Efficiency Analysis of Model-based Review in Actual Software Design

Hitoshi FURUSAWA, Eun-Hye CHOI, and Hiroshi WATANABE
Research Center for Verification and Semantics,
National Institute of Advanced Industrial Science and Technology (AIST),
1-2-14 Shin-Senri Nishi, Toyonaka, Osaka, 560-0083 Japan
{hitoshi.furusawa, e.choi, hiroshi-watanabe}@aist.go.jp

ABSTRACT
In this paper, we quantitatively analyze the efficiency of the Model-Based Review (MBR) method in an actual software design from the two points of view; cost and reviewability. The MBR method is a modeling procedure for the purpose of reviewing preliminary design specifications of web-based applications. We have collected process data in applying both of the MBR method and an ordinary review to a preliminary design of a developing web-based library system. Analyzing the collected process data, we quantitatively compare the efficiency of the MBR method and that of the ordinary review. As a result of this comparative analysis, we show that the MBR method is superior to the ordinary review in terms of not only reviewability but also cost through the experimental design process.

Categories and Subject Descriptors: D.2.4 [SOFTWARE ENGINEERING]: Software/Program Verification

General Terms: Experimentation

Keywords: Cost estimation, Design specification, Model-Based Review, Reviewability, Web-based application

1. INTRODUCTION
The Model-Based Review (MBR) method [6] is a modeling procedure for the purpose of reviewing preliminary design specifications of web-based applications. The MBR method models preliminary specifications, such as page-flow diagrams and functional specifications of web page items, into asynchronous processes with synchronous communication. Since the MBR method provides a specific and detailed operational modeling procedure, it enables review of fine quality without depending on reviewer’s knowledge, experience, and perception. In addition, the models constructed by the MBR method can be used for more detailed inspection using the model checking technique [1].

In this paper, we quantitatively analyze and compare the efficiency of the MBR method and that of an ordinary review. Here, the efficiency has two points of view: one is cost and the other is reviewability. Cost indicates the time needed for review and reviewability indicates the number of defects of specifications detected by review.

Previously, we have applied both the MBR method and an ordinary review in a preliminary design phase for an actual web-based library system and have collected process data of time and detected defects [3]. We analyze the collected process data and quantify the efficiency of the MBR method.

The main difficulty of the analysis is that we did not have complete data for the analysis. Due to the time limitation of the experiment [3], we could apply the MBR method (not to the whole specification but) to only a part of the preliminary design specification. To handle this deficiency, we estimate the cost for the case when the MBR method is applied to the whole specification. We believe that this kind of estimation that fills up the lack of data is reasonable in usual process data analysis, since it is difficult to spend a huge cost for collecting process data in an actual software development. Our estimation might be generalized to a method that effectively estimates a modeling cost when the modeling procedure is clearly established.

2. PRELIMINARIES
Here we first introduce the MBR method proposed in [6]. Next, we briefly report a case that we applied the MBR method to an actual software design.

2.1 Model-based Review Method
The targets of the MBR method are the following three main specifications in a preliminary design: 1) page-flow diagrams, 2) specifications of pages including lists of items, e.g. buttons and text-fields, in each page, and 3) specifications of functions of the application. We apply the MBR method to the specifications 1)–3) of every several pages or every module in the application. Figure 1 shows an example preliminary specification to which we apply the method.

The MBR method translates these three kinds of specifications 1)–3) into an MBR model given as asynchronous processes that synchronize through message-passing, which is a fragment of modeling language used in UPPAAL[5]. We call this translation a Modeling. We can feed the MBR model into model checkers and check detailed properties in the specifications.

Modeling consists of 5 steps: 1) extraction of a page-flow process, 2) extraction of a user process, 3) extraction of internal processes, 4) synchronization for page-flow and internal processes, and 5) synchronization for user and internal processes. In Step 1, we model the page-flow behavior of the application as a page-flow process. In Step 2, we model the interaction between the user and GUI’s, capturing the “pushing buttons sequentially”, as a user process.
we model the behavior of programs or softwares, capturing the functions that occur after the events like “pushing buttons”, as internal processes. In Steps 4 and 5, we combine these asynchronous processes using input-output channels to synchronize transitions that correspond to same events in different processes. See [6] for the details of instructions of the MBR modeling. Figure 2 shows an example MBR model extracted from the specification in Figure 1.

2.2 Applying MBR to Actual Software Design

We have applied both the MBR method and the ordinary review to a preliminary design of a web-based library system and collected process data. Here, we sketch the application and the data collection. Details were reported in [5].

2.2.1 Experimental Environment

The target system was a web-based library system, which is required to fit for a library whose scale is about 100 users, 1 librarian, and about 3000 books. The development team consisted of a design engineer and two customers. The design engineer, an examinee in our data collection, had more than ten years career as a software engineer. One of the customer was a librarian, the other was a CS researcher.

Table 1: Time Required for Design and MBR Tasks.

<table>
<thead>
<tr>
<th>Page ID</th>
<th>Modeling Time (min.)</th>
<th>Checking Time (min.)</th>
<th>SUM (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0010</td>
<td>30 40 90 30 30</td>
<td>15 235</td>
<td></td>
</tr>
<tr>
<td>U0050</td>
<td>10 10 20 10 5</td>
<td>5 79</td>
<td></td>
</tr>
<tr>
<td>M0050</td>
<td>10 10 20 5 3</td>
<td>5 60</td>
<td></td>
</tr>
<tr>
<td>M0400</td>
<td>10 15 20 5 5</td>
<td>5 60</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Time Required for MBR.

2.2.2 Tasks

The design engineer was given two tasks, design task and MBR task, and recorded the time required for each activity of the tasks everyday.

The design task is classified into an investigation activity and a drawing up activity. The design engineer investigates the requirement and the specification as the investigation activity and builds the specification as the drawing up activity. The investigation task includes an ordinary review. Until ending up the design task, the design engineer had not known anything about the MBR method at all.

In the MBR task, the design engineer applies the MBR method to the specification produced in the design task. The MBR task is classified into a learning activity, a modeling activity and a checking activity. The design engineer first learns the MBR method as the learning activity, next makes MBR models as the modeling activity, and finally performs model checking including failure analysis of the target specification by himself as the checking activity.

2.2.3 Collected Data

Here we show the collected data obtained as a result of the application from the two points of view; the required time and detected failures.

Time. Table 1 shows the time required for each activity of the design task and the MBR task. As to the MBR task, due to the time limitation, the MBR method was applied to 4 page designs among total 55 page designs of the preliminary specifications. It took 6 hours for learning the MBR method (3 hours for a lecture and 3 hours for an exercise) and, for the 4 page designs, it took 32.5 hours for modeling and 7.5 hours for checking including a failure analysis.

Table 2 shows the detailed time required for applying the MBR method to 4 page designs. The time for modeling is separated into 1 through 5 corresponding to the 5 steps in the modeling phase of the MBR method. The table shows the required times for modeling and checking for each page design.

As a result, it took much longer for Page C0010 than the other 3 pages. The reason is that Page C0010 was the first case of the application for the design engineer and thus an extra time is needed for practicing.
The required time for an ordinary review was 33 hours, which is included in the time for the investigation in Table 1, and that was about 10% of the time for the whole design task. This average coincides with the recommended average time required for review in [4].

Detected Failures. During the design task, the engineer detected 5 defects by the ordinary review. Among them, two are unspecified requirements, another one is a lack of a data table, and the other two are missing explanation of functions in page designs. After revising these 5 defects, the design engineer started the MBR task. Then, the design engineer found 2 more defects. One is a missing in the page-flow specification, and the other is a missing function of a button. Totally, 7 defects were found.

3. COST ANALYSIS

In this section, we compare the cost of the MBR method and the cost of the ordinary review in the case of the library system design. Here the cost stands for the time required for review.

3.1 Cost of MBR

In the experiment, the MBR task was applied to 4 page designs among total 55 page designs of the library system. Here we estimate the time required for MBR in the case of to be applied to whole preliminary design specification.

We first build a cost formula for each step of the modeling phase and a cost formula for the checking phase in the MBR task, and next, based on the cost formulas, estimate the times required for all the rest 51 page designs. As a base of the estimation, we use the data of 3 page designs of U0050, M0070, and M0400, to which the MBR method was applied. We did not use the data of page design for C0010, since the measured data for C0010 included the extra practice time which as described in Section 2.2.3.

3.1.1 Cost Estimation for Modeling Phase

The modeling phase of the MBR method consists of 5 steps. The time required for the modeling phase is thus the sum of the times needed for the 5 steps. The time needed for each of Steps 1–3 is the time for describing processes and it thus depends on the complexity of the processes. The time needed for each of Steps 4–5 is the time for adding input-output channels to the processes and it thus depends on the number of the channels. We therefore assume that the times for each of Steps 1–3 and each of Steps 4–5 are proportional to the number of described transitions of the processes and the number of described channels, respectively.

Under the assumptions, we define cost formulas $T_1$–$T_5$ which represent the times for Steps 1–5, respectively, in the modeling phase as follows:

\[
T_1 = c_1 \times X, \\
T_2 = c_2 \times Y, \\
T_3 = c_3 \times \sum_{i=1}^{i \leq Y} W_i, \\
T_4 = c_4 \times Y, \\
T_5 = c_5 \times (Z + Z'),
\]

with coefficients $c_1$–$c_5$ and explanation variables $X$, $Y$, $W$, $Z$, and $Z'$. Coefficients $c_1$–$c_5$ are obtained as the values in Figure 3(b) from the given times of the base of the estimation and the values of the explanation variables. Variable $X$ denotes the number of reachable pages in a page-flow diagram. Variable $Y$ denotes the number of buttons. Variables $Z$ and $Z'$ denote the number of page-transfers and the number of reachable pages described in the specification of buttons, respectively. Variable $W_i$ denotes the number of added transitions to represent a procedure of each button $i(1 \leq i \leq Y)$ in a page. See [2] for the explanation of the cost formulas.

Cost estimation is performed for the rest 51 page designs using the defined cost formulas and obtained coefficients, as shown in Figure 4. The estimated time of modeling for the
51 pages is 942.297 minutes and the given time of modeling for the 4 pages is 400 minutes as in Table 2. Hence, we conclude that the total time for the modeling phase of the MBR method is 1342.297 (=942.297+400) minutes.

3.1.2 Cost Estimation for Checking Phase

In the checking phase of the MBR method, reachability checking was performed. The time required for the checking phase can be considered to be propositional to the number of the generated formulas. Since the number of generated formulas equals to the number of reachable pages in a page-flow diagram, we define a cost formula \( T_b \) to represent the time required for the checking phase as follows:

\[
T_b = c_6 \times X
\]

where \( c_6 \) is a coefficient and explanation variable \( X \) is the number of reachable pages in a page-flow diagram. As the result of the estimation, the time required for the checking phase of the 51 page designs is 50.5 minutes. The time required for the checking phase of the 4 pages, C0010, U0050, M0070, and M0400, was 30 minutes as in Table 2. Hence, we conclude that the total time for the checking phase of the MBR method is 80.5 minutes.

3.2 Cost Comparison of MBR and Ordinary Review

By the estimation explained in Section 3.1, the time required for the modeling phase and the checking phase of the MBR method in the case of to be applied to the whole preliminary design specification were respectively 1342.297 and 80.5 minutes. In addition, the time required for learning the MBR method was 6 hours as shown in Table 1. Hence, the total time required for the MBR method is estimated to about 29 hours and 42.8 minutes. On the other hand, the time required for the ordinary review was 33 hours in the experiment.

As a result, one can see that the time required for the MBR method is shorter than the time for the ordinary review. We expect that, as the size of a target design specification becomes larger, the MBR method becomes more efficient than the ordinary review under the same cost.

4. REVIEWABILITY ANALYSIS

In this section, we compare the reviewability of the MBR method and the reviewability of the ordinary review in the case of the library system design. Here the reviewability is simply measured by the number of defects detected by review.

Recall that 5 defects were found in the ordinary review, as shown in Section 2.2. We reexamined the previous version of the preliminary design specification before revising the 5 defects by using the MBR method. We then certified that 2 of the 5 defects can be detected by the MBR method. The other 3 defects, however, could not be detected by the MBR method since they were out of the scope of the MBR method, and such defects need a proper investigation of both requirement and data table design to be detected.

By the MBR method, 2 defects were detected from the preliminary design specification revised after the ordinary review, even though the MBR method was applied to only 4 page designs among 55 page designs. Moreover, we certified that more 8 defects can be detected by applying the MBR method to the rest 51 page designs. The 8 defects were found as a side-effect of an imaginary (or rough) modeling for the cost estimation for the rest 51 page designs.

As a result, the number of defects that can be detected by the MBR method was 10, while the one by the ordinary review was 5. Therefore, one can see that the reviewability of the MBR method is higher than that of the ordinary review.

5. CONCLUSION

A difficulty for the analysis was that the given process data for the MBR method was for a part of the preliminary design specification of the library system. To handle this difficulty in the cost analysis, we constructed the cost formulas and estimated the cost of the MBR method in the case of to be applied to the whole preliminary design specification. An estimation to fill up a lack of data is necessary in data analysis where the target is an actual software and it spends a huge cost for data collection. We believe that the way of our estimation can also be effective for general cost estimation of formal modeling.

As a result of the analysis, the cost of applying the MBR method including preliminary learning cost was less than the cost of an ordinary review. In addition, the reviewability of the MBR was higher than that of the ordinary review. Let’s consider the efficiency of review using the following criterion:

\[
\text{Reviewability}(= \text{Number of defects detected by review}) \quad \text{Cost}(= \text{Time required for review})
\]

From the results of Sections 3 and 4, the efficiency of the MBR method is about 0.42 (= 10/23.7) and that of the ordinary review is about 0.15 (= 5/33). Hence, we can ascertain that the efficiency of the MBR method is much higher than that of the ordinary review.

6. REFERENCES


Acknowledgments A part of this work is supported by Japan Science and Technology Agency and also by MEXT Japan. Authors would like to thank Prof. Tohru Kikuno and Assistant Prof. Osamu Mizuno of Osaka University for their helpful suggestions and comments. Authors would like to thank Akihiro Tokai, Atsuo Kishimoto, and Masahi Kamo of AIST for their advice on collecting data, and thank to members of the development team, Yoshihito Wakano of KS Solutions and Kazuyu Murakami of CVS, AIST. Authors also thank to anonymous referees for their comments.