INVERSE SIMULATION FOR RECOMMENDATION OF BUSINESS SCENARIO WITH QUALITATIVE AND QUANTITATIVE HYBRID MODEL

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Abstract: In order to decide an effective management plan, managers often draw up and evaluate business scenarios. To make the evaluation, a simulation method on the qualitative and quantitative hybrid model represented as causal graph has been proposed. There is a strong need to get optimal input values for the target outputs in the simulation, but exhaustive search can not be realistically applied to it from considering the processing time. Therefore, we propose a quick search method for optimal input values cencerning the qualitative and quantitative hybrid simulation. Our approach is to get optimal values of input nodes by inverse propagation of effects from the value of target output nodes on the simulation model. However, it generates the contradiction that the value of a separated node in the causal graph decided from one of destination nodes is different from the value of the other destination nodes. Therefore, we re-execute the inverse propagation repeatedly from the nearest qualitative node connecting to a quantitative node for solving the contradiction. By experimental results about the proposed method, time could be reduced for reaching the solution. We also could confirm a certain level of accuracy about the solution.

1 INTRODUCTION

In order to decide an effective management plan, managers often draw up and evaluate business scenarios that indicate a series of changes about business factors. For evaluating the business scenarios, the modeling and simulation is often used(Forrester, 1961). However, it was considered to be difficult to execute simulation on the models including both qualitative and quantitative information which are general factors of business systems(Kuipers, 1986).

Based on this situation, a simulation method on qualitative and quantitative hybrid model has been proposed(Samejima et al., 2007a). In the method, both qualitative and quantitative factors can be handled in a model. The model consists of nodes which show business factors and arcs which show cause-effect relations between the business factors. All nodes have values, and in the simulation, they are changed by propagation of effects through arcs. The value of input nodes are decided according to the business plan, and the value of output nodes are checked for evaluation of the plan. In the method, the propagation of the effect between quantitative and qualitative nodes is achieved using random numbers by monte carlo method. So, the outputs are represented as a form of probability distribution.

On the hybrid simulation, it is required to decide optimal input values that bring target output values at the highest probability. Of course such an input can be decided by exhaustive search, but it takes much time. Therefore, we propose the quick search method for optimal input in the hybrid simulation.

In order to decide the optimal input for the target output, our approach is simply utilizing the simulation model proposed in the work(Samejima et al., 2007a), which is made by users for cut-and-try solution. In the model, propagation of effects between nodes is defined as a rule. It is considerd to be possible to decide the value of source node from the value of destination node by using the rule inversely. Therefore, values of input nodes are obtained by deciding the value of source nodes repeatedly. The values of input nodes obtained from that way is considered nearly as the optimal input value, so we repeat the inverse simulation to get probability distribution on input values.

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2 INPUT VALUE SEARCH ON HYBRID SIMULATIONL MODEL

2.1 Qualitative and Quantitative Hybrid Simulation

In qualitative and quantitative hybrid simulation, both factors are handled together in a model. The model consists of qualitative and quantitative nodes, and arcs between nodes. Qualitative nodes were given with the value range. In this method, because the propagation of an effect between quantitative and qualitative factors is achieved using random numbers by monte carlo method, output is distribution of probability as shown in Fig.1(Samejima et al., 2007b).

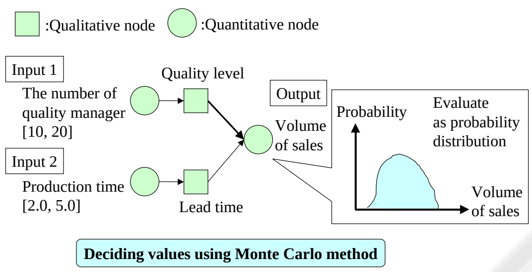

Figure 1: Qualitative and quantitative hybrid simulation.

Propagation between quantitative nodes is decided by mathematical expression given by the user. Between qualitative nodes that are given with state values (five kinds of values), the value of destination node is decided as the pair of the value of source node in consideration of cause-effect relation (ex. monotonically increasing or decreasing).

We describe about the propagation between qualitative and quantitative nodes as follows. A quantitative node connecting to a qualitative node is divided into five ranges by landmarks given by the user, and the particular range is paired with the state value of the qualitative node on the basis of cause-effect relation, as shown in Fig.2

- Propagation from a qualitative node to a quantitative node

  In the corresponding pair of range with the state value of the qualitative node, a unique value of the quantitative node is decided by generating random numbers.

- Propagation from a quantitative node to a qualitative node

  The state value of the qualitative node is decided as the corresponding pair of range made by landmarks in which the value of quantitative node exists.

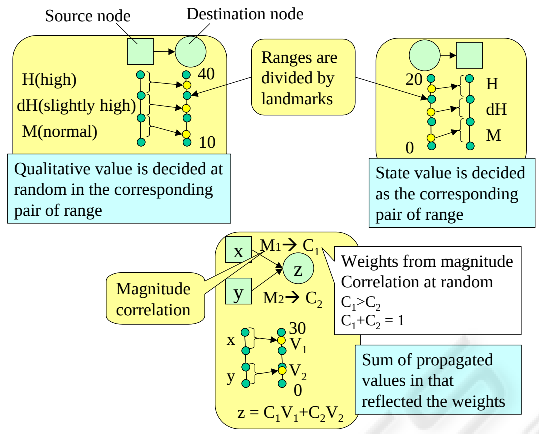

Figure 2: Propagation of effect between qualitative and quantitative nodes.

- Propagation from multiple nodes to a node

  Propagation from each source node to the destination node is executed by the above-mentioned manner. On the basis of magnitude correlation about connecting arcs to the destination node, weighting coefficient about each arc is decided using random number. As a result, sum of each propagated value multiplied by the coefficient was decided as the value of destination node.

In propagation of effect from a qualitative node to a quantitative node, the value of destination node is not decided in a unique manner. So by repeating a chain of propagation in a model, distributions of the values about output nodes are generated.

2.2 Problems about Searching Optimal Input Values

As we mentioned in the introduction, it is required to decide optimal input values that bring target output values at the highest probability. On the hybrid simulation, the optimal input can be decided by exhaustive search. However, it takes much time because a certain amount of time is needed to get an output of distribution in the simulation. The brute-force search is not considered to be realistically available. Therefore, we propose the quick search method for optimal inputs in the hybrid simulation.

3 MODEL-BASED INVERSE PROPAGATION

As mentioned in section.2.2, it is difficult to decide optimal input values by exhaustive search in the qualitative and quantitative hybrid simulation. Therefore, we propose the method to obtain optimal input values for the target outputs quickly.

3.1 Problem on Inverse Propagation

In order to decide the optimal input for the target output, our approach is to use original simulation models defined by users. On the model, propagation of effects between a source node and a destination node is defined as a rule. So, it is possible to decide the value of source node from the value of destination node by using the rule inversely. We define the inverse propagation as shown in Fig.3.

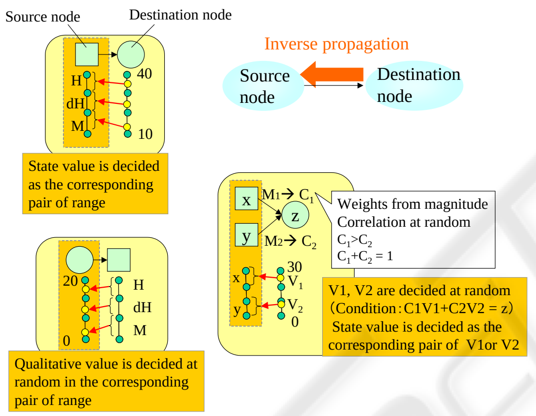

Figure 3: Inverse propagation between qualitative and quantitative nodes on a model.

- Inverse propagation from a quantitative node to a qualitative node
  The state value of the qualitative node (source node) is decided as the corresponding pair of range made by landmarks in which the value of quantitative node (destination node) exists.
- Inverse propagation from a qualitative node to a quantitative node
  In the corresponding pair of range with the state value of the qualitative node (destination node), a unique value of the quantitative node (source node) is decided by generating random numbers.
- Inverse propagation from a node to multiple nodes
  On the basis of magnitude correlation about connecting arcs to the destination node, weighting coefficient value about each arc is decided at random. Moreover, a random number about each arc is generated so that sum of the products about the random numbers multiplied by the weighting coeeficients is corresponding to the value of destination node. Finally, the value of each source node is decided, by inverse propagation of each arc's random number in the above-mentioned manner.

A set of values about input nodes that will generate the target output can be obtained by deciding the value of source nodes repeatedly. The set of values about input nodes is considered as candidates of the optimal values of input nodes, so we repeat the inverse simulation to get probability distribution on input values. The sets of values got at high possibility are defined as the optimal inputs.

However, if a source node has more than two destination nodes, called "branch node", there is a possibility that the value of source node from one of destination nodes is different from the value of other ones as shown in Fig.4. It contradicts the rules of propagation about normal direction that the value of each destination node is decided from the same source node. It is possible to adjust the different values to the average, but that is not an appropriate way for executing inverse propagation correctly.

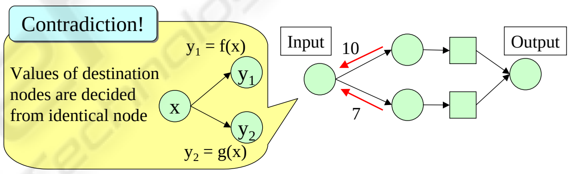

Figure 4: Contradiction about inverse propagation at a branch node.

In case of the contradiction, our approach is to adjust the values by executing the inverse propagation of effect between qualitative and quantitative nodes again. The factors of the contradiction can be propagated from the cause-effect relation between qualitative and quantitative nodes, because values of the qualitative nodes are decided as a random number in the corresponding pair of range to the value of qualitative node. Therefore, if the contradiction has occurred at a branch node, we re-execute inverse propagation from the nearest qualitative node connecting to a quantitative node. Re-execution of propagation from the qualitative node is repeated and stopped in case of getting the corresponding values at branch node. If the contradiction can not be solved in the pre-defined number of times, all the inverse propagation is considered to be unavailable and canceled.

3.2 Input Value Search Method by Inverse Propagation

It is shown in Fig.5 the outline of input value search method by inverse propagation with re-propagation. At the beginning of the method, the values of target output are set. And, inverse propagation is executed from the output nodes to the input nodes.

The judgment is necessary whether contradiction is occurred or not. There are realistically few cases inversely propagated values to a branch node are entirely the same value. So, inconsistency needs to be allowed to some extent and we introduced a function for the judgment of contradiction. The difference between the maximum value and the minimum value of the inversely propagated values to the separate node is defined as "d", and the value range about the branch node is defined as "R". And, the judgment of contradiction is done with the following expression.

$$\varepsilon = \frac{d}{R}$$

If ε is equal to or more than the threshold k, contradiction is considered to be occurred. In case that contradiction is not occurred, the value of branch node is decided as the random number between the maximum value and the minimum value of the inversely propagated values. Effects are propagated inversely in this manner, and finally values of input nodes are decided.

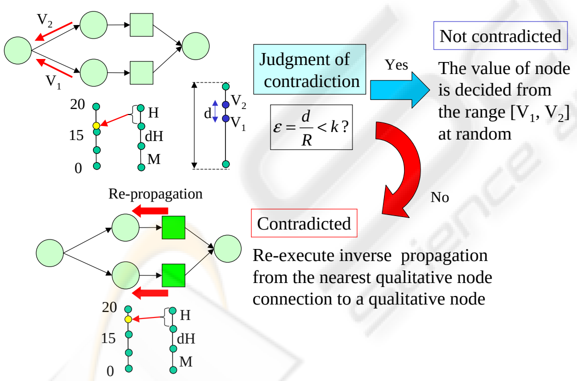

Figure 5: Input value search method by inverse propagation.

The process for getting a set of values about input nodes from the target outputs is shown as follows.

step 1 A chain of inverse propagation is executed from the output nodes to the input nodes.

step 2 If contradiction is occurred at a branch node, it is re-executed inverse propagation from the nearest qualitative node connecting to a quantitative node.

(a) In case that the contradiction is solved, inverse propagation is continued.

(b) If the contradiction can not be solved in the pre-defined number of times, all the inverse propagation is considered to be unavailable and canceled, and the process goes back to the step 1.

step 3 A set of values about input nodes is decided by inverse propagation.

Repeating the above process for the pre-defined number of times, the distribution of probability is obtained.

4 EVALUATION EXPERIMENT

4.1 Model and Output of Our Experiment

We execute experiment of the proposed method. Using the model described in Fig.6, we evaluated the processing time for getting the distribution of inputs and checked whether the sets of optimal values about inputs can be obtained or not.

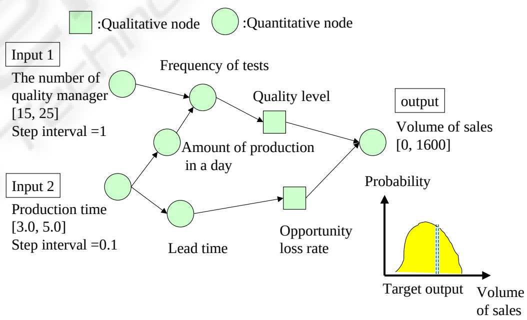

Figure 6: The model for the experiment.

"The number of managers in charge of quality" and "Production time" are set as input nodes. The value of "The number of managers in charge of quality" is given in range from 15 to 25 on step intervals 1, and "Production time" is given in range from 3 to 5 on step interval 0.1.

In qualitative and quantitative hybrid simulation in normal propagation, 10000 values of output are got from an input value. And, also in the proposed method, 10000 sets of values about input nodes are got from a target output. The limit of re-propagation from qualitative nodes is set 1000 times. The threshold "k" for the judgment of contradiction is set 0.01.

In this model, some target outputs produce input distributions with multiple peaks. It is shown in the

Fig.7 the probability distribution about sets of input nodes for the target output “700”. According to the distribution, the input sets of high probability for the output “700” are scattered about input space.

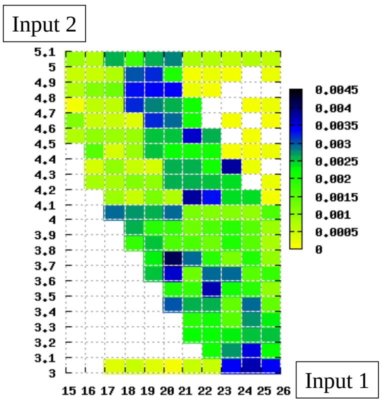

Figure 7: Probability distribution for the target output “700”.

For fifteen target outputs values between 100 to 1500 on step intervals 100 using the model, we evaluated the processing time for getting the distribution of inputs and checked whether the sets of optimal values about inputs can be obtained or not.

4.2 Processing Time

We compared the processing time for getting the distribution of inputs by the proposed method to the time by exhaustive search. The program is described with Java. Windows XP and Pentium M 1.6GHz and 512MB memory are used as the execution environment of the program.

It takes 5 minutes on an average by the proposed method, which is at least 3 minutes and at most 11 minutes. On the other hand, it takes 2 hours 10 minutes to search all sets of inputs values by exhaustive search. It is concluded that much time is reduced to get the distribution of inputs.

The reason for scattering time about proposed method is that the number of input sets that can produce target outputs is different between the target values. If the number of inputs sets that can bring about the target outputs is quite few to the input space, it is occurred re-propagation or cancellation at high probability. And it takes more time to get a distribution of inputs.

4.3 Precision of Probability Distribution about Inputs

On the probability distribution about input got by the proposed method, users probably regard the input sets at the highest probability and around them as optimal inputs. So, we defined the set of inputs at the highest probability as “suggested inputs (x, y)”(x is the value of input1, y is the value of input2), and counted the number of right optimal input sets in the range of suggested inputs and around the point as ”hit number”. Optimal sets of input values are defined as sets of top 30% at probability about all candidates. The counted hit numbers are shown in Fig.8.

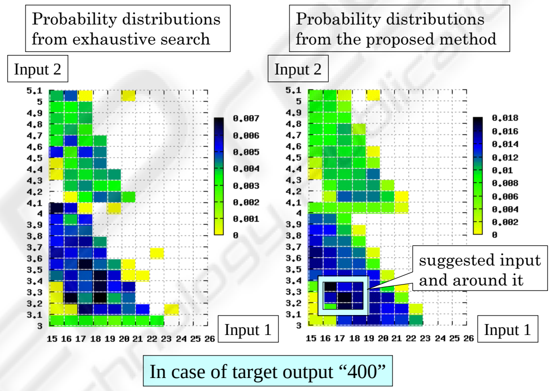

Figure 8: Suggested inputs sets and around the point.

By the result about hit numbers in Fig.9, optimal sets of inputs are included in suggested inputs or around the point for the most case of target outputs. The reason why optimal sets are not included at the case the target out put is 300 or 1500 is that the number of optimal sets is very small.

Additionally, we checked degree of coincidence between probability distributions from the proposed method and distributions from exhaustive search. We

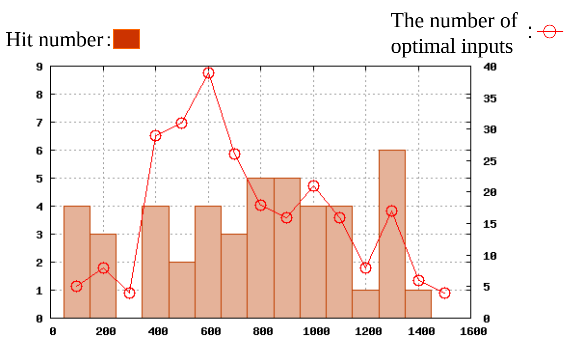

Figure 9: Hit numbers and optimal sets of inputs.

calculated degrees of precision and recall for each distribution about inputs sets of top 50% at probability. The result is shown in Fig.10, for example, the tendencies of distributions are mostly corresponding to each other at the target output "400" in which both the precision and the recall are large. In the other target outputs, precisions are considered to be large. By that result, we can say probability distributions from the proposed method have coincidence with the distributions from exhaustive search. Therefore, the proposed method has a possibility to be applied to the problem with multiple peaks.

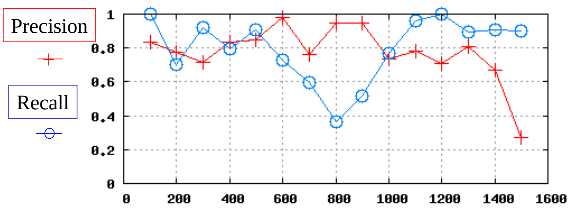

Figure 10: Precision and recall for the distributions.

At the target output "1500", however, the precision value is small while the recall value is large. It is considered that the number of inputs sets of top 50% at probability is large in the distribution from the proposed method, and they include inputs sets bottom 50% at probability in the distribution from the exhaustive search. On the contrary, the recall value is small while the precision value is large at the target output "800". It is considered that the number of inputs sets of top 50% at probability is large in the distribution from the proposed method is small, and most of inputs sets top 50% at probability in the distribution from the exhaustive search are not included in them.

5 CONCLUSIONS

In this paper, we proposed inverse simulation for recommendation of business scenario with qualitative and quantitative hybrid model. As an approach, we used the cause-effect simulation model that was made by the user and executed propagation of effects inversely in order to decide a value of a source node from a value of a destination node. Executing the inverse propagation in a chain of cause-effect relations from output nodes, we decided the values of input nodes for the target outputs. Because the value of source node is decided at random between a qualitative destination node and a quantitative source node, contradiction is occurred concerning the value of a branch node where one of destination nodes is different from the value of the other destination nodes. Therefore, in the case of the contradiction, we re-executed the inverse propagation repeatedly from the nearest qualitative node connecting to a quantitative node for solving the contradiction. According to the repeating the whole re-propagation, probability distribution of input nodes were obtained.

Evaluation was done by the processing time and checked whether optimal inputs could be obtained or not about fifteen values of target output. It took 5 minutes for the processing and much time could be reduced to get the distribution of inputs. We could get optimal inputs about thirteen target outputs out of fifteen, so it is confirmed a certain level of coincidence between probability distributions from the proposed method and distributions from exhaustive search.

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