# AMERICAN UNIVERSITY OF BEIRUT

# USING SIMULATION TO ENHANCE THE PERFORMANCE OF QUANTITY SURVEYING AND REPORTING

by

# MAGGIE BAHIJ KHADDAJ

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Engineering
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# AN ABSTRACT OF THE THESIS OF

<u>Maggie Khaddaj</u>   for      <u>Master</u> of Civil Engineering
<u>Major</u>: Construction Management

Title: <u>Using Simulation to Enhance the Performance of Quantity Surveying and Reporting</u>

Quantity Surveying (QS) is defined as the process of estimating the quantities and costs of work at the start of the project. During project execution, QS involves tracking and quantifying the progress of work as well as arranging the corresponding payments for clients. QS features several sources of uncertainty including the timeliness of payments by the client and the amounts of monetary compensation. Past studies have presented models and strategies to improve the performance of QS systems, while some studies explored the adoption of advanced technologies to enhance QS. However, these studies did not provide a methodology for exploring the external uncertainties that interfere with QS activities. The objective of this thesis is to simulate the operations of the QS system to capture the imposed uncertainties. Ultimately, the goal is to mitigate the effects of uncertainty and to enhance the operations of the QS system. The methodology adopted consists of building a simulation model in Arena and testing it on a real-world case study. An alternative model is, then, proposed and tested. The results suggest improvement in terms of payment lifecycle.

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# CHAPTER I

# INTRODUCTION

A construction project spans a lifecycle that starts with feasibility studies, proceeds with plans and designs, follows with the execution of works and ends with operation and maintenance of the facility [1]. Throughout its lifecycle, the project is managed by carefully performing control on safety, quality, time and cost.

Project controls is one of the most essential project management areas as given by The Project Management Institute (PMI) in the PMBOK Guide [2]. It is a process that extends throughout the whole project's lifecycle. The Concise Oxford Dictionary defines project controls as checks, regulations, or verifications. Project controls is a function of data gathering and monitoring actual key performance indicators (KPIs) against target plans.

Quantity surveying (QS) is an essential element of project controls. QS contributes to the design, construction and maintenance processes of a project [3]. For instance, preliminary quantity surveys are required at early stages of construction projects for feasibility studies and budget plans [4]. Then during execution of work, QS is utilized to measure and price the amounts of completed work [5]. During construction, the contractor collects money from the client by periodically submitting bills of the performed work to the client's representatives.

Contractors deploy experienced project controllers to execute control, monitor the work in progress and consistently bill the client. Ideally, project controls personnel should have experience with quantity surveying, cost estimation, planning, procurement and material management and ultimately project management. From real life observations, the controllers are highly paid employees due to their scarcity, high

experience and importance of their works. Any mistake or inaccuracy in the regulation of the costs during construction may result in a profit loss to the contractor. In fact, a number of studies listed the lack of experience with project location and type, and inaccurate quantity surveying [6, 7] as top reasons behind costs overruns, besides fluctuations in material prices.

Even if the contractor's human resources are highly experienced employees who submit the bills accurately, the contractor may face uncertainty with regards to collecting money from the client. For example, the client might disagree on the billed quantities because of unclear documentation of the billed amounts or because of quality control problems of the executed work. In addition, the client representatives might take longer than expected to approve the payment certificate. Meanwhile, the contractor may have outstanding bills to settle with subcontractors. As a result, the contractor may stop, or at least slow down, the work until payments are approved.

Several studies suggested ways to improve the performance of QS and generally project controls functions. Some academics suggested an organizational shift to improve the performance of the QS function [8]; whereas, others proposed models that require adapting specific strategies to influence the QS function's competitive position [9, 10]. Many researchers suggested the implementation of IT concepts and techniques for QS to render the project controls process more efficient [11-13]. Specifically, Building Information Modelling (BIM) has gained momentum for integration with QS activities. For instance, Nadeem, et al. [14] proposed extracting quantities from BIM into a suitably prepared electronic format of Bill of Quantities with 3D view ,while Stanley and Thurnell [15] examined the advantages and disadvantages of applying 5D BIM in QS. Also, Mitchell [16] devised a method to apply 5D BIM in order to achieve better cost

certainty and Elbeltagi, et al. [17] presented a model that is integrated with BIM to monitor the costs and to visualize the actual expenditures against the set baselines.

Although the literature is rich with studies about the performance of QS systems and project controls functions, limited work has been done to investigate the external uncertainties imposed on the system, their impacts and ways to mitigate their effects. This paper aims at studying the mechanics of QS as an integral component of project controls, by developing a simulation model, which ultimately serves as a tool to improve the performance of project controls. The simulation model mimics the real-life operations during the execution of the construction project while capturing all the imposed sources of uncertainties on the system. The model is applied on a real-world case study involving a contractor who has been facing difficulties in getting payment requests approved on-time. The model estimates the proportion of all submittals that get approved and also measures the total time required to get approval. The outcomes also reveal the stations at which rework and delays occur. The ultimate objective of the proposed model is to enhance the performance of the QS system by implementing innovative strategies such as the lean concepts. An alternative QS system incorporating lean principles is expected to remove non-value adding steps of the operation, which results in increasing the rates of approval as well as shortening the billing and payment cycle.

The research starts with a brief review of various studies tackling project controls and the use of simulation tools. Then, the methodology used to meet the study objectives are presented. Afterwards, the simulation model is presented including input and assumptions. Testing of the model on a real-world case study is followed by an explanation of lean principles and the corresponding alternative QS systems.

# CHAPTER II

# LITERATURE REVIEW

The literature exploring project controls is diverse and ranges from tools and technologies that facilitate operations of controls to various frameworks and methods that analyze key performance indicators of controls. This section starts with a general overview of project controls, followed by major sources of uncertainties in project controls. Techniques used to model uncertainties in project controls are then discussed including simulation.

## 2.1. General Background about Project Controls

Project controls involve planning, monitoring and correcting for any deviations between the preliminary planning variables compared with actual performance [2, 18]. Designing proper systems for project controls is essential to ensure the robustness of control methods [19]. The control methodology helps in executing the project according to preset plans and eventually contributes to its success. Many papers emphasized the importance of project controls to meet the project's objectives [20-22].

As mentioned by Westhuizen and Fitzgerald [23], the primary factors for success of projects are time, budget and quality. Therefore, some of the studies around project controls focus on quality monitoring; whereas, the majority of research targets time and cost controls. For instance, Boukamp and Akinci [24] present a framework to automate the processing of construction specifications to facilitate quality control tasks, such as inspection and defect detection. Nassar, et al. [25] emphasizes that rarely do projects finish on time ; thus,  a number of tools with different functions are established

for time control [26, 27]. Similarly, quantitative methods are developed for cost control

[28]. Time and cost controls are integrated in a number of studies [29, 30].

Another set of studies attempted to automate the process of project controls.

These include a study by Zhang, et al. [31] who use computer vision technology which

gives computers human-like functions to analyze captured images and automate the

measurement of work-in-progress. Similarly, Isaac and Navon [32] monitor productivity

on site and deviations from plans through a methodology which semi-automates project

controls. The methodology incorporates both manual and automatic data collection.

Shahi, et al. [33] established a process management framework that fuses information

from automated technologies (3D imaging), reports or schedules. The framework also

tracks the related activities rather than objects to achieve efficient and reliable project

controls. Navon [34], on the other hand, investigated how Automated Data Collection

(ADC) technologies (GPS, LADAR and RFID) can be used to facilitate safety

management and to assist in developing project performance control tool from daily site

reports.

## 2.2. Sources of Uncertainty

Automating project controls activities cannot guarantee that the project meets its

targets as uncertainties and risks are at the core of construction activities. Ideally, project

controls and management systems are designed to mitigate the effect of uncertainties.

The uncertain events are usually classified by their source or potential impact [35].

In this research, uncertainties are classified according to their sources, i.e.

internal or external [36]. Internal risks are organization-specific (e.g., contractor), and are

under his control [37]. For instance, contractors are typically responsible for materials

delivery, equipment and labor's availability, and managerial efficiency in tasks such as

tracking of claims and variation orders, monitoring budget overruns and delays in completion-time dates, and resolving other human-relation problems [38-40]. External uncertainties are not organization-specific, but can greatly affect the contractor. These include natural hazards (e.g. floods, hurricanes, or earthquakes), economic factors (inflation, fluctuation of prices), technical matters (design liability, quality of construction documents), and political instability (government relations, war, riots, labor restrictions) [37, 41, 42].

## 2.3. Tools to Model Project's Uncertainty

The various sources of uncertainties in construction projects can lead to a significant negative impact on the overall project's performance. Therefore, it is important to employ effective project controls systems to avoid the threat of these uncertainties [19].  Several methods – qualitative and quantitative - have been proposed for this purpose.

Qualitative methods include frameworks and decision support systems used to control projects under uncertain environments. For instance, Ward and Chapman [40] presented a framework to improve project management practices by controlling the broader perspectives of uncertainties rather than managing the mere risky events. Also, De Meyer, et al. [35] analyzed 16 different projects that failed to recognize uncertainties. The authors suggest proper methods for identifying and modifying uncertainty. Zwikael and Ahn [43] demonstrated that planning activities can effectively alleviate the negative impacts of uncertainty on project targets. Other studies used decision-support systems for scheduling and risk analysis. For instance, Megow, et al. [44] presented a decision-support system that integrates scheduling and risk analysis for planning large scale maintenance operations in chemical manufacturing. More recently, Arashpour, et al. [45]

proposed a risk analysis framework to understand the effect of integrated uncertainties on-site and off-site during construction.

Quantitative methods deployed for uncertainty analysis are numerous. The methods include mathematical modelling, optimization, algorithms, and simulation [46]. These approaches can be used in combination with common project controls methodologies such as the Earned Value technique as Hazır [21] explains. For example, the Earned Value technique can be combined with mathematical or statistical models such as Data Envelopment Analysis, to assess the performance of projects [47]. Other relevant work includes Adeli and Karim [30] who proposed a model that automatically generates the optimum schedule at the minimum cost and Naeni and Salehipour [48] who studied project performance by deploying fuzzy set theory to model percent completions as fuzzy numbers.

Using effective technologies is a pre-requisite for the success of qualitative and quantitative methods in modelling and managing uncertainties in project controls. For example, Zhang and Gao [28] utilize Building Information Modeling (BIM) techniques on a case study to alleviate project costs and optimize project schedules while Hartmann, et al. [49] deploy BIM tools to perform project controls activities for risk mitigation on a large infrastructure project. Lee and Rojas [50] invented a visual representation of gathered data to help decision-makers easily identify deviations between target and actual performance.

## 2.4. Simulation Tools for Modelling Uncertainties in Project Controls

While traditional quantitative methods such as mathematical modeling offer optimal solutions under deterministic scenarios, they are not designed to handle uncertainty and generally problems of stochastic nature. On the other hand, simulation

techniques, as Hollocks [51] states, are designed to handle uncertainties such as the ones faced in project controls processes. Computer simulations capture randomness and dynamic interaction [52]. Consequently, the application areas of this technique are numerous and include various aspect construction project management.

Numerous studies have used simulations for project controls. For instance, H. Zhang et al. [53, 54] integrated fuzzy theory with discrete event simulation to model uncertainty in activities duration, while Öztaş and Ökmen [55] studied schedule risk analysis under a methodology called Judgmental Risk Analysis Process (JRAP) which is based on Monte Carlo Simulation. Lee, et al. [56] analyzed scheduling simulations and the effect of the probability distributions of activity duration on the probability distributions of project completion time. The authors created an algorithm in MATLAB to quantify the associated risks in the simulation output due to the changes in probability distributions of the activity durations. Other studies applied simulations for productivity analysis [57]. Scheffer, et al. [58] deployed simulation to understand the impact of site layouts and logistics on the performance of tunnel construction projects.

In a recent study, Sadeghi, et al. [59] applied fuzzy discrete event simulation to capture uncertainty in asphalt phasing operation. Zhou, et al. [60] deployed simulation on a concrete-dam-construction project. The authors used probability distributions and statistics to feed the simulation model. Thus, amidst all uncertain events, the model can still reveal the impact of production system faults on the concrete placement duration and its monthly placement strength.

In an effort to examine the applicability of computer simulations in QS and generally project controls systems, this research uses simulation to assess the performance of the QS system during construction. The aim of deploying simulation is to

capture the random factors imposed on the project controls system and analyze their effect on the process of billing and collecting the incurred cost related to the executed work on site. Ultimately, the objective is to enhance the robustness of the project controls system by offering a platform to mitigate the effects of the uncertainties associated with construction work. Improvements are introduced by changing the management environment into a more collaborative one that integrates innovative techniques such as lean management.

# CHAPTER III

# METHODOLOGY

In order to study the performance of QS systems during construction using simulation, the methodology shown in Figure 1 is set. The methodology relies on previous studies [52, 61, 62] and includes the following steps:

1. Identify the problem, define its objectives and the data needed

2. Observe the system and collect data

3. Build a computer-based model

4. Verify and validate the model and go back to Steps 2 and 3 as necessary

5. Analyze the output, experimental design, and number of runs and replications

6. Introduce alternatives and improvements to the system

7. Document and present the final results

The simulation process is developed as described in the above seven steps starting with problem identification and ending with suggestions to improve the system.
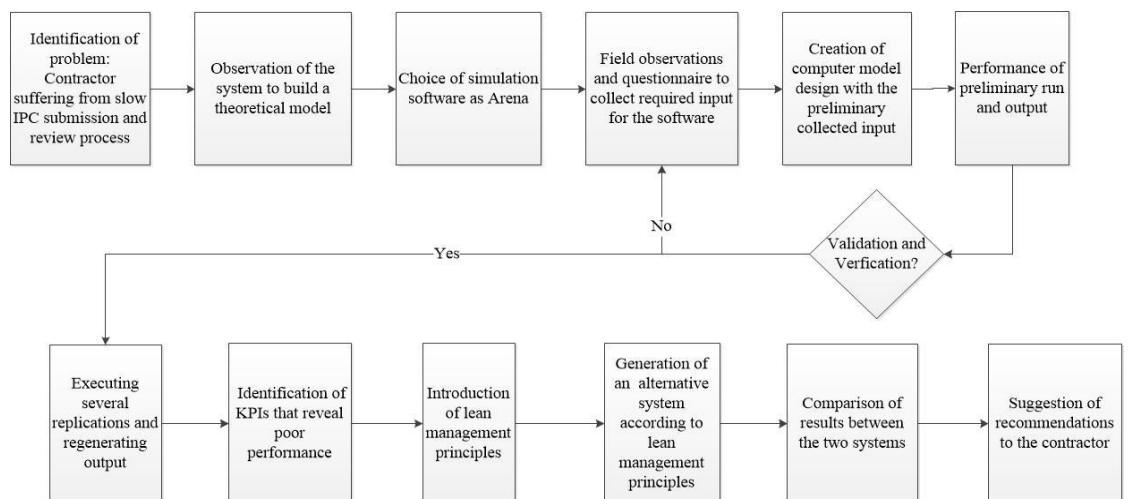


**Figure 1 Research Methodology**

First, the problem is identified from a real-world case of a contracting firm that uses a traditional management approach for field progress measurements on most of its construction projects. This company suffers from delays in getting approvals on the Interim Payments Certificates (IPC) and reimbursements on a hotel renovation project, composed of 157 rooms, in Beirut, Lebanon. The project was handed over two years later than the scheduled date. Even several months after handing over, the contractor continued to submit Interim Payment Certificates (IPCs) to ensure that all the executed works have been reimbursed.

A model of the adopted QS system is developed using Arena Simulation Software by Rockwell. Arena is widely accepted for Discrete Event Simulation and comprehensive as it addresses various organizational needs. The process of billing costs of the completed works is then tracked for a certain period of time with the goal of collecting required data for simulation purposes. In addition, decision-makers and civil engineers were interviewed to gather input that cannot be physically monitored. The model is fed with all the collected input followed by a preliminary run. Using this output, the built model is verified and validated. Verification involves checking the accuracy of the model and the generated results using logical tests (e.g. Little's Law [52]). For the validation, experts' feedback is used to make sure that the model offers an accurate representation of what occurs in reality.

After ensuring that the model is verified and validated, output is regenerated and the experiment is repeated several times. The higher the number of replications is, the more accurate the output is. A modeler realizes that a good number of replications is reached once the output is generated with corresponding confidence intervals. Then, the results are used to spot the key parameters that require improvement. Lean management

principles are, then, introduced and the QS process is re-engineered accordingly. After

redesigning the alternative QS system, the corresponding results are compared against

the traditional system. Finally, the paper offers a set of recommendations and insights for

the decision-makers involved in project controls.

# CHAPTER IV

# PROTOTYPE MODEL

## 4.1. Process Overview

Before using computer simulation to analyze the performance of the QS system, it is necessary to describe the steps of the process. Figure 2 shows an overview of the stages that depict a typical QS system in contracting firms. The stages are a series of activities that run at three different levels of human resources. First, foremen track and report the progress of work on site. Second, quantity surveyors document the measurements and prices of the completed field works. Third, the Project Manager checks the documents prepared by the quantity surveyors before submitting to the client.

Subcontractors go through a similar process for billing their clients (i.e. general contractors). However, there is an additional level of complexity for subcontractors. The subcontractor submits his IPC to the contractor who in turn checks for mistakes in measurements, links or documentation. If mistakes are detected, the subcontractor corrects and resubmits the IPC to the contractor. If the subcontractor's IPC is correct, the contractor aggregates the items relevant to the subcontractor's work with its own and submits them in the same IPC to the client.
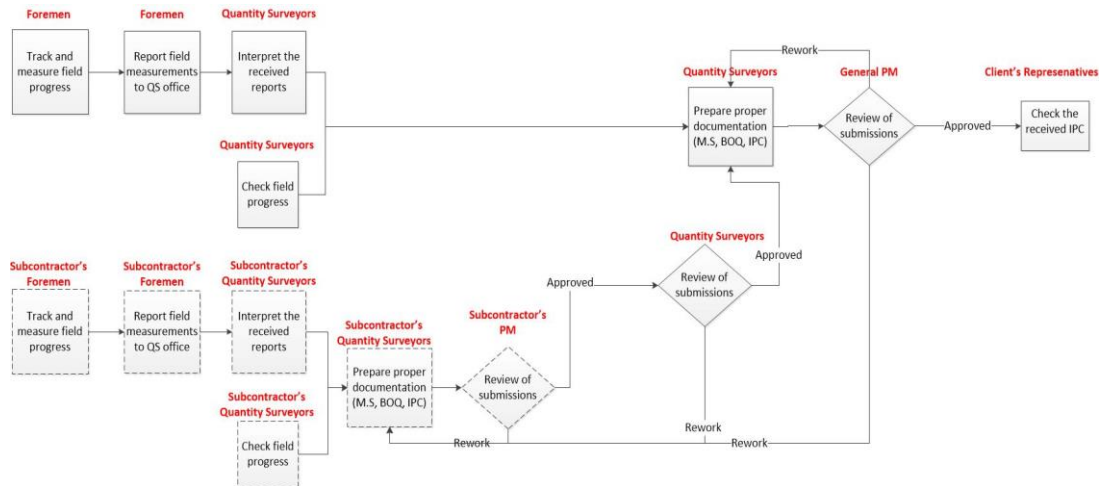
**Figure 2 Process flowchart of a typical QS system**

The documents prepared by both subcontractors' and contractors' surveyors are:

1) Measurement Sheets (MS) which are Excel sheets to note the detailed measurements of every executed item. For instance, Figure 3 shows an example of the MS used to calculate the weight of installed steel beams.

2) Drawings: CAD files for labeling the measured quantities.

3) Bill of Quantities (BOQ): Excel files which contain the contractual price for items. The Quantity Surveyor is required to fill out the quantities of the executed work and calculate the corresponding price of the executed work. Figure 4 shows an example of a steel BOQ item adopted from the local contractor's work. The figure shows a quantity under the "amount executed in this period" of 1000 kg, which was obtained from the MS (Figure 3). After having this quantity linked in the BOQ, the total costs for this period can be obtained ($5,000 in this example).

4) IPC: the collection of the documents (BOQs, MS and drawings and their summaries) aggregated and submitted on a monthly basis.

| Volume 8-Section 5.1.a | | | Dimesion | | | Cover | Bar | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Floor | Description | No | L. | W. | H. | Side | Spac. | num of stirrups | no. | layers | Ø | Bend 1 | Bend 2 | length | Bar length | weight |
| **SUPERSTRUCTURE** | | | | | | | | | | | | | | | | |
| *Entrance* | B1 | S401 | 7 | 1 | 0.40 | 0.04 | | | 8 | 2 | 25 | | | 7 | 7 | 207 |
| | B2 | S401 | 7 | 1 | 0.40 | 0.04 | | | 2 | 1 | 12 | | | 7 | 7 | 6 |
| | B3 | S401 | 7 | 1 | 0.40 | 0.04 | 0.20 | 102 | 3 | 1 | 10 | 0.10 | 0.10 | 7 | 7 | 6 |
| | B4 | S401 | 7 | 1 | 0.40 | 0.04 | 0.20 | 34 | 1 | 1 | 10 | 0.10 | 0.10 | 7 | 7 | 2 |
| | B5 | S401 | 15 | 2 | 0.40 | 0.04 | | | 13 | 1 | 14 | | | 15 | 15 | 119 |
| | B6 | S401 | 15 | 2 | 0.40 | 0.04 | | | 13 | 1 | 16 | | | 15 | 15 | 155 |
| | B7 | S401 | 15 | 2 | 0.40 | 0.04 | | | 2 | 1 | 12 | | | 15 | 15 | 13 |
| | B8 | S401 | 15 | 2 | 0.40 | | 0.20 | 380 | 5 | 1 | 10 | 0.10 | 0.10 | 15 | 15 | 24 |
| | B9 | S401 | 15 | 2 | 0.40 | | 0.20 | 76 | 1 | 1 | 10 | 0.10 | 0.10 | 15 | 15 | 5 |
| | B10 | S401 | 15 | 2 | | | 0.20 | 76 | 1 | 1 | 10 | 0.10 | 0.10 | 15 | 15 | 5 |
| | B11 | S401 | 13 | 2 | 0.40 | 0.04 | | | 10 | 1 | 25 | | | 13 | 13 | 255 |
| | B12 | S401 | 13 | | | 0.04 | | | 10 | 1 | 16 | | | 13 | 13 | 105 |
| | B21 | S401 | 18 | 2 | 0.40 | 0.04 | 0.20 | 355 | 4 | 1 | 10 | 0.10 | 0.10 | 18 | 18 | 22 |
| | B22 | S401 | 18 | 2 | 0.40 | 0.04 | 0.20 | 89 | 1 | 1 | 10 | 0.10 | 0.10 | 18 | 18 | 6 |
| | B23 | S401 | 7 | 1 | 0.40 | 0.04 | | | 9 | 1 | 16 | | | 7 | 7 | 48 |
| | B24 | S401 | 7 | 1 | 0.40 | 0.04 | | | 9 | 1 | 12 | | | 7 | 7 | 27 |
| | Total | | | | | | | | | | | | | | | 1,003.98 |

**Figure 3 Example of a measurement sheet (adopted from Local Contracting Firm)**

| | Breakdown Structural BOQ - 8.00 Volume 3 part 2 (STEEL STRUCTURE ) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Project : XXX Hotel Renovation | | | From: | | Contractor | | Date: | |
| Location : - | | | To : | | XYZ Group | | Revision No. | |
| | | | | | Contract amount | | Amount Executed this period | |
| Item | Description | | Unit | Total Quantity | Unit Cost ($) | Total Cost ($) | Quantity | Total Cost ($) |
| | The unit price rate shall include the preparation of the shop drawings, the fabrication and Erection of all the steel structures including steel beams Channel & IPE, IPN, HEA profiles, base plates, bolts, nuts, and washers, roof purlins, welding, grouting, devices, fittings, accessories, sandblasting, painting for a 10 year guaranteed life and all other related works, all as specified by the Engineer, and as shown on drawings. | | | | | | | |
| 5-1 | AT THE ENTRANCE | | | | | | | |
| | a) Curved Steel Frames and supporting beams, including the necessary base plates and fixation plates. | | Kg | 2,000 | $5.00 | $10,000.00 | 1,000.00 | $5,000.00 |
| | b) Epoxy Injection Bolts | | LS | | | | | |
| 5-2 | SKYLIGHTS AT ROOF | | | | | | | |
| | a) Steel Frames and beams, including the necessary base plates and fixation plates. | | Kg | | | | | |
| | b) Epoxy Injection Bolts | | LS | | | | | |
| | To Collection | | | | | 10,000.00 | | 5,000.00 |
| | TOTAL SECTION 5 | | | | | | | |

**Figure 4 Steel BOQ (adopted from a Local Contracting Firm)**

## 4.2. Parameters Definition

Discrete-event simulation is applicable for dynamic operations and for processes that consist of a chronological sequence of events with a range of uncertainty [52]. The QS process explored in this study is a flow of ordered events as explained in the previous

section. Moreover, the QS model entails many sources of uncertainties (Figure 5) which is why discrete-event simulation can be fairly utilized for modelling.
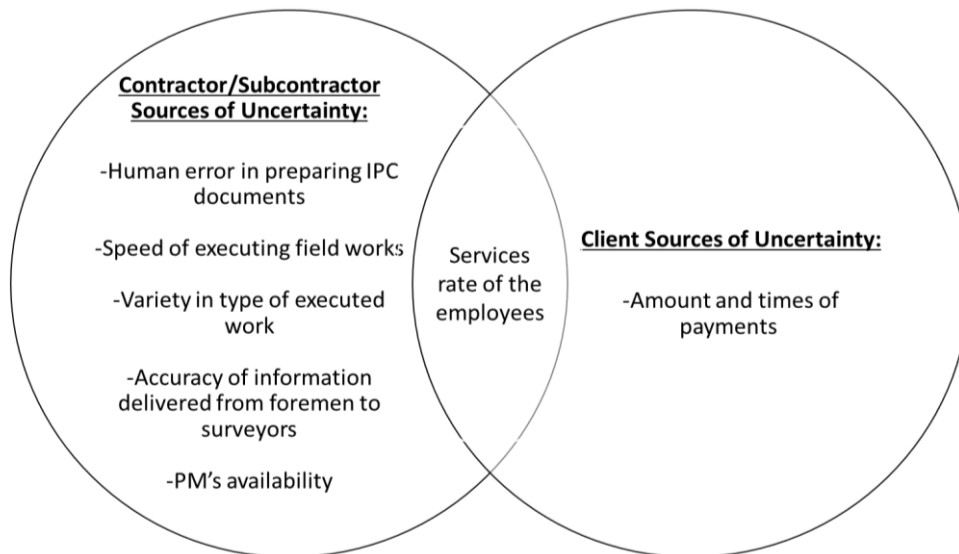


**Figure 5 Sources of uncertainties in the QS model**

The uncertainties in the QS model originate mainly from the three parties interacting in this system: the subcontractor, contractor and client. They are as follows:

- The speed of executing field works. Sometimes many BOQ items are executed simultaneously. At other times little work is performed leading to a variability in initiating the BOQ items for billing, whether sub or contractor-related work.

- Variety in the type of executed works. Some can be easily measured and have corresponding shop drawings for labeling; whereas, other types of work require extra effort for measurement and documentation. For example, counting and documenting the number of installed doors on a floor is easier than measuring a plastered area in a basement.

- Inconsistency of forms delivered from foremen to the quantity surveyors. For instance, the foremen might deliver incomplete information like not sharing the 3D measurements of actual work. The

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quantity surveyor might exert extra effort to process these incomplete reports.

- The services rate of the employees. The speed at which the contractor's surveyor records the BOQ item might vary. Some days, the engineers might be working at a very fast pace (billing a BOQ item in one working day), while they may not work very effectively on other days (using 3 to 4 working days to process a BOQ item). The latter could be due to the fact that the resources are occupied with other tasks or that they do not perceive the urgency of completing the task quickly. Similarly, the subcontractor's surveyor may have a variable rate in preparing the IPC due to a lack of resources. The time the client's representative takes to check the submitted IPC is another variable in the model.

- The likelihood of human error in preparing the IPC. While preparing an IPC, both contractor's and subcontractor's resources are prone to making mistakes. For instance, the surveyor might mistype the quantities in the Excel files or might even misplace the quantities for their corresponding items. These errors are inevitable and result in a variable amount of inefficiencies and rework in the system.

- The Project Manager's availability. Project managers are almost always busy. The team could rarely guarantee their availability to approve the submission of the IPCs.

- The time and amounts of payments by the client. The client decides when to pay and how much he will pay back the contractor. This client's decision depends on the quality of work in the field, the proper

documentation of the IPC, and mainly the financial status of the client himself.

Because there are numerous factors of uncertainty in QS systems, simulating the process of QS and issuing payment certificates using discrete-event simulation captures most of these sources by applying probability distributions as required. Ultimately, the objective of the simulation is to mitigate the impact of uncertainty on likelihood, timeliness, and amount of payment.

One of the software that deploys discrete-event simulation is Arena from Rockwell Software. Arena is the chosen software for simulation because it models the dynamic interactions in the system and offers a wide range of probability distributions including empirical distributions, standard statistical distributions, and external prediction models to capture variability in the process [63]. Using Arena, the processes can be properly defined by assigning resources to perform the tasks, priority level and order of task, and time needed for execution. In addition, Arena offers report generation options and animation capabilities. Another helpful feature of Arena is the pre-defined library of building blocks, which allow for modelling any process without requiring custom programming.

It is necessary to describe the building blocks of Arena that will be deployed for modelling the QS system before explaining the logic of its operation in the software. The modules used to build the QS model are: entities, processes, resources, attributes, variables, batches, and statistical counters.

- <u>Entities</u> are players in the system. They are created as simulation begins, undergo a set of processes, move around, change status and get disposed at the end of the simulation. The entities in this research are

BOQ items corresponding to every executed work on-site by the contractor or his subcontractors.

- Resources are agents that execute a process or offer a service. The entities compete for a resource to receive the needed service. Entities seize the available resource, get served, and release the resource. In our case, the resources are the quantity surveyors and the engineers/project managers of both the subcontractor and the contractor. These resources perform the necessary processing for the BOQ items that are created in the system.

- Queues are the waiting places for entities that cannot move on because the resource needed is tied-up with another entity. The queues usually correspond to the time-ordered sequence of activities that directs how an entity moves through the system. For QS, the queues are formed at the activities such as data collection, documents preparation (MS, labelled drawings or IPC) and IPC revision.

- Attributes are common tags to all entities. Although attributes are tags common to entities, they can carry different values. Attributes are useful for individual characterization of the entity. For instance, color can be a common attribute in any model, with the ability to assign a different color for every entity. In reference to the QS model, attributes are used to differentiate among BOQ items in terms of the time they take to circulate in a QS system (this will be further explained in Section 4.3).

- Variables are pieces of information that reflect some features of the system regardless of the kind of entity. Unlike attributes, variables are not tied to an entity but are rather related to the system at large. In contrast

to an attribute, which is like a tag carrying a piece of information and
attached to an entity, the variable is a floating piece of information that can
be rewritable throughout the simulation.

- The variables have many different usages. In this study, we
  use three variables to build an algorithm that aggregates the
  BOQ items every 30 days at the contractor's level. A time of
  30 days is chosen because contractors and subcontractors
  typically bill the owner for the executed work every month.
  These variables are:

  - $Timer$: a variable that counts 30 days,
  - $Cyclenumber$: the variable that marks every 30
    days as a cycle,
  - $EntityCounter$: a variable that stores the
    number of all the entities being served in a cycle.

- Similarly, three variables ( $Timer,$
  $Cyclenumber, EntityCounter$ ) are used to aggregate the
  subcontractor's BOQ items every 30 days. An explanation of
  how these variables form up the aggregation algorithm is
  presented in Section 4.3.

- Another important variable utilized in the QS model is
  quality index (q-index). Q-index is a metric that
  characterizes the quality of a submission. The rubric
  presented in Table 1 describes the different quality levels
  based on three criteria the client follows for evaluating the

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content of the submitted IPC. For example, a score of 3 means that the submission is of good quality because it is clearly documented, with proper supporting documents and with reasonable claimed dollar amount. Having a score of 3 guarantees the client's approval and payment. A score of 2 indicates an acceptable quality which means that the client is likely to pay after the contractor addresses the comments and resubmits the request. The client does not approve a payment that scores 1. As soon as an entity is created in the QS system, a random q-index is assigned to it.

**Table 1 Rubric for evaluating the quality of submissions based on criteria clients typically look for**

| Criteria / Scoring-level | Clarity of submission | Support of documents | Reasonable claim |
|---|---|---|---|
| 3-Good | Well-documented. Consistent and correct formulas for quantity and price calculations. Properly organized BOQ sheets of different disciplines and clearly summarized and linked into one sheet. | Accurately labelled drawings that show the measurements and quantities. Well-referenced to specs and drawings. | Claimed prices accurately reflect the completed work on site. Claims of completed work passed the quality control inspection. |
| 2-Acceptable with minor changes | Acceptable documentation and organization with minor calculation mistakes and broken Excel links. | Minor mistakes in the labels of the drawings. Properly referenced specs and drawings. | Claimed prices reflect the completed work on site. Minor comments from quality controllers on the claimed completed quantities. |

| 1-Unacceptable | Poorly documented. Inconsistent usage of formulas for calculations. Unorganized BOQ sheets. Broken links on the summary sheets. | Missing labelled drawings and references. | Claimed prices do not reflect the competed work on site. |
|---|---|---|---|

- Batches are grouping mechanisms within a simulation model. A batch module is used to group a number of specified entities. All the entities wait in queue until a predefined number of entities is reached. Once the entities are grouped, a new representative entity, which is a batch of the grouped entities, is created. We deploy the batch module to aggregate entities every 30 days into a batch of entities that represents the submitted IPC. Therefore, the predefined number of entities in our case is the sum of all entities being processed in a month.

- Finally, statistical counters are accumulator variables used to collect output performance indicators. The statistical counters are used in the QS simulation model to collect output regarding the number of approved items, number of items assigned for rework (by PM to QS, by QS to sub, or by client to QS) and lifecycle of entities.

  - The lifecycle of an entity is defined as the amount of time a BOQ item spends in the system from the day of its completion on-site until the client pays for it. Figure 6 explains how the lifecycle is measured in the model. The figure shows three IPCs each having four submitted items (represented by alphabets). Green boxes indicate that the client will reimburse the contractor for executing the

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activity, whereas red boxes mean that the client will not reimburse for the execution of the activity. The contractor will keep submitting the activities with red boxes until they finally get cleared out (green box). For instance, Activity D appeared in IPC 1 and 2 until it got an approval on the 3rd submission. The lifecycle of activity D is measured from start of IPC 1 to end of IPC 3. For example, Activity A appeared in IPC 1 and got approved right away and hence has a shorter lifecycle than that of Activity D.
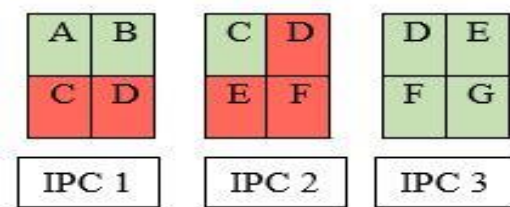


**Figure 6 Representation of the lifecycle of BOQ items**

## 4.3. Computer Simulation Logic

Appendix 1 shows three different parts of the model in Arena. The simulation starts at time t=0 when entities, which are the BOQ items, are created. BOQ items can be initiated by the main contractor or by a subcontractor. Items generated by the main contractor are categorized as Type A (slow) or Type B (fast); and items generated by a subcontractor are categorized as C (slow) and D (fast) (Table 2). This classification refers to the time needed to process the BOQ item and is further explained in Section 4.4.

Both contractor's and subcontractor's items are processed simultaneously and are aggregated in one IPC at the end of every month. Starting with the subcontractor, the

algorithm to aggregate the processed BOQ items deploys the three different variables defined in Section 4.2.

Initially, the variables are set according to Equation (1)

$$Timersub = TNOW = 0, \& \, cyclesub = 0, \tag{1}$$

where $TNOW$ is a built in expression that gives the current simulation time.

Then, a condition (Equation 2) is tested.

$$Timersub \geq 0 \, \&\& \, Timersub \leq 30 \tag{2}$$

If the result is true, the variables EntityCounter Sub and $Timbersub$ are updated as per Equations (3a and 3b):

$$EntityCounter \, Sub = EntitiesWIP \, (EntityC) + EntitiesWIP \, (EntityD)$$

(3a)

where EntitiesWIP is a predefined expression in Arena that counts all the subcontractor's entities in process, and

$$Timersub = TNOW \times 30 \tag{3b}$$

If the condition is not satisfied, i.e. $Timersub > 30$ , set of Equations 4a, 4b and 4c will apply.

$$Timersub = TNOW = 0 \tag{4a}$$

$$cycleSub = cycleSub + 1 \tag{4b}$$

$$EntityCounter \, Sub = 1 \tag{4c}$$

These set of equations reset the timer back to zero; in this way, the condition of Equation 2 will be satisfied for another 30 days' run-time. Moreover, this set of equations helps in marking the passage of a cycle and resets the variable $EntityCounter \, Sub$ as soon as a new cycle begins.

We demonstrate the algorithm using the following numerical example:

From time $TNOW = 0 \; to \; TNOW = 30 \; days$ , the condition of Equation (2) is satisfied; thus, we apply Equations 3a and 3b.

$$Timersub = TNOW - cycleSub \times 30 ,$$

$$= TNOW - 0 \times 30 ,$$

$$Timersub = TNOW - 0 = TNOW,$$

which indicates that the $Timersub$ is equal to $TNOW$ throughout this time range. The entities created in this month are added up and stored in the variable $EntityCounter \; Sub$ . The batch module is assigned a batch size equal to the variable $EntityCounter \; Sub$ . Therefore, once the month passes, all the entities counted using $EntityCounter \; Sub$ are transformed into a single entity representing the monthly IPC.

At $TNOW = 30$ , the condition in Equation 2 is not satisfied; thus, Equations 4 applies:

$$Timersub = 0, cycleSub = 1 , EntityCounter \; Sub = 1. ,$$

Now that the $Timersub$ is reset back to 0, and the conditions of Equation 2 are satisfied again. So, from $TNOW = 31.00 \; to \; 60 \; days$, we apply Equations 3 as follows:

$$Timersub = TNOW - cycleSub \times 30,$$

$$= 31 - 1 \times 30 = 1.$$

Meanwhile, the number of entities are stored in the variable $EntityCounter \; Sub$. At $TNOW = 60.00 \; days,$ the $Timersub$ becomes 30 again $(60 - 1 \times 30 = 30.00)$. Once more, Equations 4a, 4b, and 4c apply, the two variables $Timersub$ and $EntityCounter \; Sub$ are reset, while the variable $cycleSub$ is incremented into 2. The algorithm is implemented through the run-time of the model.

After the batching algorithm runs for a month at the subcontractor's level, the PM of the subcontractor checks and signs the IPC. Once signed, the subcontractor

submits the IPC to the contractor's surveyor. The batch splits back into the entities it was

comprised of initially. The contractor's surveyor checks each item separately and decides

if they meet the requirements for documenting and filing up the certificate. If the

contractor accepts the subcontractor's submission, the subcontractor's entities run

through the algorithm that aggregates the contractor's entities. If the submissions are not

acceptable, the contractor assigns the subcontractor's entities for rework. Any issue with

the subcontractor's submissions is typically related to documentation and not to the

submitted amounts. As long as the contract type is back-to-back, the contractor does not

pay the subcontractor unless the client approves the payment. Therefore, the entities for

rework are reassigned in the system to the stage of preparing the MS and not to the stage

of data collection. These entities receive a set of attached attributes that allocate less time

to perform the billing processes. Then, they are counted using statistical counters to track

down the number of times rework was assigned.

The subcontractor processes and batches his items into an IPC which he submits

to the contractor. Concurrently, the contractor's entities (A & B) are created, processed

and aggregated on a monthly basis. The aggregation at the contractor's level utilizes the

same algorithm used for grouping the subcontractor's items. The only difference lies in

the variables used to generate the algorithm. The three following

variables: $Timer, Cycle number, Entity Counter$ are deployed for building the

algorithm of item accumulation at the contractor's level.

The batched IPC that is released from the contractor's office, then, passes to the

client's appointed PM for checking and approval. The PM might in turn assign rework to

both, subcontractor or contractor. Any rejected entity is sent back to the MS preparation

step. The rework assignments are then counted and classified according to the entity type

through a set of differentiating attributes. Once checked, the IPC reaches the client's station. At this stage, the client's representatives may revise the submission. Only then, the IPC explodes back into individual BOQ items, which the client assesses one by one. The client decides whether to reimburse the contractor for executing a BOQ item upon the probabilistic q-index an entity holds.

- As mentioned earlier, an entity with a q-index of 3 results in the approval of payment. The model counts the number of these entities and measures their lifecycle before disposing them out of the model.

- For entities with a score of 2, the client accepts paying the contractor under certain conditions. This case of conditional acceptance implies that there are some minor errors in documentation or even in the presentation of the submission. Therefore, the contractor is expected to correct and resubmit such items to receive the payment. In the model, the instances of conditional acceptances are also tracked and reassigned to the system at the point of BOQ preparation, where the insertion of links from MS and calculation of prices occur. These items are also assigned a new random q-index so that these items can eventually earn a score of 3 and be cleared out of the system.

- Entities with a q-index of 1 are rejected due to conflict about the billed measurements or because of unacceptable quality of the executed work on site. The rejected items are counted and sent back to the first steps where the MS is prepared.

The aforementioned scenario runs for a year after which the output is collected. It is necessary to run the model for one year to observe the operations of the QS model

over a span of time that fairly represents the variability in preparing and submitting the IPC.

## 4.4. Assumptions

In order to represent the real QS system as accurately as possible in the prototype computer model, several assumptions were made.

- For simplicity, we assumed there is one subcontractor in the model. Consequently, there are two types of entities (subcontractor's and contractor's); whereas real-world cases may feature more than one subcontractor, thus more entity types circulating in QS systems. The addition of subcontractors in the model does not involve a lot of effort, but the results will become harder to handle and analyze as the scope of the study becomes wider.

- In the model, the subcontractor's entities are created at a faster rate than the contractor's entities. This assumption is set because the subcontractor has a narrower scope than that of the contractor. Therefore, he might be able to easily survey his work progress on a daily basis. However, processing the subcontractor's entities in the QS system requires more time as these entities pass through an additional revision stage at the level of the contractor's surveyor.

- As mentioned in Section 4.3, each of the subcontractor and contractor has two different sub-types (Table 2): A and B for the contractor and C and D for the subcontractor. These subtypes were created to illustrate two levels of complexity in a QS system. In reality, various activities are

executed in one year from concrete to finishing works. These activities correspond to the creation of BOQ items that vary on the scale of complexity in the QS system. Since we cannot include the various types of activities that might be executed in a year in the computer model, we group the entities in two representative subtypes that vary in complexity of processing in a QS system. Entity types A and C are more complex to process in a QS system than types B and D; hence, they are assigned more time to perform the QS steps specifically, data collection, MS preparation and labelling the related drawings. For instance, Types B and D (e.g., plastering in hallways) might be related to activities that are executed in easily accessible places; thus, the 3D dimensions can be easily measured and documented. However, Type A and C (e.g., plastering in basements) are related to activities executed in hardly accessible places with a lot of details that require more time to measure and properly document. Also, the difference in complexity does not have to do with the place of executing the activity but the difference might lie in the nature of the activity. For instance, counting and documenting the number of installed doors in a room is less complicated than measuring the amount of gypsum in the same room.

**Table 2 Different entity types and subcategories**

| Type / Subcategory | Contractor | Subcontractor |
|---|---|---|
| Complex Processing | Type A | Type C |
| Easy Processing | Type B | Type D |

- The scope of the model does not cover the part when the cost controllers in the head office follow up on the submitted IPC with the accounting department.

- The model does not differentiate among the reasons that prompt the client to reject the billed quantities. For instance, in practice, the client might not pay the contractor because of quality problems on-site or other financial hardships.

- Rework takes about half the time it takes to do the work for the first time assuming that the resource becomes more familiar with what he is supposed to do the second time. We used attributes to achieve this kind of differentiation in Arena. For instance, every time rework is assigned, the entities will hold a set of attributes that automatically allocates less time for processing.

- To model the client revising the submitted IPC, we used the delay module. Delay module ensures that the entities are queued at this process for a certain period of time without necessarily having a seized resource to cause the queue. Adding a client's resource is not important because we are not interested in the utilization rate of the client's resource. The model's objective is to study the variability of the client approval time allotted at this station.

# CHAPTER V

# CASE STUDY

This section presents a case study to assess the capability of the built model in capturing the uncertainties associated with QS as a project controls function. To clarify the impact of these uncertainties, we deploy a real-world case study of a contractor renovating a five-star boutique hotel. The hotel has 157 beds. The general contracting unit on-site consisted of QS engineers, a procurement engineer, a document controller, architects, site engineers, foremen and workers. The contractor faced difficulties in collecting payments from the client. The client paid late and did not reimburse all of the contractor's submitted IPCs. Due to these reasons, the contractor suspended work on site. In turn, the client became firmer about the quality of the delivered work on-site, which led to an adversarial relationship between the two parties.

Before running the simulation model described in Chapter 4, we needed to collect the required input by referring to historical records, interviewing site and QS engineers, and carefully observing how the QS system functions on site.

## 5.1. Input Parameters

- Starting with Entities, we collected monthly IPC records over a year to study the creation of both contractor's and subcontractor's entities. Appendix 2 tabulates the number of entities submitted for a chosen contractor's and subcontractor's BOQ.
    - Arena requires an input for the time it takes to create one entity; i.e. the inter-arrival times between entities. This is why the numbers in Appendix 2 were transformed to time

intervals measured in days; for example, if every month 4 contractor entities are executed, it would take 3.75 days to create one entity for the QS system in Arena. The data in days was automatically fitted using the Input Analyzer tool provided by Arena. Appendix 3 lists the possible fits from best to worst based on the difference in the square error[1]. The Beta distribution has the least square error; however, the Beta distribution shows (Appendix 3) a drop towards the end of the year. The interviewed experts in the company believe that there is no reason to have such a fluctuation in the inter-arrival times of entity submission. Therefore, the Uniform distribution, which ranks second in the square of errors criterion (Table 3), resembles more reality.

- A similar approach was used for the subcontractor's entities. The data was interpreted using the Input Analyzer in Arena. Appendix 4 shows that the Earlang distribution is the best when it comes to the square of errors criterion. However, Earlang distributions are usually used in situations where the entities occur in successive phases and each of the phases has an exponential distribution [63].The Poisson distribution

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[1] Square Errors in Arena's Input Analyzer is calculated as the sum of [ fi - f(xi)] $^2$ over all histogram intervals. "fi" refers to the relative frequency of the data for at the ith interval; whereas, f(xi) refers to the relative frequency for the fitted probability distribution function [63].

ranks the second, but this distribution defines discrete data, which is not the case for the inter-arrival times. This is why we chose the Triangular distribution which ranks third based on square of errors (Table 3).

- In table 3, the distributions of the inter-arrival times of entities is presented along with their mean (E[a]) which will be utilized later in this research for verifying the model. The mean for each of the distributions is calculated as follows (Eq. 5):

$$E(a)_{uniform} = \frac{Lower\ Bound + Upper\ Bound}{2} = \frac{0.5 + 10.5}{2} = 5.5 \tag{5}$$

$$E(a)_{uniform} = \frac{Lower\ Bound + Middle\ Bound + Upper\ Bound}{3} = \frac{0.5 + 3.25 + 8.5}{3} = 4.083 \tag{5}$$

- The mean of the inter-arrival times indicates that the speed of preparing entities varies between contractor and subcontractor. For instance, the contractor executes one BOQ item on site on an average of 5.5 days; whereas, the subcontractor requires 4 days on average to execute one BOQ item. This is expected because the subcontractor has a specialized and usually smaller scope, thus, administering BOQ items at a faster rate than the contractor.

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**Table 3 Entity Input Parameters**

| Entity type | Type of probability Distribution | E(a) (number of days for 1 occurrence) |
|---|---|---|
| A & B | Uniform (0.5,10.5) | 5.50 |
| C &D | Triangular (0.5,3.25,8.5) | 4.08 |

- At the level of Queues, Arena requires input for the time required to process the items. The contractor does not deploy a tracking system to measure the exact number of hours an employee spends preparing each of the tasks. Therefore, we relied on the experience of the surveyors and engineers to estimate the time needed to complete QS tasks. We asked for an approximation of three parameters: minimum, maximum and most likely number of hours needed to complete every step of the system (Table 4). The three parameters define a triangular probability distribution; therefore, they fairly capture the variability in employee's service rate.

    - The triangular distribution is a suitable approximation for almost all the tasks performed by the contractor and the subcontractor in the QS system. However, the time spent by the client to revise the IPC may require a different distribution. The time needed by the client may be highly variable and critical; thus, we collected historical records of IPC submissions and approvals. The time interval between these two events is identified as the client's approval time (Appendix 5). We performed statistical analysis on the obtained time to deduce the probability distribution that

properly represents the collected data. The input analysis is further explained in the following section.

- Table 4 also shows the <u>Resources</u> responsible for completing the QS tasks. In summary, in this case study, there are two quantity surveyors with an engineering background, one working for the subcontractor, while the other one works for the contractor. Both surveyors work on an 8 am to 6 pm schedule with a one-hour lunch break. Throughout the month, the resources constantly process the BOQ items. However, towards the end of the month, they only work on finalizing the IPC submission. This task has the highest priority on their schedule. In other words, the resources will stop surveying and documenting the newly executed work during this period of time because they will be preoccupied with the administrative duties of submitting the IPC.

  - In addition to the engineers, there are two PMs, one working for the subcontractor; whereas, the other one is a general manager responsible for all the contracted work on-site. The PMs allocate only 2 hours a day, usually from 11 am to 1 pm, to do the required checks for the items being processed in the QS system.

**Table 4 Process and resource input parameters**

| Entity type | Resource | Process | Probability Distribution | Best (Hours) | Most Likely (Hours) | Worst (Hours) |
|---|---|---|---|---|---|---|
| A | Contractor's Surveyor | Check databases/Take Measurements from Site | Triangular | 10 | 12 | 15 |
| | | Measurement Sheet Preparation | Triangular | 4 | 6 | 8 |
| | | Measurement Sheet Preparation_ Rework | Triangular | 2 | 3 | 4 |
| | | Drawing Labelling | Triangular | 4 | 6 | 8 |
| | | Drawing Labelling _ Rework | Triangular | 2 | 3 | 4 |
| | | Link to Corresponding BOQ | Triangular | 0.5 | 1 | 1.5 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| B | Contractor's Surveyor | Check databases/Take Measurements from Site | Triangular | 8 | 10 | 12 |
| | | Measurement Sheet Preparation | Triangular | 3 | 5 | 7 |
| | | Measurement Sheet Preparation_ Rework | Triangular | 1 | 3 | 5 |
| | | Drawing Labelling | Triangular | 2 | 3 | 5 |
| | | Drawing Labelling_ Rework | Triangular | 1 | 2 | 3 |
| | | Link to Corresponding BOQ | Triangular | 0.5 | 1 | 1.5 |
| C | Sub Contractor's Surveyor | Check databases/Take Measurements from Site | Triangular | 5 | 10 | 15 |
| | | Measurement Sheet Preparation | Triangular | 4 | 6 | 8 |
| | | Measurement Sheet Preparation_ Rework | Triangular | 2 | 3 | 4 |
| | | Drawing Labelling | Triangular | 4 | 6 | 10 |
| | | Drawing Labelling _ Rework | Triangular | 2 | 3 | 5 |
| | | Link to Corresponding BOQ | Triangular | 0.5 | 1 | 1.5 |
| D | Sub Contractor's Surveyor | Check databases/Take Measurements from Site | Triangular | 6 | 8 | 12 |
| | | Measurement Sheet Preparation | Triangular | 2 | 4 | 8 |
| | | Measurement Sheet Preparation_ Rework | Triangular | 1 | 2 | 4 |
| | | Drawing Labelling | Triangular | 4 | 6 | 10 |
| | | Drawing Labelling _ Rework | Triangular | 2 | 3 | 5 |
| | | Link to Corresponding BOQ | Triangular | 0.5 | 1 | 1.5 |
| C & D | Sub's PM | Check Sub IPC _Send to Contractor | Triangular | 5 | 10 | 12 |
| All | Contractor's Surveyor | Summary Formation of the Monthly IPC | Triangular | 2 | 4 | 8 |
| | | Printing-Batching | Triangular | 4 | 5 | 7 |
| All | General PM | PM revision | Triangular | 5 | 10 | 16 |
| All | None | Submission Delay | Triangular | 12 | 24 | 36 |
| All | None | Client Approval Time | Has a historical record which is analyzed to deduce its probability distribution | | | |

- In Arena, <u>Decision Modules</u> are the instances at which rework is assigned. To quantify the amount of rework in this case study, approximate probabilities are used (Table 5). For instance, the probability that the contractor's surveyor assigns rework for an IPC issued by the subcontractor is 40%, as the contractor's surveyors estimated. Also, the probability that the PM assigns rework or comments about the submission is around 20%, as the contractor's decision-makers approximated.

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- As mentioned earlier, the client's decision on whether to reimburse the contractor is based on the quality of the submitted IPC as reflected by its q-index.

**Table 5 Decision module input parameters**

| Decision Model | Probability | |
|---|---|---|
| Contractor accepting subcontractor's submission | 60% | - |
| PM approving what is administered in the IPC | 80% | - |
| Client accepting to pay for what is presented in IPC | q-index | • |

- Also, as mentioned earlier, the q-index is assigned to every entity as soon as they are created in the system. Unfortunately, no data is available on the quality of submission because neither the contractor nor the client scores the submission. Therefore, to be able to assign individual scores for the entities, we referred to the engineers to estimate the probability of achieving each of the three scores on a typical IPC. The engineers believe that 80 to 90% of submissions in a typical IPC would have a score of 3 using Table 1, 5% of the items would have a score of 2 and the remaining 10% items would have a score of 1. This information is used to generate random numbers for the q-indices by using an empirical discrete probability generator. The generator in Arena is fed by the cumulative probability and the value associated with this probability. For the case study at hand, the generator is as follows: DISC (0.1,1,0.15,2,1,3) which correspond to a score of one 10% of

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the times, score of 2 5% (0.15-0.10) of the time, and score of

3 85% of the time (1-0.15). The random numbers are stored

in the q-index variable throughout the run-time of the model

until the client revises the IPC. Only then, the q-index is

used as a basis for the client's decision upon the monetary

compensation of the item.

## 5.2. Input Analysis

### 5.2.1. Client's Approval Time

Uncertainty associated with the client in the QS system typically relates to

delays in paying the contractor. To carefully assess the impact of this factor, we collected

relevant data on the time the client takes to pay the contractor (Appendix 5), determined

its representative probability distributions, and studied the performance of the QS system

in Arena. The data set was fitted using ExpertFit which provides several interactive

histogram and graphics, unlike the Input Analyzer tool of Arena. ExpertFit uses

Exploratory Data Analysis (EDA), which is a statistical method for analyzing data

usually deploying visual methods.

Input analysis in ExpertFit starts by importing the data set (Appendix 5)

prepared for the time taken to pay the contractor's IPCs. Appendix 6 shows summary

statistics for the collected data. The data is comprised of 109 observations (n= 109) with

minimum and maximum observation of 0 and 216, respectively.  The mean value is equal

to 44.2 days. The data has a positive skewness coefficient (1.56) which implies that the

data is skewed to the right. The information about skewness also rules out the possibility

of a uniform distribution. The coefficient of variation is 1.06, which implies that the

distribution is exponential.

Histograms were also generated to check whether the data truly resembles an exponential distribution. The histograms in Appendix 7 are based on 25 intervals of 9 units of width which were determined by trial and error in ExpertFit. The shape of the histograms confirms that the distribution is skewed to the right; and hence, the best fit distribution is likely to be exponential.

ExpertFit provides automatic fitting and evaluation options. The evaluation consists of a report with a "Relative Score"[2] of the three best distributions and an "Absolute Evaluation"[3] of the best distribution. The "Relative Score" is a number from 0 to 100 that indicates how well the data matches the fitted distribution. The higher the score is, the better the fitted distribution represents the data. However, these scores do not give an overall assessment of the quality of fit because they are comparative in nature and result in ranking the distribution in relative to one another [64]. ExpertFit provides also the "Absolute Evaluation" which is a separate assessment indicating whether the highest-ranked model is actually good to use in application.

After using this option to rank and evaluate various distributions of the data set, the Beta distribution ranked first and received a "Relative Score" of 86.54 followed by Random Walk and Weibull distributions with Relative Scores of 73.08 for both (Appendix 8). Despite ranking first, the Beta distribution may not necessarily be the best

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[2] Relative Scores in ExpertFit are computed using 15 heuristics that can differentiate between a good and a bad fit. These 15 heuristics are applied to a random sample size "N" that is generated from a known "parent distribution". The process is repeated for 200 independent samples using 175 parent distribution/sample-size. This results in several superior heuristics which are combined to give the overall algorithm for ranking distributions and for calculating their relative scores [52].

[3] The method for computing Relative Scores results in 35,000 generated data sets which are also used to create algorithms for determining the "Absolute Evaluation" [52].

distribution to use in simulating the performance of the QS system [52]. In fact, the "Absolute Evaluation" of this distribution is not favorable. In this case, ExpertFit recommends the use of an empirical distribution.

Despite ranking 4th, the exponential distribution seems to offer the best fit as evidenced by its coefficient of variation (COV) of 1 and the density histograms of Appendix 9. Appendix 10 shows the distribution function differences plot for the possible distribution functions. These plots depict the difference between the cumulative probabilities of the true data and the cumulative probabilities of the possible fits (y- axis); the x-axis shows the ordered set of data. In a perfect fit, the plot is a horizontal line. The farther the data from the predicted fit is, the higher the discrepancy will be. For thee data set at hand, the acceptable bound of errors[4] is -0.12 to 0.12 and is represented by the blue dotted horizontal line (Appendix 10). The exponential distribution is once again the best of the distributions with the lowest mean difference 0.02183. A P-P plot or probability-probability plot, is a graph of the cumulative probabilities of the ordered statistics from the theoretical distribution (y-axis) versus the probabilities from the sample distribution function (x-axis). If the distribution resembles the theoretical distribution, the cumulative probabilities (from the theoretical distribution and from the sample distribution) will be almost equal. In these cases, the p-p plot is linear with a slope of 1. These plots (Appendix 11) also show that the exponential distribution is preferable with the lowest discrepancy 0.08143. Hence, an exponential distribution with a mean 44.2 days was selected to represent the time taken by the client to reimburse the contractor's IPCs.

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[4] The error bounds are calculated from the differences of each of the 35,000 data sets used for generating the "Relative Score" and the "Absolute Evaluation" [52].

## 5.3. Simulation Results

The simulation model is set to run for 365 days. Running the model for a year is necessary to allow the IPC submissions to be repeated enough times to ensure that the model is observed over a range of time that captures the uncertainties that might occur while processing BOQ items in the QS system. This yearly experiment was repeated 100 times until an acceptable confidence interval with a margin of error of about 2 to 3 percent is obtained. For example, the average lifecycle of Entity Type A is 131.96 days with a $\pm$ 3.76 confidence interval. This process ensures that the output is accurate and has is statistical significant. Tables 6 and 7 show a sample run of the simulation model.

**Table 6 Example of lifecycle durations for different types of entities**

|        | Lifecycle (Days) | Value Adding Time (Days) | Wait Time(Days) |
|--------|------------------|--------------------------|-----------------|
| Type A | 111.74           | 3.12                     | 108.62          |
| Type B | 136.32           | 2.86                     | 133.46          |
| Type C | 150.44           | 4.60                     | 146.14          |
| Type D | 131.72           | 4.72                     | 127.00          |

**Table 7 Summary of the results collected from the statistical counters**

|        | 1. Number of Entities in | 2.Number of Entities Out | 3. Number of times the Client Rejects Entities | 4. Number of times the client assigns rework | 5. Number of times the contractor assigns rework to the Sub | 6. Number of times the PM assigns rework | 7. WIP |
|--------|-----|-----|-----|-----|-----|-----|-------|
| Type A | 66  | 16  | 1   | 0   | 0   | 5   | 31.73 |
| Type B | 72  | 11  | 1   | 0   | 0   | 4   | 28.78 |
| Type C | 91  | 35  | 6   | 4   | 40  | 11  | 85.44 |
| Type D | 92  | 40  | 1   | 0   | 39  | 8   | 67.54 |

### 5.3.1. Verification

Model verification ensures that the simulation operates properly and logically, i.e., verification relates to debugging the simulation program [52, 65, 66]. In his book *Simulation Modeling and Analysis*, Law [52] identified eight techniques to verify a system, one of which consists of running the simulation while varying the input parameters to check whether the output is reasonable. Another powerful technique is to animate the model to be able to carefully observe the behavior of the entities in the

system. In this case study, the technique used for verification consists of comparing the state of variables and statistical counters side-by-side with hand-calculations to check if the program is operating as planned.

First, the lifecycle durations of entities are verified.  As shown in Table 6, the lifecycle is the summation of the value-adding time and the waiting time. The value-adding time is the processing time, i.e., the time consumed by all resources (QS engineers, PMs) to actually perform work that contributes to the formation and submission of the monthly IPC. The waiting time in this case is defined from the perspective of the contactor as the time the client takes to review the contractor's submissions. Clearly, waiting time is much longer than value-adding time, which corresponds to the experience of the interviewed personnel.

Then, the statistical counters presented in Table 7 are verified. "Number of entities in" is defined as all the entities created in the lifecycle, while "numbers of entities out" are the approved entities and which are cleared by the end of the run-time. Every 5.5 days, Entity Types A and B are created (Table 4). Thus, during the 365 days' run-time, we expect the creation of about 66 (365/5.5) entities (A and B). The model generated 66 and 72 entities of Type A and Type B (Table 7), which is an acceptable result. The frequency of creating Entity Types C and D is once every 4.1 days (Table 3). By the end of the year, approximately 89 entities must be created. The model resulted in 91 entities of Type C and 92 Type D entities (Table 7). These are also reasonable results which indicate that the model is doing what it is designed to do.

The number of times the client rejects or accepts conditionally added to the "number of entities out" have to be less than or equal than "the number of entities in". In other words, the sum of Columns 2,3 and 4 should be less than the 1st column. This

condition is indeed met in Table 7. The difference between the total created entities and the number of entities disposed as well as rejected or assigned for rework is explained by the existing work in progress (WIP). However, the WIP reported in the last column of Table 7 is not actually the difference of the number of entities reported in Columns 1, 2, 3 and 4. This is partly due to the fact that some entities may circulate more than once. In fact, the values reported in the last column represent the average of all WIP values observed at every instance of time throughout the run-time of the simulation, which is why they are not necessarily integer.

Next, we proceed to verify the amount of rework assigned by parties other than the client (Columns 5 and 6). The total rework assigned by the PM has to be approximately 20% as discussed earlier (Table 5). The model shows a total of 28 assignments of rework (Table 7) which is about 27% of the "total entities in". The obtained result further confirm that the simulation model is functioning properly. Also, the rework assigned by contractor to the subcontractor shall be around 40% (Table 5). The total values in Column 6 of Table 7 are 79, which is approximately 25% of all created entities. The discrepancy is explained by the large WIP amounts at the level of the subcontractor which constrain the movement of the subcontractor's entities to the revision station by the contractor.

In another verification step, Little's law is utilized to verify that the system is operating as intended. The law is as follows:

$$l_q = \lambda \times W_q \qquad (6) ,$$

where:  Arrival rate (entity/time), $\lambda = \frac{1}{E[a]}$ ,

where E[a] is the mean of the inter-arrival times,

$l_q$: mean number of entities in the queue

$W_q$ : mean waiting time of an entity in the queue or simply the mean delay.

We proceed by choosing the first process in the system after the creation of the entities. The process is the data collection and database checks. From Arena, $W_q$ and $l_q$ are collected and tabulated below (Table 8). In this process, the highest number of entities waiting in queue corresponds to an average of 9.5 for Entity A with an average waiting time of 46 days per entity. Using Little's Law, we calculated $l_q$ using $E[a]$ from Table 3. The corresponding percentage error in $l_q$ is calculated using Equation 7:

$$\frac{l_{q_{Arena}} - l_{q_{calculated}}}{l_{q_{Arena}}} \times 100 \qquad (7).$$

The results show that the calculated $l_q$ is close to the $l_q$ obtained from the model with an average error of 7 percent, which indicates the model is operating as intended. Little Law applies perfectly for queuing systems in steady state, i.e., systems that run for an infinite time [52].

**Table 8 Verification using Little's Law**

| Process | Entity Type | $W_q$ (Model results) | $l_q$ (Model results) | $\lambda$ (entity/day) | $l_q$ (calculated) | Percentage Error |
|---------|-------------|-----------------------|-----------------------|------------------------|--------------------|------------------|
| Data Collection and database checks | A | 46.16 | 9.28 | 0.18 | 8.39 | 10% |
| | B | 48.41 | 8.11 | 0.18 | 8.80 | 9% |
| | C | 9.75 | 2.51 | 0.25 | 2.39 | 5% |
| | D | 9.64 | 2.49 | 0.25 | 2.36 | 5% |

After verifying that the model is functioning properly at the level of the first process, we proceeded by checking the consequent activities in a similar way. However, the discrepancy between the calculated $l_q$ and the $l_q$ obtained from the model increased

to an average of 44% (Table 9). This is expected because the waiting time and length of queue at the first process station (data collection and database checking) is solely related to the rate of the creation of entities ($\lambda$) that follows Uniform or Triangular distributions, which is why the results from Little's Law were very close to what the model generated. However, the rest of the processes (measurement sheet preparation, labelling of drawings and inserting links for the BOQ) are not solely related to the rate of entity generation. For example, the waiting time and average length of the queue for these processes are affected by the service rates at the prior station. Therefore, it is only normal to have a larger percentage of discrepancy in $l_q$ for these processes.

**Table 9 Applying Little's Law to the various processes in the system**

| Process | Entity Type | $W_q$ (Model results) | $l_q$ (Model results) | $\lambda$ (entity/day) | $l_q$ (calculated) | Percentage Error |
|---|---|---|---|---|---|---|
| Measurement Sheet Preparation | A | 34.84 | 5.79 | 0.18 | 6.33 | 9% |
| | B | 45.39 | 6.08 | 0.18 | 8.25 | 36% |
| | C | 10.34 | 4.08 | 0.25 | 2.53 | 38% |
| | D | 10.15 | 3.79 | 0.25 | 2.49 | 34% |
| Labelling of Drawings | A | 35.13 | 4.33 | 0.18 | 6.39 | 47% |
| | B | 44.21 | 4.43 | 0.18 | 8.04 | 81% |
| | C | 10.15 | 3.63 | 0.25 | 2.49 | 31% |
| | D | 10.22 | 3.66 | 0.25 | 2.51 | 32% |
| Inserting links to BOQ | A | 27.25 | 3.34 | 0.18 | 4.95 | 49% |
| | B | 38.79 | 3.28 | 0.18 | 7.05 | 115% |
| | C | 10.68 | 3.61 | 0.25 | 2.62 | 28% |
| | D | 10.57 | 3.44 | 0.25 | 2.59 | 25% |

### 5.3.2. Validation

Validation, unlike verification, determines whether a simulation model accurately represents the real system [52, 65, 66]. Techniques used to validate a model include conversations with subject-matter experts, and evaluation of system performance versus other well-established models [52].

The results of the built QS model were presented to subject matter experts for validation. The interviewed experts, the construction manager and a project controller, were part of the contractor's team on the renovation project. They each have more than 10 years of experience in their respective fields. As discussed earlier and shown in Table 6, the lifecycle of Entities A, B, C and D are 112, 136, 150 and 132 days respectively. This means that that the average time to approve and reimburse an IPC is 133 days, i.e. approximately 4.5 months. As discussed earlier, most of this time is attributed to delays in the client's approval process. To determine whether the numbers provided by the simulation models are reasonable, a meeting was held with the managers in the contracting firm. The managers confirmed that the contractor and subcontractor usually do their best to submit their IPCs as soon as they execute an activity; however, the client takes a long time to evaluate, revise, and approve the submissions. They also confirmed that the process usually takes 4 to 5 months.

To further validate the results of the simulation model, the statistical counters shown in Table 7 were compared with the experience of the interviewed project managers. Overall, the number of Entities A, B, C, and D created in the year run time were 66, 72, 91 and 92 respectively leading to a total of 321. Of these entities, 102 items (i.e. 32 percent) are accepted. According to the project managers, this percentage is reasonable. For further validation, we collected historical records of submitted requests and corresponding payments by the client. These include submission of IPCs and variation orders. To avoid releasing confidential information, the contractor scaled down the numbers by dividing them by a factor (Appendix 12). We calculated the percentage of acceptance rate and averaged it over the number of submissions. The resulting average rate of acceptance is 57%. The average acceptance rate differs from the 32% percent

obtained from Arena. The discrepancy can be explained by the relatively small record of observed submissions. Also, the average rate of payments is not solely calculated from the IPCs but also from payments of variation order claims. Furthermore, the model continuously runs for a year while capturing uncertainty of client delays as well as other uncertainty factors related to the quality of submitted IPCs. All these factors explain the difference between the two averages.

While some submissions are accepted after rework, others are never accepted. The average number of entities assigned for modifications by the client is 1%, while the rejection rate is about 3%. According to the project managers, the low percentages are reasonable because entities typically pass through several layers of checks before being issued to the client. They too add that the client usually rejects the submitted items rather than suggesting rework.

Several entities featured rework, which contributed to the high rates of WIP. As explained by the project, the amount of WIP typically increases as new activities are being executed; hence, new assignments are created while older entities are still circulating. The simulation model also suggests that, on average, the WIP of contractor's entities is approximately 40% of the WIP of the subcontractor. This is an expected result given that the subcontractor's entities circulate for a larger period of time since the subcontractor submits his IPC to the contractor first who in turn submits a combined IPC to the client.

### 5.3.3. Summary of the Results

This section summarizes the results of the 100 trials run to calculate the key performance indicators (KPI) describing the performance of the studied QS system (Table 10). First, the entities' lifecycle appears to be high with an average of $139 \pm$

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3.21 days (approximately 4.5 to 4.75 months). Second, the ratio of accepting items by

the client is 30% which is quite low and can be improved. Third, the average WIP is high

(66% of all the entities created). Entities assigned for rework are higher for the

subcontractor than they are for the contractor.

|  | A | B | C | D |
|---|---|---|---|---|
| Lifecycle (Days) | 131.96 | 131.91 | 147.33 | 143.8 |
| Half width | 3.76 | 3.9 | 2.65 | 2.52 |
| Entities in | 66.81 | 66.87 | 90.51 | 90.3 |
| Half width | 0.85 | 0.76 | 0.86 | 0.75 |
| Entities Out | 15.84 | 15.92 | 31.62 | 32.36 |
| Half width | 0.51 | 0.55 | 0.82 | 0.95 |
| Ratio of Acceptance | 0.24 | 0.24 | 0.35 | 0.36 |
| Average WIP (Days) | 31.45 | 30.97 | 77.11 | 77.17 |
| Half width | 0.6 | 0.67 | 1.44 | 1.25 |

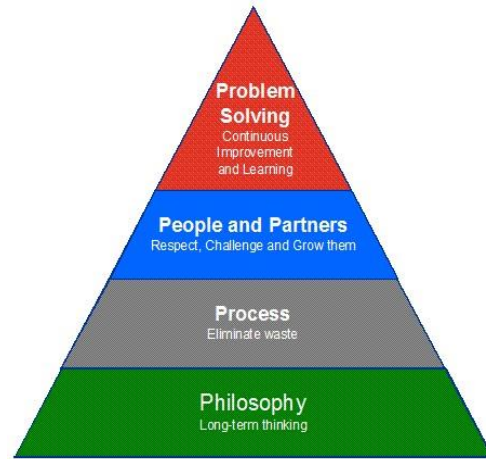**Table 10** **KPIs after 100 yearly run of** — **Summary of trials of a the model.**

# CHAPTER VI

# ALTERNATIVE SIMULATION MODEL

As discussed in the previous section, the application of the simulation model on the case study revealed inefficiencies in the QS system. The amounts of WIP are large. Entities circulate for long periods of time before being approved and paid which adds financial burdens on the contractor and subcontractor. To improve the performance of the QS system, an alternative system is suggested and discussed in this chapter. The proposed system incorporates lean management principles to mitigate the impacts of uncertainties associated with the client's approval and payment processes. The following sections describe the basics of lean management principles and elaborate on the changes that the QS system should include to improve its performance.

## 6.1. Lean management theory

Liker [67] describes lean management principles through Toyota's manufacturing system. The system emphasizes waste elimination throughout activities and operations without compromising quality or value. Muda, Mura and Muri are the three kinds of wastes to be eliminated in a lean system. Ohno viewed Muda as steps that do not add value to the product or process. Muri is defined as the waste of unnecessary burdens; whereas, Mura is defined as the waste of inconsistency or unevenness of work. Liker (2005) points that Mura and Muri drive the Muda. He described seven types of Muda as overproduction, correction, motion, material movement, processing, inventory and waiting (Liker, 2005). Before eliminating wastes, the value in the eyes of the costumer must be identified. The next step after identifying what is valuable for the customer is to create a continuous flow.

Liker [67] organized lean management principles through a 4-P pyramid model shown in Figure 7. The first P of the pyramid stands for "Philosophy." Philosophy is similar to the True North. It sets the purpose of the business. A lean philosophy does not only focus on short-term key performance indicators for success but rather aims for sustainable growth



**Figure 7 4P Lean Model (adopted from Liker 2004)**

and builds right relationships with clients, employees and suppliers for long-term benefits.

The second P stands for "Process." Toyota leaders believe that the right process will develop the desirable products. The right process is one that has minimum waste of all types. Unlike Muda, Mura and Muri (unevenness and overburden) are counterintuitive; thus, harder to remove than Muda. Leveling out work load schedule (Heijunka) ensures reduction of Mura. As unevenness is eliminated, Muri and Muda would accordingly be alleviated. As part of this second P as well, Jidoka calls for stopping production when there is a quality problem. Jidoka gives accountability to people and a sense of responsibility to fix problems, which is at the base of the enabling bureaucratic structure. In order to facilitate the employees' job of solving errors and eliminating waste, lean processes are coupled with visual systems (e.g. Andon) that signal the arousal of a problem. Kanban and A3 processes are other examples implemented in lean systems. Kanban serves pull systems and indicates the need for replenishing certain stations. Pull systems are necessary to avoid overproduction. Continuous flows are the optimal requirement of processes to expose inefficiencies and

to make it easier to track the cause/effect of errors. Another important characteristic of a lean system is standardization. A standardized process is a means for further improvement and innovation and not the end of creation.

The third P corresponds to "People and Partners". They are the valuable assets to a lean management system, and without them neither the process nor the philosophy apply. Investment in people, and internally growing leaders, add value to the process and contribute to achieving the purpose of the business. People have to be empowered and challenged to constantly improve and develop to optimize the entire supply chain.

The last P stands for "Problem Solving". This part describes Kaizen which is sustaining the attitude of continuous innovation and improvement. Nevertheless, without the consensus of the team members, Kaizen is not possible. Building consensus is crucial for implementing improvements at any stage or in any process. For this purpose, the see-for- yourself (Gemba) approach needs to be embraced.

## 6.2. Application of lean theories into the QS system

The principles of the second P in Liker's Pyramid form the basis for redesigning the QS system. The transformation of the QS system starts with simple changes in the process which do not necessarily entail People or Philosophy. The modifications in the QS process are broken down into two sections: organizational and technological changes.

Since the subcontractor's entities have the longest lifecycle, and largest amount of WIP and rework, we decided to implement organizational modifications by removing Muda, specifically, the wasteful movements of the subcontractor's entities. At the level of the subcontractor, the list of potential steps which can be improved includes preparation of the batch of entities, and submission of this IPC to the contractor who in turn assigns rework. In order to remove these wasteful steps, it is suggested to have a

standardized set of Excel sheets to be used by the subcontractors for quantifying and billing the work in progress. In this way, the likelihood of administrative and mathematical errors will be reduced and the contractor will no longer have to check the submission of the subcontractor.

Implementing this change strengthens the trust between the two parties as they will be collaborating towards preparing a unified IPC in the shortest possible time. The whole IPC will be batched and checked only once by the general contractor before submission to the client. The client's appointed PM is even expected to assign less rework to the subcontractor and the contractor after the utilization of a standardized electronic billing system. To illustrate this change in Arena, a batch algorithm is applied to aggregate the subcontractor's and contractor's entities into one entity, consequently, all entities pass through one checkpoint before submission to the client as depicted in the modified flowchart below (Figure 8).
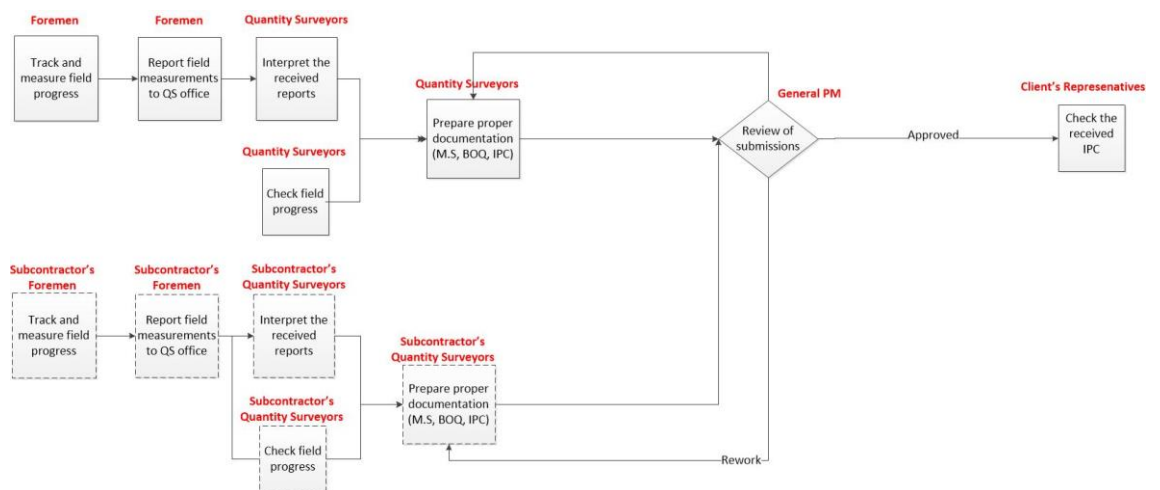


**Figure 8 Modified Process Flowchart after the organizational changes**

The other process change is the adoption of a reliable technology, which is a BIM-based platform. BIM offers the possibility of automating the quantity takeoff and cost estimating process. Instead of measuring quantities from 2D/3D CAD drawings and typing the results in Excel sheets, the quantity surveyor could automatically extract the

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quantities from the 3D BIM model. It is worth noting that many authors considered this kind of automation as the most-important BIM based feature that is capable in revolutionizing management of construction projects [68-72]. The implementation of a BIM platform shall start at the very early stages of the project's lifecycle and continue through execution. For instance, accurate design data at the phase of tendering and planning ensures accurate cost estimation. Later, as construction starts, the progress can be easily tracked as the initial quantities of the BOQs are accurate. Monteiro and Martins [68] emphasize that the more the data from the 3D BIM is reliable, the more the output of the next stage is accurate. Not only does BIM ensure the accuracy of the measures but it also saves time during the quantity take-off process which is typically 50 to 80% of the surveyor's time [73]. Moreover, during project execution, remote sensing techniques such as laser scanning (LIDAR) and photogrammetry can be used to automate the process of collecting spatial data which feed parameters into the as-built BIM models [74, 75]. This way, the QS surveyors can track and measure the progress of executed works based on the as-built BIM. The benefits of implementing these technologies are translated in Arena as an overall improvement in the quality index of the submitted entities.

## 6.3. Results and Discussion

First, we implement the organizational suggestions into the Arena model and compare the obtained results with the results presented in Chapter 5. In the proposed model, we eliminate the step where the contractor's quantity surveyors review the subcontractor's IPCs. This is attributed to the use of common procedures to prepare IPCs and supporting documentation by both the contractor and subcontractor. Table 11 summarizes the KPIs obtained for the current system and the proposed system. The

proposed system shows a significant improvement in the three indicators. For instance, the ratio of accepting BOQ items increased from 30% to 56% on average. The lifecycle decreased to 106 days (3.5 months) which means that the lifecycle in the proposed model is a month shorter than that in the current one. This is reflected in faster collection of money for the contractor. Also, the Average WIP decreased from 54 to 35 entities. The WIP constituted 69% of all the created entities; whereas, in the proposed model WIP constitutes 44% of all the entities. In the current system, the subcontractor's entities were 2.5 times the entities of the contractor's, as opposed to 1.5 times in the proposed system, which is explained by the removal of non-value added steps. According to lean management principles, excessive WIP is an indicator of waste caused by bottlenecks in the system [67]. Too much WIP is undesirable because it ties up large amounts of money to unfinished work that can be generating higher returns at other instances of the system. The decrease in WIP reflects an added efficiency in the system. It indicates that the entities are not remaining for long in their unfinished states; i.e. they are being processed faster.

**Table 11 Results of the KPIs before and after organizational rearrangement of the system**

|  | Acceptance Ratio | Lifecycle (days) | WIP Average (Entities) |
|---|---|---|---|
| Current System | 0.237 | 131.96 | 31.45 |
|  | 0.238 | 131.91 | 30.97 |
|  | 0.349 | 147.33 | 77.11 |
|  | 0.358 | 143.80 | 77.17 |
|  | 30% | 138.75 | 54.17 |
| Proposed System | 0.438 | 120.00 | 29.68 |
|  | 0.447 | 120.45 | 29.31 |
|  | 0.668 | 92.32 | 39.74 |
|  | 0.668 | 92.34 | 40.05 |
|  | 56% | 106.28 | 34.70 |

Next, we investigate the effect of implementing technologies to automate collection of spatial data and generation of as-built BIM on the performance of the

studied QS system. This is modelled in Arena as a decrease in the estimated probability of scoring 1 on the q-metric and a parallel increase in the probability of entities scoring 3, while maintaining the same probability for entities scoring 2. The percent change in the probability of scoring 1, 2 and 3 are tabulated below (Table 12). For instance, if we consider that implementation of BIM technologies improves the quality of work by 50%, the percentage of entities scoring 1 will drop from 10 to 5, while the probability of scoring 3 increases from 85% to 90%. Clearly, these figures are hypothetical and serve to illustrate the benefits of implementing technologies.

**Table 12 The percentage of score distributions as a function of the amount of improvement in the q-index**

| % Improvement in q | % Scoring 1 | % Scoring 2 | %Scoring 3 |
|---|---|---|---|
| Current system | 10 | 5 | 85 |
| 5% | 9.5 | 5 | 85.5 |
| 10% | 9 | 5 | 86 |
| 20% | 8 | 5 | 87 |
| 30% | 7 | 5 | 88 |
| 40% | 6 | 5 | 89 |
| 50% | 5 | 5 | 90 |
| 60% | 4 | 5 | 91 |
| 70% | 3 | 5 | 92 |
| 80% | 2 | 5 | 93 |

The model is run for a year, 100 independent times. Figure 9 shows the results of the 3 KPIs as a function of changes in q. As the quality improves, the average ratio of acceptance is expected to increase. Indeed, the red points show a trend of minor increase in the ratio of acceptance. For instance, as the quality improves from 5 to 80 percent, the acceptance ratio increases only by 5%. The lifecycle of IPCs shall theoretically be shorter with the improved quality of submissions. Also, the plot shows a slow decreasing trend.

The lifecycle decreases by maximum of 7 days. Finally, the amounts of WIP diminish from 34.7 to 31.7 entities when improving the q-index up to 80%. The results show that altering the q-index slightly improves on the three studied KPIs. This proves that the model is robust; i.e. it generates consistent results which do not fluctuate when altering one of its parameters.
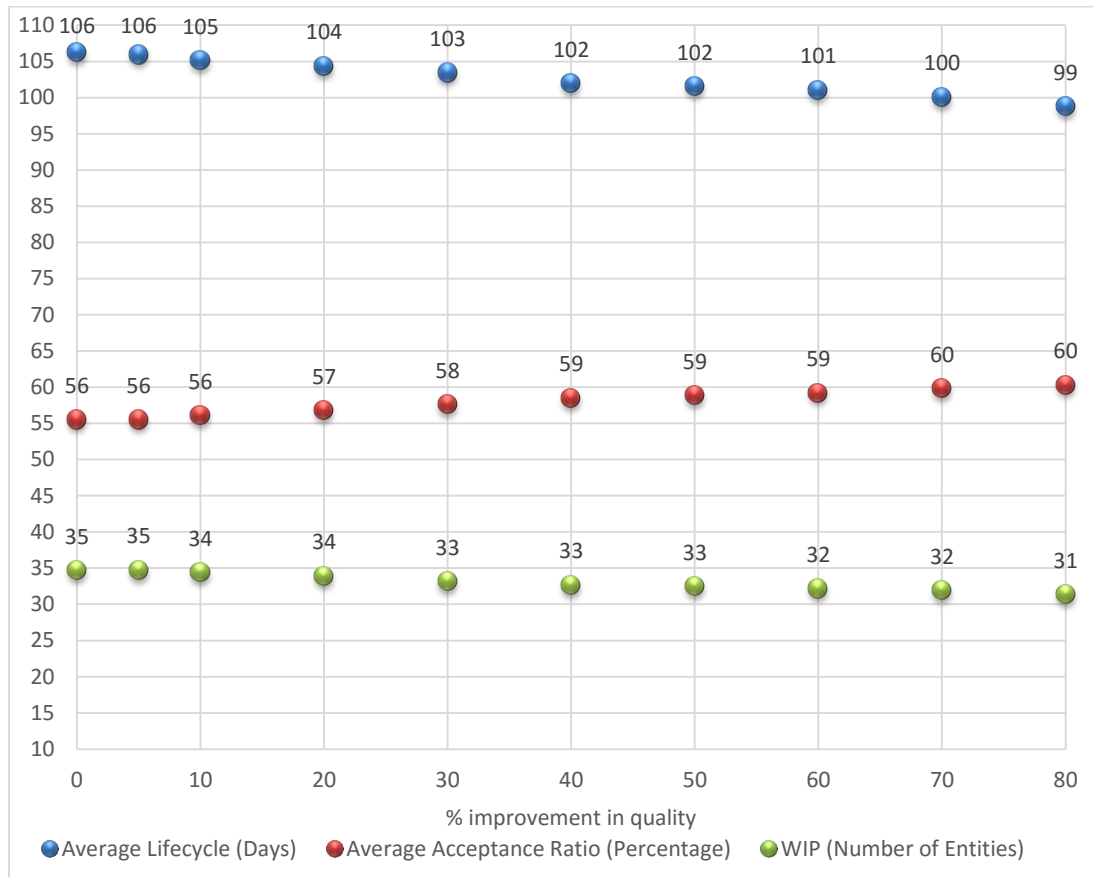


**Figure 9 Results of KPIs as a function of the percentage of change in quality of submission**
After analyzing the results of modifying the system organizationally and technologically, we recognize that the significant improvements are due to the organizational rearrangement of the system. The incorporation of the technology has added improvements but they are not as significant as the ones resulting from the organizational change. This shows that the contractor can enhance the performance of the QS system by putting minimum investment costs.

# CHAPTER VII

# CONCLUSIONS AND RECOMMENDATIONS

During construction, the contractor deploys an intricate system of project controls to monitor expenditures and to ensure that there are minimum deviations from the budget plans. An effective and efficient quantity surveying and reporting system is, hence, needed to track work in progress and collect reimbursement from the client. Similar to any other activity in construction, this project controls activity entails several sources of uncertainty. Some of the variable factors are imposed by the organization itself; whereas, others are imposed by external parties. Many studies attempted to improve the performance of QS by assessing the applicability of BIM platforms and other IT solutions; however, limited efforts have been exerted on exploring the effect of uncertainties on the operations of the QS system.

This study examines sources, and effects, of uncertainties in the QS system. For instance, the time taken by the client to approve and pay IPCs is random. Similarly, the amounts reimbursed feature uncertainty. In order to understand and mitigate the effects of these uncertainties, we utilized simulation to model a typical QS system adopted by a local firm. Recommendations are then made and tested to mitigate the effects of uncertainty on the performance of the QS system.

The methodology devised relies on simulation using Arena Rockwell Software. To be able to model the QS as nearly as possible to the reality, several assumptions were taken. The input for simulation was collected through interviews and historical records. To properly characterize uncertainties such as payment time, we collected data on payment times. The data set was fitted to the best probability distribution (Exponential) using ExpertFit. To capture uncertainties related to the amounts approved by the client,

we introduced a quality metric (q-index) which was randomly generated and assigned to every BOQ item in the model. The q-index forms the basis upon which the client decides if an items is to be reimbursed or not. After feeding the model with all the required input, we performed a run for a year and collected the results. These results were utilized to verify, validate, and illustrate the model. Once verified and validated, the model was simulated yearly for 100 times until a convenient confidence interval was obtained.

The results of the simulation show long waiting times for BOQ items during the one-year operation of the QS system adopted by a local contracting firm. The average lifecycle of entities was about 4.5 months, whereas WIP constituted 66% of all the entities and the ratio of acceptance of submitted entities was 30%. Changes inspired by the lean management philosophy are proposed in an attempt to improve the performance of the QS system. The alternative system incorporates lean practices through organizational rearrangements and through the introduction of a collaborative technology. The results are expected to show a faster circulation of BOQ items, less rework and reduced non-value added steps. By studying the results of the current and proposed systems, we noticed that even when the client takes the same time to review and approve submissions, the acceptance rate improves significantly (from 56% to 30%). The lifecycle of entities is approximately a month less in the proposed model. Also, the amounts of WIP decreased significantly as a result of implementing the suggestions.

Mostly the enhancement of the system's performance is realized after re-organizing the submission system by removing the non-value adding steps related to the processing of the subcontractor's entities. This result suggests that the contractor does not necessarily need to deploy technologies to speed up the process of collecting IPCs.

This study is limited by the availability of data. Future research should address this limitation by tracking the time resources take to measure and document the amounts of executed work on site. Moreover, the model suggests that the generation of contractor and subcontractor's entities follows a Uniform and Triangular distribution, respectively, which can be also validated in future studies. The model can be expanded to address the works of several subcontractors' instead of one. Furthermore, prospective research can target scoring the quality of the submission for a better estimation of q-index input in Arena. Additional research might aim at cross- validating the system with several case studies. Also, it is necessary to check a real-case scenario where lean principles are applied in the QS system to ensure that our hypothetical redesign of the system is an accurate representation of reality. Finally, further recommendations might integrate the social network theory to study the interaction of the resources in the QS system before and after implementation of the proposed system.

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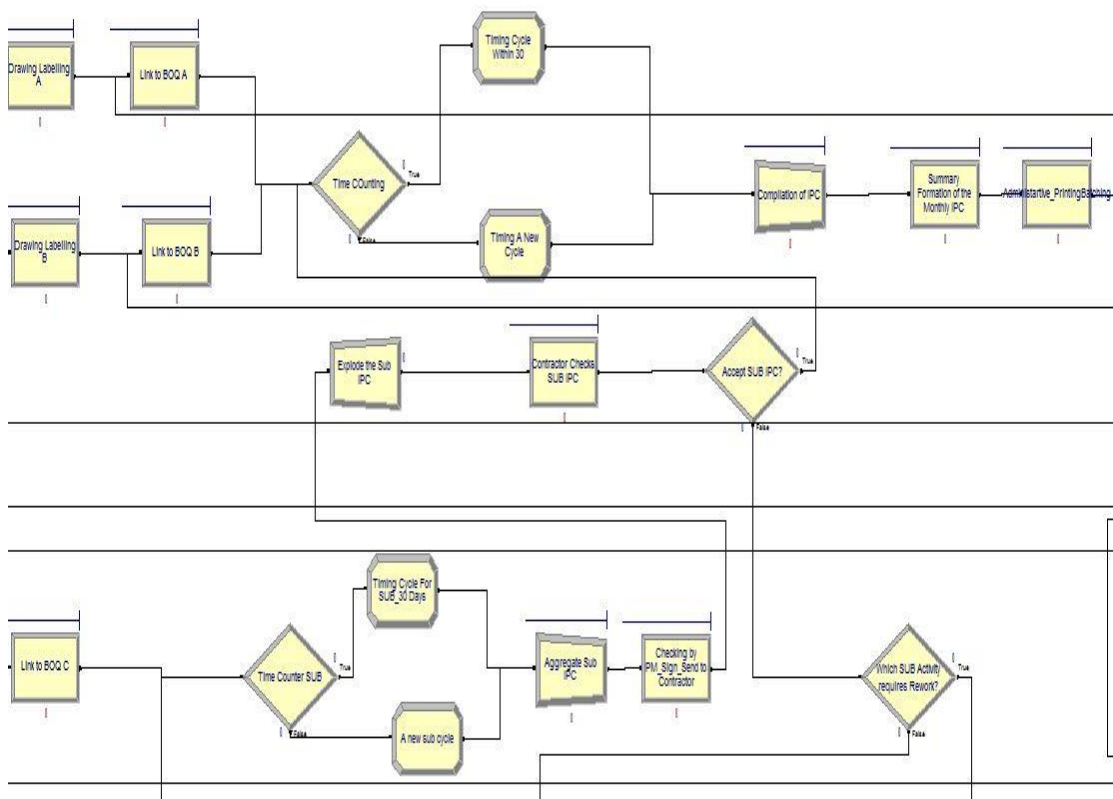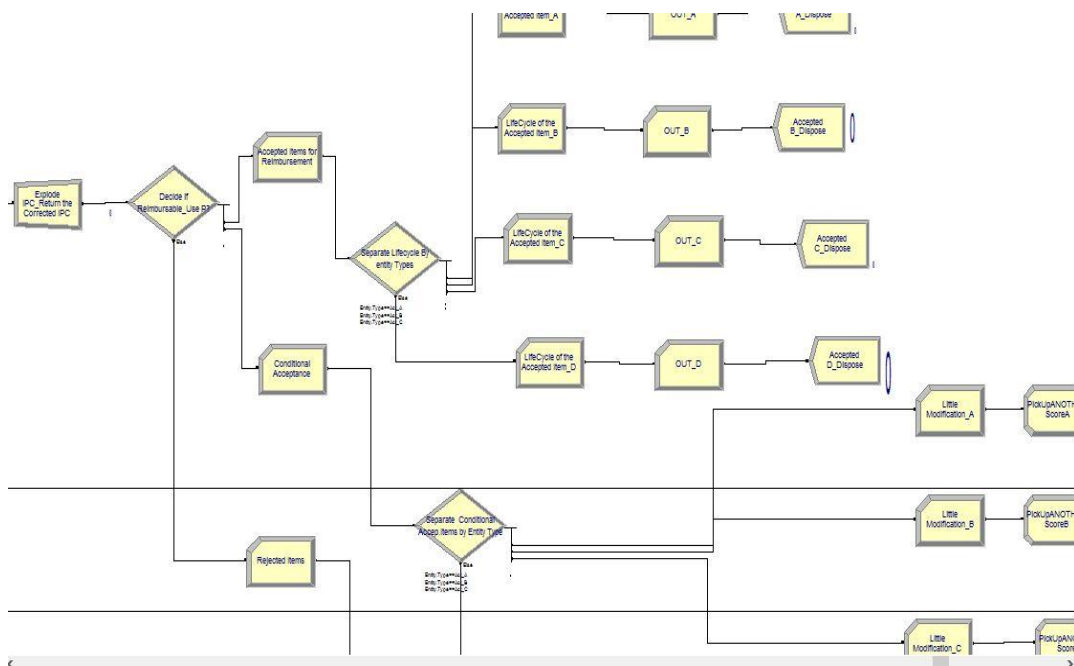
# APPENDICES

**Appendix 1 Parts of Arena Model**

Creation and Processing of Entities
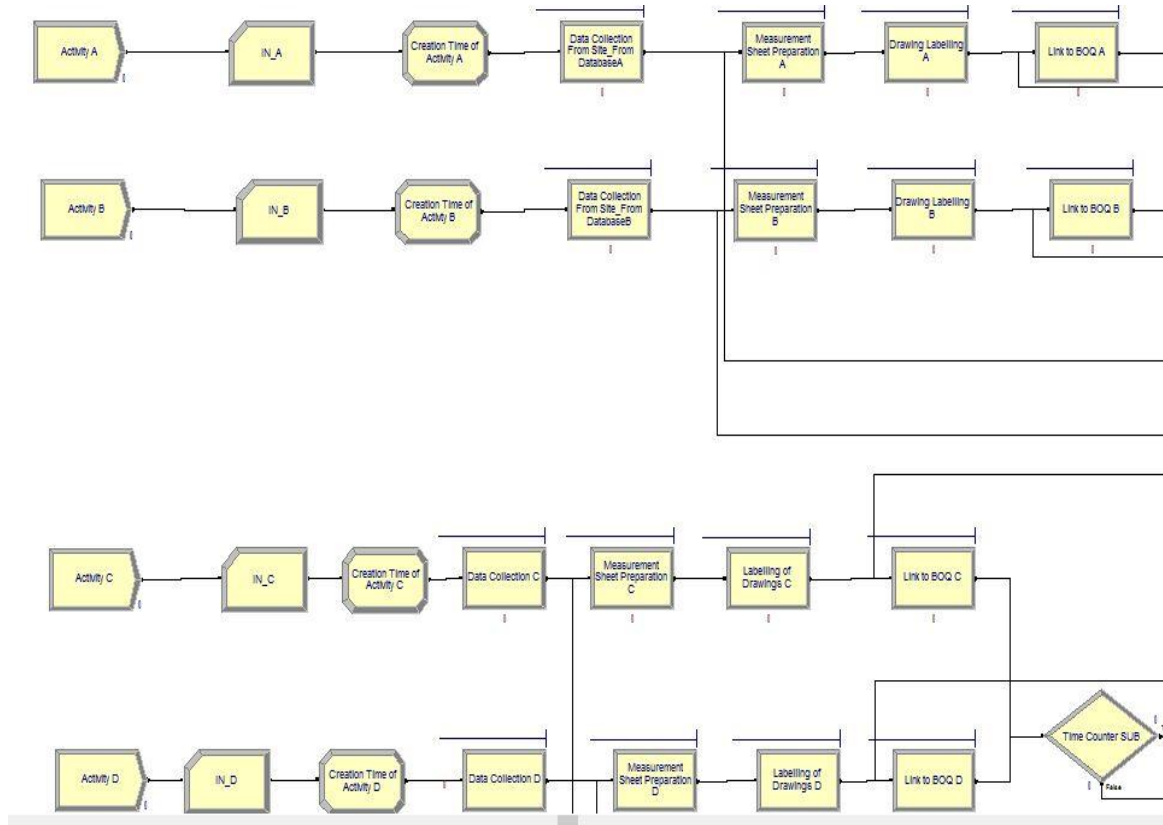
## Batch Algorithm of entities



## Client's approval of payments

**Appendix 2 Number of submitted contractor and subcontractor items over a year of IPC submissions**

| Contractor's Entities | Subcontractor's Entities |
|:---:|:---:|
| 4 | 8 |
| 3 | 8 |
| 15 | 10 |
| 30 | 8 |
| 6 | 8 |
| 5 | 15 |
| 6 | 10 |
| 3 | 4 |
| 10 | 6 |
| 30 | 10 |
| 5 | 4 |
| 5 | 30 |

**Appendix 3 Possible fitted distribution for the inter-arrival times of the contractor's entities**

```
                          Distribution Summary

                Distribution:    Uniform
                Expression:      UNIF(0.5, 10.5)
                Square Error:    0.052778


Function       Sq Error                  Data Summary
--------------------------
Beta           0.0499       Number of Data Points   = 12
Uniform        0.0528       Min Data Value          = 1
Normal         0.0613       Max Data Value          = 10
Weibull        0.068        Sample Mean             = 5.17
Exponential    0.0689       Sample Std Dev          = 2.98
Gamma          0.0711
Triangular     0.0717                Histogram Summary
Erlang         0.0756
Poisson        0.0764       Histogram Range         = 0.5 to 10.5
Lognormal      0.0852       Number of Intervals     = 11
```

```
        Distribution Summary

Distribution:   Beta
Expression:     0.5 + 10 * BETA(0, 0)
Square Error:   0.052362
```
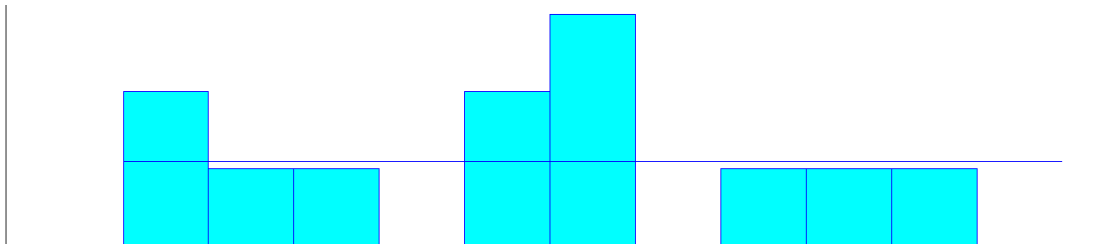


```
        Distribution Summary

Distribution:   Uniform
Expression:     UNIF(0.5, 10.5)
Square Error:   0.052778
```

**Appendix 4 Possible fitted distribution for the inter-arrival times of the subcontractor's entities**

```
Distribution:    Triangular
Expression:      TRIA(0.5, 3.25, 8.5)
Square Error:    0.065778
```

```
Function      Sq Error
----------------------
Erlang        0.064
Poisson       0.0654
Triangular    0.0658
Gamma         0.0662
Weibull       0.0668
Normal        0.0749
Lognormal     0.078
Beta          0.0906
Uniform       0.0972
Exponential   0.123
```

```
            Data Summary

Number of Data Points   = 12
Min Data Value          = 1
Max Data Value          = 8
Sample Mean             = 4.08
Sample Std Dev          = 2.11

            Histogram Summary

Histogram Range         = 0.5 to 8.5
Number of Intervals     = 12
```

**Appendix 5 Time taken to pay the contractor: difference between submission and payment dates**

| Date submitted | Payment Date | Time in Calendar Days | Date submitted | Payment Date | Time in Calendar Days |
|---|---|---|---|---|---|
| 31-Jan-13 | 31-Jan-13 | 0 | 13-May-14 | 20-May-14 | 7 |
| 1-Feb-13 | 15-Mar-13 | 42 | 31-Mar-14 | 20-May-14 | 50 |
| 15-May-13 | 12-Jun-13 | 28 | 22-Apr-14 | 20-May-14 | 28 |
| 28-Jun-13 | 14-Aug-13 | 47 | 23-May-14 | 14-Jun-14 | 22 |
| 14-Aug-13 | 13-Sep-13 | 30 | 26-Jun-14 | 14-Jul-14 | 18 |
| 2-Aug-13 | 22-Oct-13 | 81 | 26-Jun-14 | 26-Jun-14 | 0 |
| 8-Oct-13 | 5-Nov-13 | 28 | 22-Apr-14 | 14-Jul-14 | 83 |
| 21-Oct-13 | 5-Nov-13 | 15 | 28-May-14 | 14-Jul-14 | 47 |
| 12-Sep-13 | 23-Nov-13 | 72 | 22-Jun-14 | 31-Jul-14 | 39 |
| 23-Oct-13 | 13-Dec-13 | 51 | 2-Jul-14 | 31-Jul-14 | 29 |
| 9-Dec-13 | 13-Dec-13 | 4 | 18-Jul-14 | 5-Aug-14 | 18 |
| 2-Dec-13 | 3-Jan-14 | 32 | 27-Jun-14 | 14-Aug-14 | 48 |
| 9-Dec-13 | 3-Jan-14 | 25 | 1-Aug-14 | 13-Aug-14 | 12 |
| 17-Dec-13 | 24-Jan-14 | 38 | 28-May-14 | 6-Sep-14 | 101 |
| 31-Jan-14 | 24-Feb-14 | 24 | 22-Jun-14 | 6-Sep-14 | 76 |
| 31-Jan-14 | 24-Feb-14 | 24 | 13-Aug-14 | 6-Sep-14 | 24 |
| 31-Jan-14 | 24-Feb-14 | 24 | 28-Aug-14 | 26-Sep-14 | 29 |
| 6-Jan-14 | 24-Feb-14 | 49 | 28-Aug-14 | 30-Sep-14 | 33 |
| 1-Feb-14 | 1-Feb-14 | 0 | 22-Sep-14 | 1-Oct-14 | 9 |
| 5-Feb-14 | 13-Mar-14 | 36 | 27-Aug-14 | 3-Oct-14 | 37 |
| 5-Feb-14 | 13-Mar-14 | 36 | 15-May-14 | 3-Oct-14 | 141 |
| 25-Feb-14 | 13-Mar-14 | 16 | 16-Jul-14 | 16-Jul-14 | 0 |
| 13-Feb-14 | 13-Mar-14 | 28 | 18-Jul-14 | 10-Oct-14 | 84 |
| 10-Feb-14 | 13-Mar-14 | 31 | 20-Sep-14 | 14-Oct-14 | 24 |
| 13-Feb-14 | 8-Apr-14 | 54 | 30-Sep-14 | 14-Oct-14 | 14 |
| 6-Feb-14 | 12-May-14 | 95 | 2-Sep-14 | 14-Oct-14 | 42 |
| 10-Mar-14 | 8-May-14 | 59 | 12-Sep-14 | 16-Oct-14 | 34 |
| 2-Jul-14 | 12-Nov-14 | 133 | 26-Mar-15 | 4-May-15 | 39 |
| 9-Oct-14 | 12-Nov-14 | 34 | 30-Sep-14 | 4-May-15 | 216 |
| 2-Jul-14 | 12-Nov-14 | 133 | 11-Sep-14 | 11-Sep-14 | 0 |
| 11-Nov-14 | 28-Nov-14 | 17 | 30-Dec-14 | 30-Dec-14 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 13-Aug-14 | 5-Jan-15 | 145 | 11-Feb-15 | 11-Feb-15 | 0 |
| 2-Sep-14 | 5-Jan-15 | 125 | 26-Mar-15 | 4-May-15 | 39 |
| 10-Nov-14 | 5-Jan-15 | 56 | 25-Feb-15 | 4-May-15 | 68 |
| 28-Aug-14 | 9-Jan-15 | 134 | 9-Oct-14 | 13-Jan-15 | 96 |
| 10-Nov-14 | 13-Jan-15 | 64 | 18-Dec-14 | 13-Jan-15 | 26 |
| 16-Dec-14 | 13-Jan-15 | 28 | 13-Aug-14 | 13-Jan-15 | 153 |
| 8-Jan-15 | 3-Feb-15 | 26 | 9-Oct-14 | 3-Feb-15 | 117 |
| 8-Jan-15 | 3-Feb-15 | 26 | 10-Nov-14 | 23-Feb-15 | 105 |
| 2-Sep-14 | 23-Feb-15 | 174 | 10-Feb-15 | 23-Feb-15 | 13 |
| 8-Jan-15 | 23-Feb-15 | 46 | 13-Aug-14 | 23-Feb-15 | 194 |
| 10-Nov-14 | 23-Feb-15 | 105 | 30-Sep-14 | 10-Mar-15 | 161 |
| 30-Jan-15 | 10-Mar-15 | 39 | 10-Feb-15 | 10-Mar-15 | 28 |
| 16-Mar-15 | 23-Mar-15 | 7 | 23-Mar-15 | 30-Mar-15 | 7 |
| 30-Mar-15 | 13-Apr-15 | 14 | 6-Apr-15 | 14-Apr-15 | 8 |
| 13-Apr-15 | 4-May-15 | 21 | 12-Mar-15 | 4-May-15 | 53 |
| 26-Mar-15 | 4-May-15 | 39 | | | |

**Appendix 6 Summary statistics of time taken to pay billed amounts**

| Data Characteristic | Value |
|---|---|
| Source file | Delay |
| Observation type | Real valued |
| Number of observations | 109 |
| Minimum observation | 0.00000 |
| Maximum observation | 216.00000 |
| Mean | 44.18349 |
| Median | 29.00000 |
| Variance | 2,208.74380 |
| Coefficient of variation | 1.06368 |
| Skewness | 1.56047 |

Data-Summary Table

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Print
Help
Done

**Appendix 7 Histogram of payment times with interval width= 9 days**



Histogram

25 intervals of width 9

73
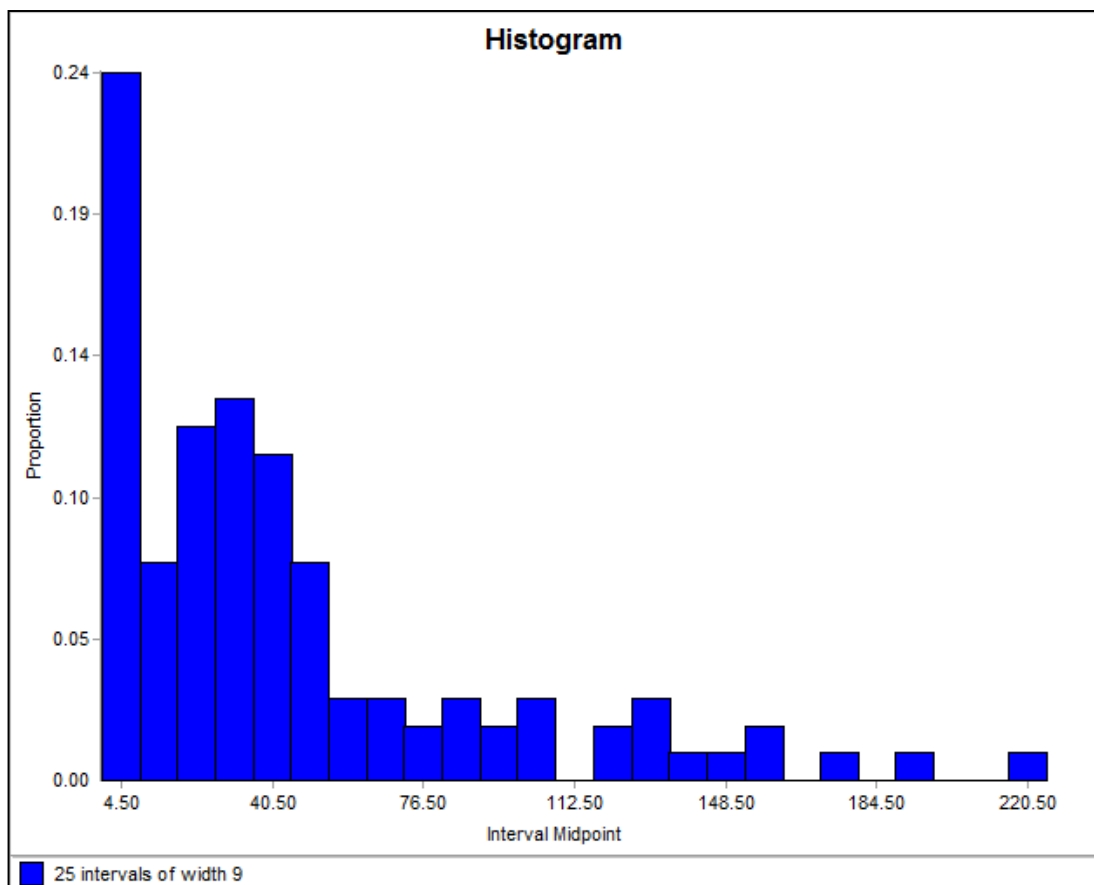
**Appendix 8 Curve fitting of payment time data**

### Automated-Fitting Results

#### Relative Evaluation of Candidate Models

| Model | Relative Score | Parameters | |
|---|---|---|---|
| 1 - Beta | 86.54 | Lower endpoint | 0.00000 |
| | | Upper endpoint | 216.27049 |
| | | Shape #1 | 0.15864 |
| | | Shape #2 | 0.77828 |
| 2 - Random Walk | 73.08 | Location | 0.00000 |
| | | Scale | 1.92661 e 7 |
| | | Shape | 0.02263 |
| 3 - Weibull | 73.08 | Location | 0.00000 |
| | | Scale | 16.79503 |
| | | Shape | 0.22832 |

14 models are defined with scores between 7.69 and 86.54

#### Absolute Evaluation of Model 1 - Beta

Evaluation: Bad

Suggestion: Use an empirical distribution.
　　　　　　 See Help for more information.

#### Additional Information about Model 1 - Beta

"Error" in the model mean
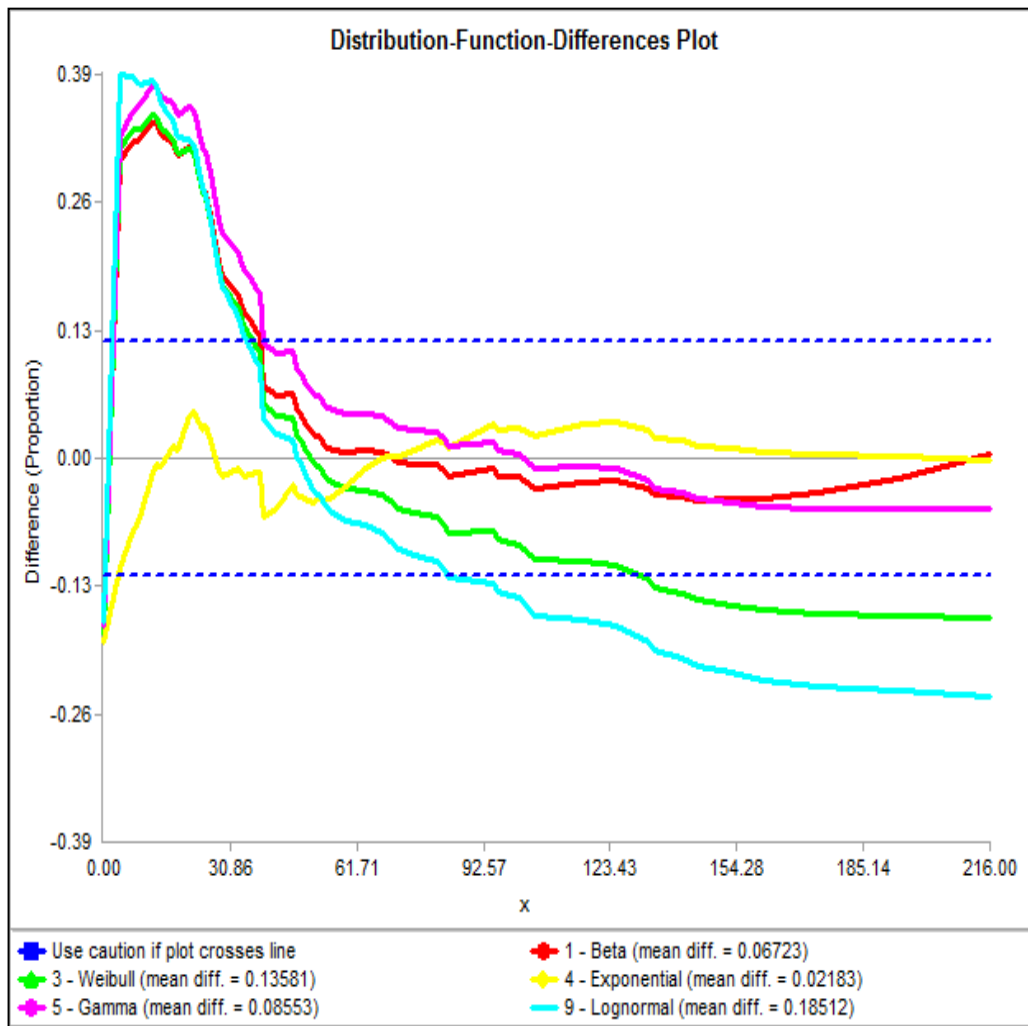relative to the sample mean 　　　　7.56363 = 17.12%

### Model Fitting

Specified Models:

1 - Beta
2 - Random Walk
3 - Weibull
4 - Exponential
5 - Gamma
6 - Erlang
7 - Johnson SB
8 - Pearson Type VI
9 - Lognormal
10 - Rayleigh
11 - Uniform
12 - Inverse Gaussian
13 - Wald
14 - Chi-Square(E)

74

**Appendix 9 Density histogram plots for the payment time data**



Density-Histogram Plot
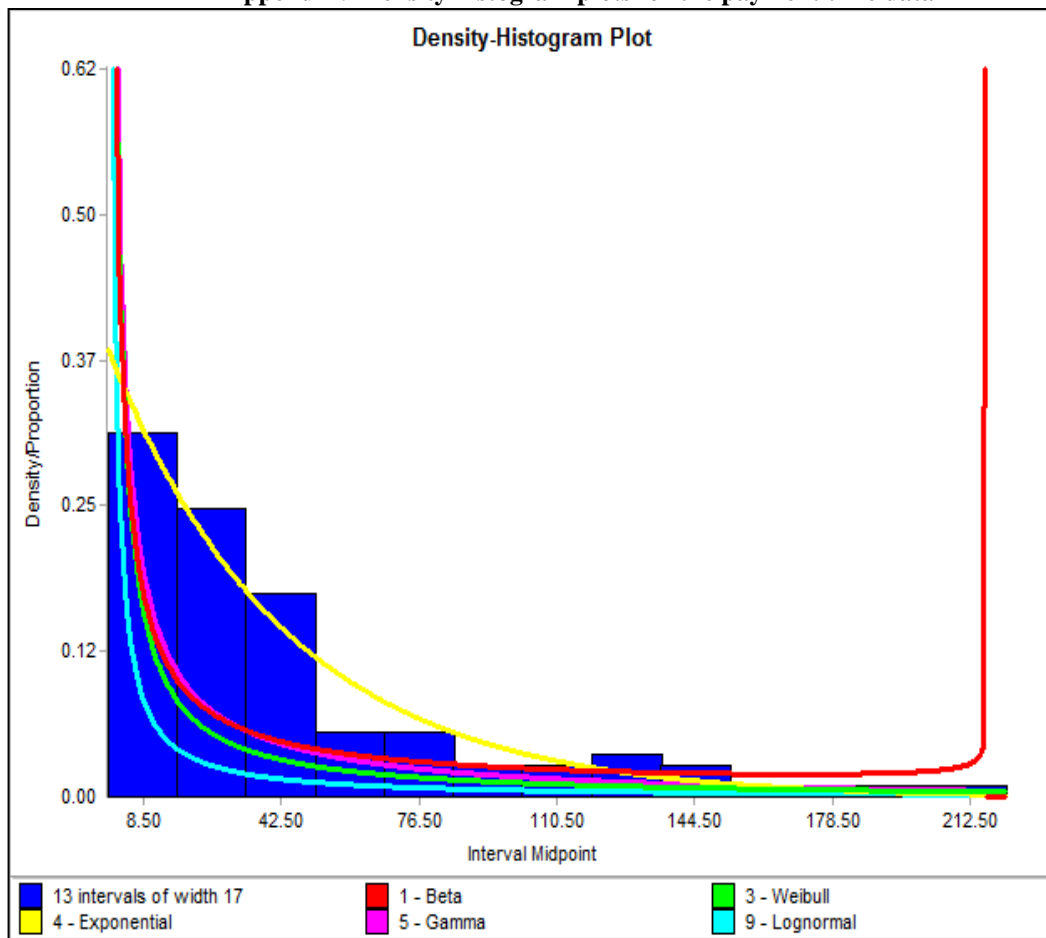
**Appendix 10 Distribution function differences plots for the payment time data**



Distribution-Function-Differences Plot

Legend:
- Use caution if plot crosses line
- 1 - Beta (mean diff. = 0.06723)
- 3 - Weibull (mean diff. = 0.13581)
- 4 - Exponential (mean diff. = 0.02183)
- 5 - Gamma (mean diff. = 0.08553)
- 9 - Lognormal (mean diff. = 0.18512)

**Appendix 11 P-P plots for the payment time data**
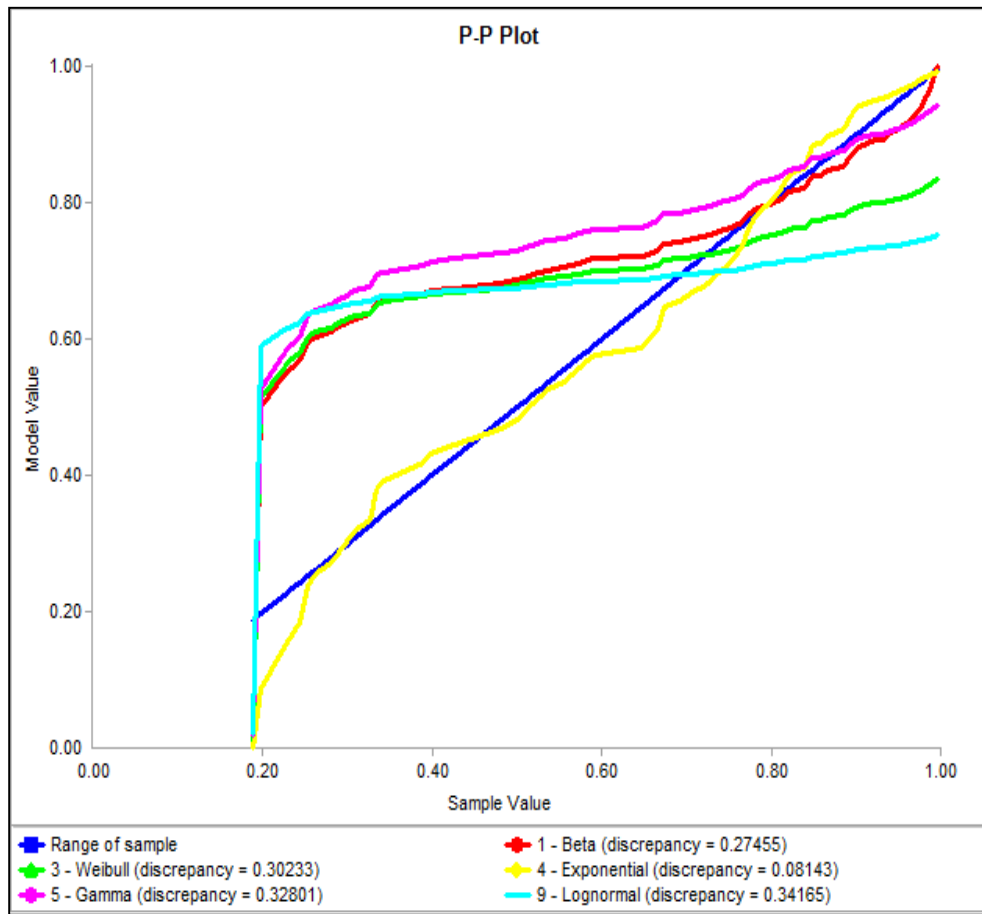


**Appendix 12 Records of amounts submitted by the contractor, amounts paid by the client and ratio of approved payments**

| Billed amounts | Paid amounts | Percentage Reimbursed | Billed amounts | Paid amounts | Percentage Reimbursed |
|---|---|---|---|---|---|
| $ 1,349,671.88 | $ 1,349,671.88 | 100% | $ 585,894.60 | $ 172,609.42 | 29% |
| $ 67,117.30 | $ 67,113.62 | 100% | $ 195,298.20 | $ - | 0% |
| $ 86,941.24 | $ 86,941.49 | 100% | $ 24,871.88 | $ 24,871.87 | 100% |
| $ 104,031.61 | $ 104,031.88 | 100% | $ 40,191.09 | $ 40,191.09 | 100% |
| $ 112,727.26 | $ 112,728.29 | 100% | $ 231,541.76 | $ 216,320.55 | 93% |
| $ 136,935.83 | $ 136,936.34 | 100% | $ 56,416.72 | $ 11,920.01 | 21% |
| $ 126,369.04 | $ 115,177.91 | 91% | $ 87,157.84 | $ 45,233.10 | 52% |
| $ 28,889.43 | $ 28,889.43 | 100% | $ 479,036.88 | $ 479,036.88 | 100% |

| | | | | | |
|---|---|---|---|---|---|
| $ 157,204.94 | $ 157,204.94 | 100% | $ 44,546.38 | $ 40,496.71 | 91% |
| $ 297,195.51 | $ 162,196.81 | 55% | $ 27,784.53 | $ 27,784.53 | 100% |
| $ 54,181.09 | $ 54,181.09 | 100% | $ 785,867.71 | $ 327,721.22 | 42% |
| $ 272,937.53 | $ 166,352.84 | 61% | $ 261,955.90 | $ - | 0% |
| $ 57,852.67 | $ 57,852.67 | 100% | $ 68,851.31 | $ 91,801.74 | 133% |
| $ 19,874.34 | $ 17,162.71 | 86% | $ 22,950.44 | $ - | 0% |
| $ 55,342.32 | $ 42,490.87 | 77% | $ 877,068.60 | $ 818,597.66 | 93% |
| $ 33,104.38 | $ 16,157.73 | 49% | $ 292,356.20 | $ - | 0% |
| $ 41,432.11 | $ 16,547.69 | 40% | $ 171,342.05 | $ 173,851.60 | 101% |
| $ 150,475.87 | $ 124,289.02 | 83% | $ 57,114.02 | $ - | 0% |
| $ 625,000.00 | $ 625,000.00 | 100% | $ 803,602.73 | $ 638,497.61 | 79% |
| $ 326,812.71 | $ 356,350.37 | 109% | $ 267,867.58 | $ - | 0% |
| $ 26,180.00 | $ 22,715.00 | 87% | $ 63,804.05 | $ 63,804.05 | 100% |
| $ 127,643.13 | $ 114,055.67 | 89% | $ 388,401.03 | $ 304,631.10 | 78% |
| $ 92,180.63 | $ 79,980.33 | 87% | $ 129,467.01 | $ - | 0% |
| $ 68,474.05 | $ 61,103.99 | 89% | $ 275,406.12 | $ 257,045.71 | 93% |
| $ 93,613.16 | $ 69,339.35 | 74% | $ 91,802.04 | $ - | 0% |
| $ 337,722.23 | $ 292,671.90 | 87% | $ 82,021.01 | $ 82,021.01 | 100% |
| $ 33,914.85 | $ 30,287.59 | 89% | $ 151,509.45 | $ 119,915.24 | 79% |
| $ 223,367.85 | $ 98,473.30 | 44% | $ 50,503.15 | $ - | 0% |
| $ 418,497.83 | $ 250,500.00 | 60% | $ 129,778.22 | $ 52,687.90 | 41% |
| $ 86,374.30 | $ 86,373.91 | 100% | $ 162,803.44 | $ 96,379.99 | 59% |
| $ 68,750.00 | $ 62,500.00 | 91% | $ 87,009.90 | $ 80,695.96 | 93% |

| | | | | | |
|---|---|---|---|---|---|
| $ 687,500.00 | $ 625,000.00 | 91% | $ 29,003.30 | $ - | 0% |
| $ 510,613.55 | $ 260,937.50 | 51% | $ 150,252.36 | $ 140,235.54 | 93% |
| $ 15,584.32 | $ 11,345.39 | 73% | $ 50,084.12 | $ - | 0% |
| $ 5,194.77 | $ - | 0% | $ 137,500.00 | $ 125,000.00 | 91% |
| $ 820,169.10 | $ 536,403.27 | 65% | $ 137,500.00 | $ 125,000.00 | 91% |
| $ 273,389.70 | $ - | 0% | $ 137,500.00 | $ 125,000.00 | 91% |
| $ 48,873.09 | $ 51,587.58 | 106% | $ 137,500.00 | $ 125,000.00 | 91% |
| $ 55,458.91 | $ 36,125.88 | 65% | $ 137,500.00 | $ 125,000.00 | 91% |
| $ 63,865.66 | $ 63,865.66 | 100% | $ 13,427.10 | $ - | 0% |
| $ 11,368.78 | $ - | 0% | $ 133,380.25 | $ - | 0% |
| $ 18,343.46 | $ - | 0% | $ 95,060.88 | $ - | 0% |
| $ 35,754.24 | $ - | 0% | $ 31,686.96 | $ - | 0% |
| $ 400,140.75 | $ - | 0% | $ 5,003.69 | $ - | 0% |
| $ 57,177.63 | $ 57,177.63 | 100% | $ 116,855.44 | $ 116,855.44 | 100% |
| $ 43,389.16 | $ 43,389.16 | 100% | $ 3,028.66 | $ 3,028.66 | 100% |
| $ 34,748.31 | $ 34,748.31 | 100% | $ 46,623.58 | $ 46,623.58 | 100% |
| $ 158,951.14 | $ - | 0% | $ 52,983.71 | $ - | 0% |
| $ 103,895.33 | $ - | 0% | $ 10,933.11 | $ - | 0% |
| $ 34,532.72 | $ - | 0% | $ 11,510.91 | $ - | 0% |
| $ 1,948.58 | $ - | 0% | $ 4,445.38 | $ - | 0% |
| $ 103,128.77 | $ - | 0% | $ 23,779.68 | $ - | 0% |
| $ 31,081.12 | $ - | 0% | $ 194,783.51 | $ - | 0% |
| $ 64,927.84 | $ - | 0% | $ 50,711.88 | $ 50,711.88 | 100% |