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Adding Value to Change Order Management Process Using Simulation Approach: A Case Study

Jing Du, MSC and Mohamed El-Gafy, Ph.D.
Michigan State University
East Lansing, Michigan

Amine Ghanem, Ph.D.
California State University, Northridge
Northridge, California

Change orders are inevitable in almost everyday's construction project. They can significantly increase the project cost and duration, and lead to big number of claims and disputes, which in turn create an adversarial relationship among project participants. Studies revealed that improving the administrative process of change orders are beneficial in reducing the cost and risk for all the project participants and encouraging a more trustful relationship. Most process improvement proposals in current literature are mainly based on qualitative studies and may lead to sub-optimal solutions. This paper presents a comprehensive and quantitative analysis framework to accelerate change order processing for facility management settings. Discrete Event Simulation (DES) and Sensitivity Analysis (SA) were employed to examine the quantitative impacts of a variety of improvement proposals. A case study from a North American University is presented. The results demonstrate that the combined use of DES and SA as an analysis approach can help optimize the change order administrative process.

Key Words: Change Orders, facility management, Discrete Event Simulation, Sensitivity Analysis.

Introduction

It has been revealed that change orders can have a significant administrative and financial effects on construction projects, such as increased disputes, decreased productivity, increased project duration (Hanna et al. 1999), and cost overruns (Moselhi et al. 1991).

The administering of change orders is an integral part of construction project management (Yelakanti 2005). This process is always time consuming and causes project delays because it is not well organized and streamlined. Universities, considering project complexity and administrative requirements, typically have long processing time, as well as high administrative cost for change orders (Mechanda 2005). Various strategies have been proposed to improve the change order management process in current literature (Mechanda 2005). The conclusions, however, are mainly based on qualitative studies and may rule out the real optimal solutions. A quantitative framework that can investigate the specific impacts of the proposed improvements for change order management process is needed.

This paper aims to develop a comprehensive and quantitative framework to accelerate change order processing for university construction projects. Discrete Event Simulation (DES) and Sensitivity Analysis (SA) are employed to examine the quantitative impacts of a variety of improvement proposals, including process reengineering, work re-designing and activity acceleration. Based on a case study conducted at Michigan State University (MSU), the framework will be tested.

Background

Although there are numerous literatures about change orders, they can be grouped into three categories: (1) The causes of change orders. This kind of studies focus on revealing the roots of change orders and, in turn, are expected to reduce the need of change orders from the beginning (Terwiesch and Loch 1999); (2) The impacts of change orders. This category of studies is interested in investigating the influences of change orders so that negative impacts can be mitigated. (Leonard 1988; Hanna et al. 1999); (3) The administrative process of change orders. These studies focus on streamlining the change order management process in order to reduce the time and cost of processing change orders (Terwiesch and Loch 1999). This study belongs to the third category, i.e., investigating the potential improvements for accelerating change order administrative process.

Sensitivity analysis (SA) is an approach of examining how different inputs of the model can qualitatively or quantitatively affect variation in the output of a model (Cruz 1973). By systematically changing parameters in a model, the effects of such changes can be determined. Currently, there are the following SA approaches: (1) Local sensitivity analysis or one at a time sensitivity analysis (OAT-SA): OAT-SA proposes changing the input one at a time to examine its influence on the output (Smith and Smith 2007); (2) Factorial sensitivity analysis: similar to OAT-SA but it adjusts more than one input at a time (Smith and Smith 2007; Ligmann-Zielinska and Sun 2010); (3) Variance based Global sensitivity analysis (GSA): GSA examines the contribution of input parameters' variation on model output variation by varying all inputs simultaneously (Wagner 1995; Saltelli 2004; Saltelli et al. 2005); (4) Sampling based SA: This is not a separate SA method, but a set of improvements on sampling techniques to address the drawbacks of aforementioned SA approaches (Box et al. 1978). Considering the nature of the problem and the needs of this project, OAT-SA will be used as a major investigation approach.

Methodology

Case study

This project is based on a previous study conducted at Michigan State University (MSU) to improve the change order management process (Mechanda 2005) . The published data of this study made up the starting point of this project and in turn, a set of DES models were built based on these data.

Modeling and Simulation

A set of DES models were built to simulate the change order administrative process at MSU. Specifically, the change order process of Engineering and Architectural Service (EAS) projects were modeled since they represent larger and more complex projects at MSU. At first, a current process map was reproduced to calibrate and validate the developed DES model; then, a revised process map was reproduced based on the experts' suggestions to test the influence of process re-engineering.

Sensitivity Analysis

After getting DES simulation results, a set of SA were conducted to examine the relative importance of proposed improvements. Based on literature and experts' suggestion, these improvements include: batching of change items, re-engineering process, accelerating particular activities, and setting value threshold for VP (Vice President at MSU). The results were mainly demonstrated graphically, and at the end of analysis, a set of recommendations were made to accelerate the change order administrative process.

Model Building

Based on interviews conducted with MSU engineers and contractors, a current process map of change order management has been produced: First, potential items that might need changes are identified through RFIs and meeting minutes; then construction representative (CR) seeks inputs from in-house and outside consultants on more details. Afterwards, the need for changes are reviewed and evaluated by architect and engineer (A/E). The length of this assembly time and number of items in a change order are not standardized and are left to the discretion of CR. Meanwhile, GC requires quotes from sub-contractors (Subs). This process may take up to two weeks. Negotiations may occur at this point, which typically takes one week. After final agreement is achieved, a final change order is drafted and authorized by A/E. This is also known as "Change order date". Then, the architect prepares three copies of change order and sends them to the GC. The design administrators (Admin) and university engineer (Engineer) at MSU signs the change order respectively, and then send it to contract and grant administration (CGA), who will examine and verify the changes. After verification, the CGA staff enters the change order information into the university information system (FAMIS). Then the Vice President (VP) signs the change order, which is indicated by the MSU authorization date in the database. Finally, MSU staff will finalize the change order and send it to physical plant and the GC. The entire process takes 205 days on average and it takes 140 days to initialize the change order. In contrast with these relatively long durations, it only takes 4 days and 5 days for architect and GC to authorize the change order respectively.

Based on the data collected from the case studies conducted at MSU, a DES model was built using Anylogic 6.0 to reproduce current process map of managing change orders (Figure 1). Then, this model was calibrated and validated by historical data. The results indicated that the simulation model is a reliable representation of current change order management process.

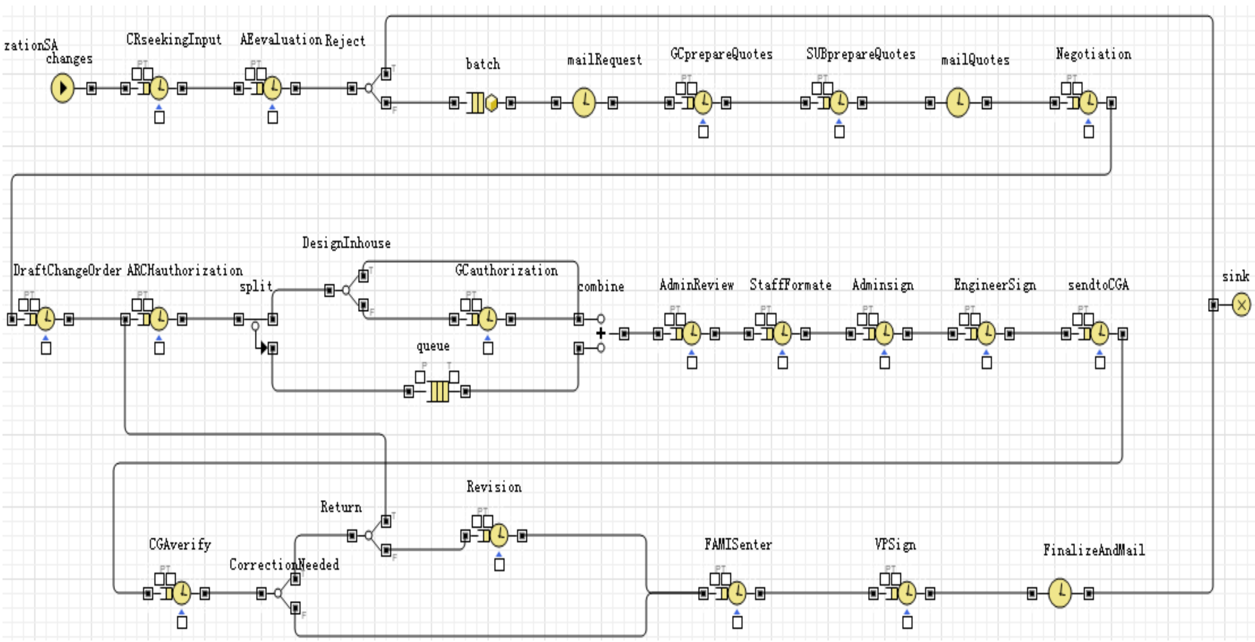

Figure 1: The developed DES model for current change orders administrative process

Simulation and Analysis

Based on further interviews with MSU engineers, designers and contractors, as well as a literature research, four potential improvements were made that are believed they can help reduce processing time of change order management, i.e., optimizing batch size, accelerating particular activities, reengineering process, and setting a change order value threshold for VP involvement. On the basis of the developed DES model and OAT-SA techniques, a set of explorations were made to investigate the following three questions:

What is the best batch size?

Once the items have been evaluated and verified as needing changes, A/E batches a particular number of items to one change order. The batch size, which refers to the number of items in one change order, can significantly affect the processing time per change order. On the basis of 130 change orders data collected from 19 projects at MSU, there is a linear relationship between the average processing time per change order and the batch size:

$$\text{aveProcessingTimePerChageOrder} = 6.41 * \text{bacthSize} + 186 \quad \text{......................} \quad (1)$$

Considering the variance of the actually happened processing time, when conducting the simulation, the processing time is generated from a normal distribution with the aveProcessingTimePerChageOrder as the mean, i.e., ProcessingTimePerChageOrder = N(aveProcessingTimePerChageOrder, σ) ......(2)

A sensitivity analysis was conducted to examine the influence of a batch size on the processing time per change order. Figure 2 demonstrates how many items can be finished within a given time under different level of batch sizes. Based upon this result, the optimal batch size is 4.

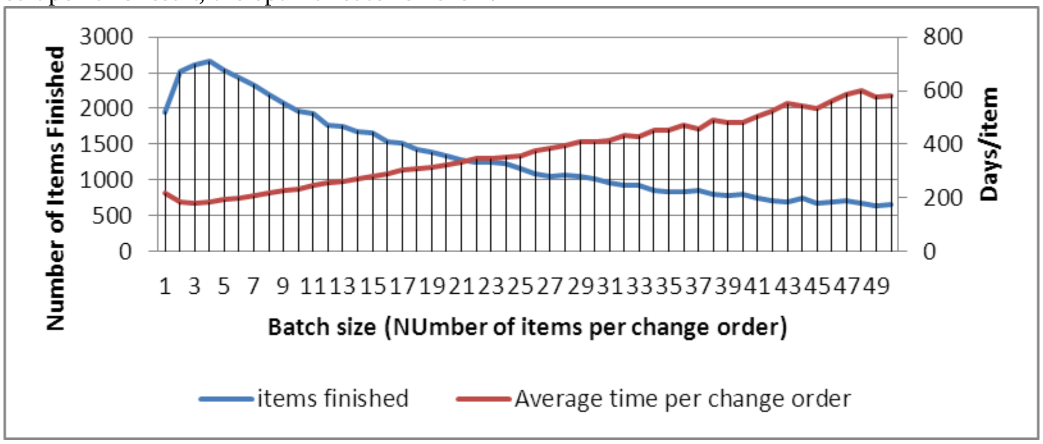

Figure 2: The impacts of batch size on

However, this result is based on an assumption that the processing of change orders is not a paralleled work. This is apparently an incorrect assumption. In fact, the processing of change orders is a concurrent work: multiple change orders can be processed during the same period. Therefore, concurrent working environment should be considered to modify the original conclusion. A concurrency index is then introduced to demonstrate the overlaps among change orders.

concurrencyIndex = totalTime / processingTimePerChangeOrder ....(3)

The value of concurrency index refers to how many change orders can be processed simultaneously. According to formula 2 and 3, bigger batch size means smaller concurrency index, i.e., less change orders will appear in the system at the same time. Then, the productivity can be obtained by the following formula:

Productivity = itemFinished / totalTime ....(4)

where,

itemFinished = batchSize * ChangeOrderFinished ....(5)

and,

ChangeOrderFinished = concurrencyIndex*totalTime/processingTimePerChangeOrder

$= (\text{totalTime}/\text{processingTimePerChageOrder})^2$ ....(6)

Figure 3 demonstrates the productivity of change order processing under different level of batch sizes. Both conditions- considering concurrency and no concurrency – are demonstrated; among which, weighted productivity represents the productivity that considers concurrency. As shown in the figure, the optimal batch size is 15 through 20. This means that batch 15 to 20 items to one change order can lead to best productivity.

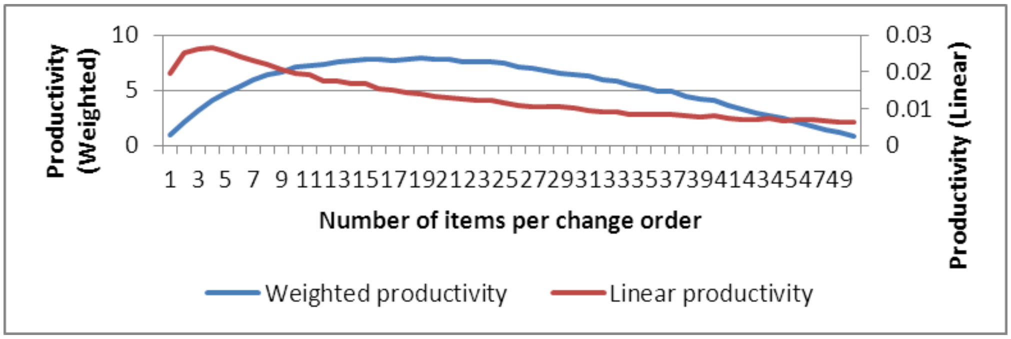

Figure 3: The productivity of change order processing under different level of batch sizes

Then the deviation of processing time per change order under different level of batch sizes is also examined (Figure 4). Lower deviation means the work is more reliable since the difference among different change order processing is smaller. As a result, the batch size should be designed to achieve the least deviation. The least deviation happened when batch size is between 3 and 15.

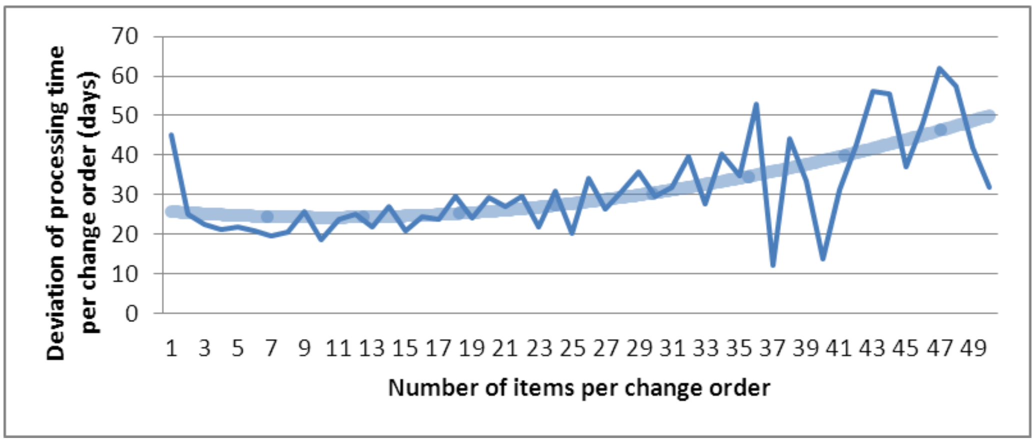

Figure 4: The productivity of change order processing under different level of batch sizes

Under a comprehensive consideration, the best batch size should be around 15 since it ensures faster finish of change orders and bigger reliability in terms of processing time per change order.

How should current process be reengineered?

Closer examination on current change order administrative process revealed that the MSU authorization and approval process is too complex. Therefore, there is a need to skip authorization and approval process if allowed. An alternative process was proposed (Figure 5).

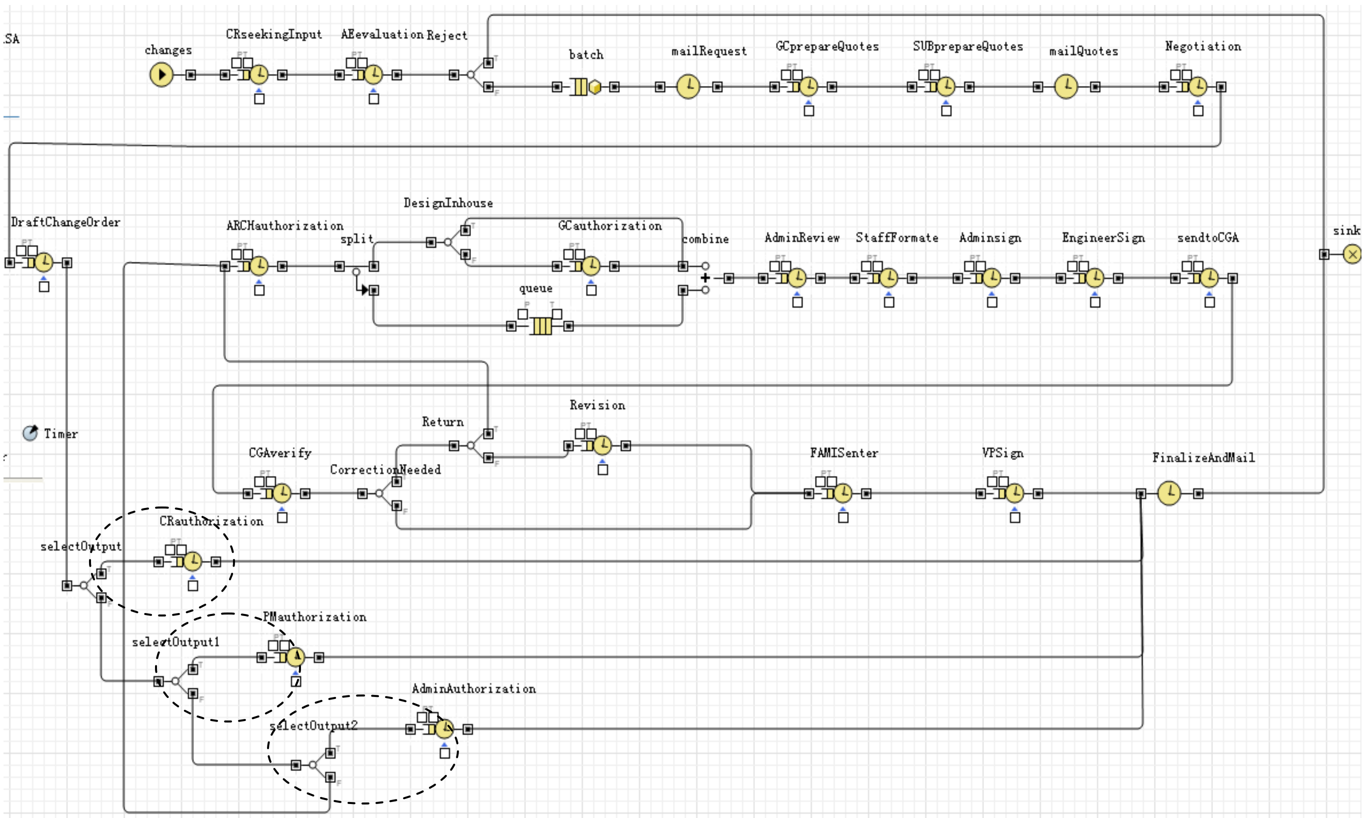

Figure 5: An alternative change orders administrative process for MSU

The major modification made to current process is adding three thresholds to reduce layers of approval in MSU organization. Change orders are categorized by dollar amount and processed on the basis of their amount. For example, if the change order dollar amount is less than $5,000, then the CR can approve it directly; if the dollar amount is between $5,000 and $10,000, then the project manager can approve it; if the dollar amount is between $10,000 and $100,000, then the design administrator can approve it; only if the dollar amount is more than $100,000, the approval process should be like the original one in order to secure the processing. By such, the complexity of change order processing has been reduced.

What is the best change order value threshold for VP involvement?

A set of experiments revealed the importance of the threshold setting: a too low threshold means the majority of the change orders will be through the complete approval process and thus is useless for reducing the processing time; but a too high threshold will make most change orders being approved through a simplified approval process and might increase the risk. Therefore, an optimal combination of threshold settings should be able to reduce the processing time per change order, while keeping the complete approval process for those change orders with relatively high dollar amount. Especially, the third threshold, which determines whether the VP will be involved or not, is the focus of this project.

According to the case study, the change item value follows a triangular distribution: triangular (0,500,10000). The items, batched to one change order, determine the ultimate dollar amount of the change order. The distribution of change order dollar amount further determines the optimal threshold for whether the VP should be involved (Threshold type 3). In other words, the optimal threshold setting is determined by two factors: batch size and dollar amount distribution of items. This amount is, however, hard to calculate using statistical approaches giving the relatively small batch size and variance dollar amount of each item. Therefore, simulation is used to explore the optimal threshold setting under different batch sizes.

Figure 6 demonstrates the average processing time per change order under different thresholds and batch sizes. That is to say, each line represents the most likely processing time per change order under different level of batch sizes and threshold for VP involvement. The optimal threshold 3 level under a given batch size is therefore the turn point of the lines. For example, when batch size equals 15, the turn point happens around $66,000; therefore, $66,000 is the optimal threshold level: if the threshold level is less than $66,000, the processing time per change order will be longer; but if the threshold level is more than $66,000, the risk will become bigger even though the processing time won't be shortened any more. Per the discussion above, $66,000 stands for a balanced point between least processing time and relatively small risk level.

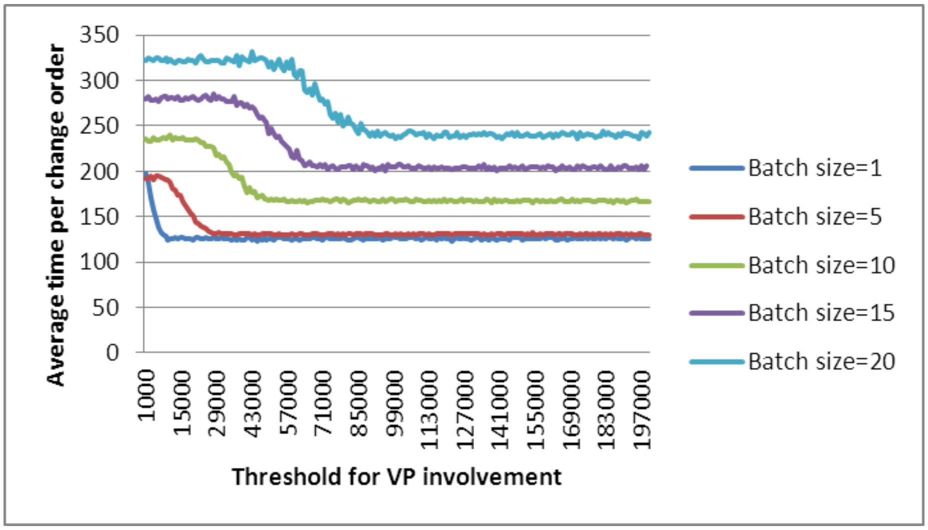

Figure 6: Average processing time per change order under different threshold settings and batch sizes

Similarly, Figure 7 demonstrates the simulation results of the overall productivity under different threshold settings and batch sizes. This result is corresponding to the above conclusion: when batch size is 15, the turn point of the line is around $66,000, which stands for a balanced point of best productivity against least risk level.

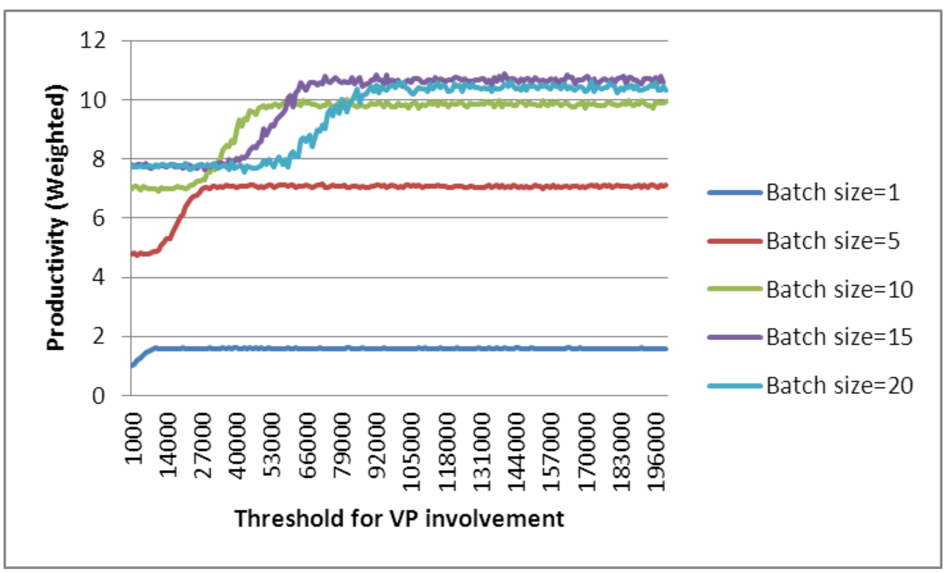

Figure 7: Overall productivity (weighted) under different threshold settings and batch sizes

Discussion

The proposed three changes - optimizing batch size, reengineering process, and setting a change order value threshold for VP involvement – provide potential improvement space for current change order administrative process at MSU. A comparative experiment was conducted to examine the influence of these changes. What should be mentioned, accelerating particular activities is not incorporated in this comparison since its consequence in accelerating change order processing is obvious.

Figure 8 demonstrates the difference in processing time per change order before and after improvements. As shown, the average processing time per change has been reduced from 230 days to 170 days. Closer examinations revealed that the average processing time per item has been reduced from 0.15 day to 0.09 day, and the productivity (weighted) has been improved from 6.65 items/day to 10.45 items/day.

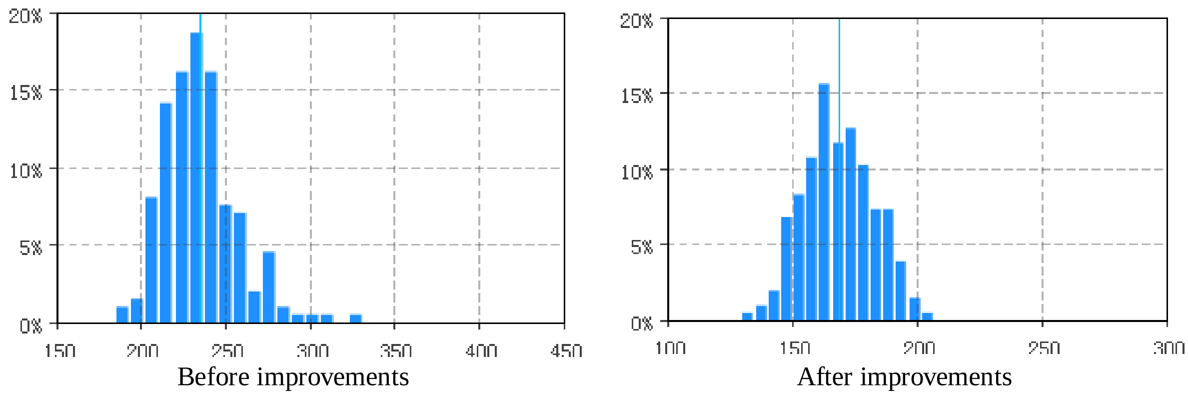

Figure 8: The histograms of processing time per change order before and after improvements

Although simulation results showed the positive effects of the proposed improvements in terms of reducing processing time of change orders, these conclusions should be carefully treated if they are going to be used as recommendations to real projects. This is because the simulation approach used in the project simplified various situations, such as the actual available time of the actors (e.g., VP), the impacts of change order dollar amount on processing productivity, and the differences between different types of projects etc. Experience gained from previous projects and simulation analysis should be combined to generate a reliable improvement proposal.

Conclusion

Change orders are inevitable in almost everyday's construction project. The impacts of change orders on the performance of construction projects are negative and significant. It has been revealed that improving the administrative process of change orders is beneficial in reducing the cost and risk for all the project participants and encourages a more trustful relationship. However, most process improvement proposals in current literature are mainly based on qualitative studies and may rule out the real optimal solutions. This project developed a comprehensive and quantitative analysis framework to accelerate change order processing for university construction projects. Discrete Event Simulation (DES) and Sensitivity Analysis (SA) were employed to examine the quantitative impacts of a variety of improvement proposals. The results demonstrate that the combination of DES and SA as an analysis approach can help optimize the change order administrative process.

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