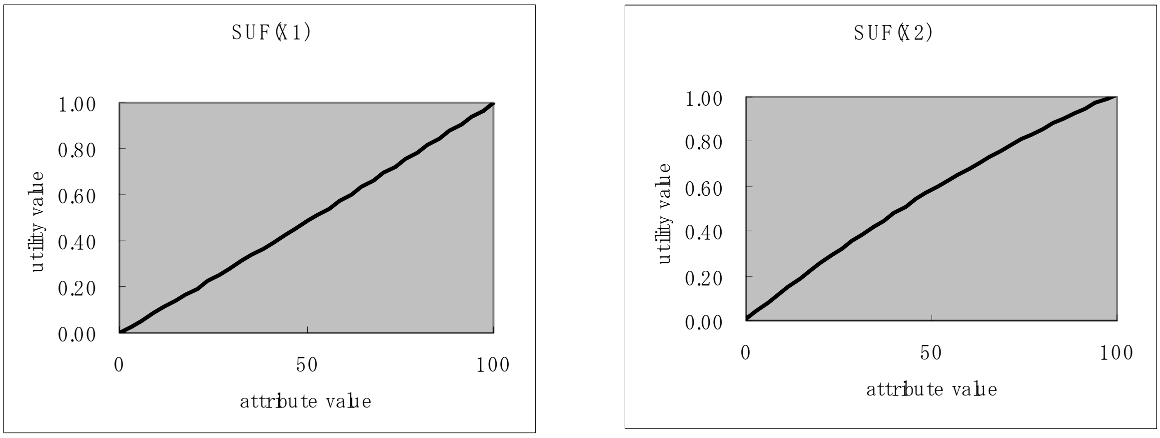

Figure 8 Single-utility Functions for attribute x_1 and x_2.

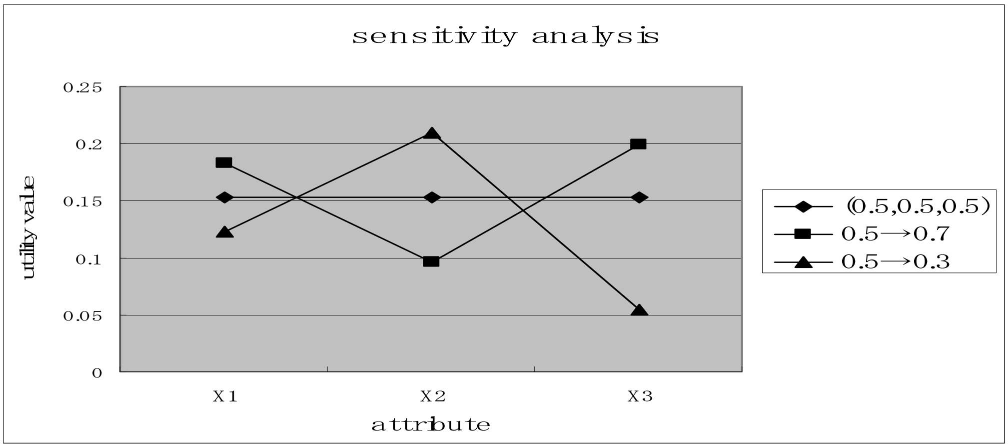

Figure 9 The results of sensitivity analysis.

$$U_{123}(x_1, x_2, x_3) = -\frac{1}{0.816}[\{1 - 0.132u_1(x_1)\}\{1 + 0.306u_2(x_2)\}\{1 - 0.374u_3(x_3)\} - 1]$$

This is written in the form of a combined three single-attribute utility function. The supply chain can therefore be conducted in a comprehensive manner using this multi-attribute utility function. In order to analyze the sensitivity of the utility function, we vary the attribute values. The first trial is to move the value from 0.5 to 0.7 and the second from 0.5 to 0.3. The result is illustrated in Figure 9, and this figure shows that the decision makers emphasize the managerial viewpoint.

CONCLUSIONS

In this study we considered the extent of lean and green supply chain management. We defined new ranges of supply chain management that can evaluate the lean and green supply chain. We first performed computational experiments to analyze the effect of information sharing in the supply chain. We quantified the benefits of information sharing that can decrease the average stock level in the supply chain and the out-of-stock ratio at a retailer at a certain level. We then applied the multi-attribute utility theory to the lean and green supply chain. We derived single-attribute utility functions and multi-attribute utility functions for the decision maker, so we were able to quantify the utility value of the supply chain. From the sensitivity analysis of the utility function, we observed the preference of the decision maker.

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