ANALYSIS AND IMPROVEMENT OF THE SECURITY BUILDING AT PG&E DIABLO CANYON NUCLEAR POWER PLANT

A Senior Project submitted
In Partial Fulfillment
of the Requirements for the Degree of
Bachelor of Science in Industrial Engineering

the Faculty of California Polytechnic State University,
San Luis Obispo

Performed by
Alyssa Carter, Natalie Christa, Phuong Anh Pham Dinh

Supervised by
Tali Freed, Ph.D., P.E.
Professor of Industrial and Manufacturing Engineering

August 2014

Graded by:_______________ Date of Submission____________________________
Checked by:______________ Approved by:_______________________________

ANALYSIS AND IMPROVEMENT OF THE SECURITY BUILDING
AT PG&E DIABLO CANYON NUCLEAR POWER PLANT

Alyssa Carter, Natalie Christa, Phuong Anh Pham Dinh
Tali Freed, Ph.D., P.E.

Abstract

A new Security building was recently designed and built at the Pacific Gas and Electric (PG&E) Diablo Canyon Power Plant (DCPP).This building's staff and equipment are responsible for performing routine inspections on all personnel entering the facility in order to prevent security-related incidents from occurring at the nuclear power plant. Similar to airport security procedures, the DCPP security building routine inspections include the use of x-ray machines, metal detectors, and explosive detectors.

The Power Plant periodically experiences pre-planned, preventive maintenance outages, that last 4-6 weeks. During an outage, a power plant reactor is shut down for maintenance, repair, and re-fueling. Since the new security building's grand opening DCPP experienced its first outage. Unfortunately, the security building processes were significantly challenged during the outage.

Before every outage hundreds of temporary outage workers are hired to perform outage-specific duties. The temporary workers are not as familiar with entrance security procedures as the permanent DCPP personnel, and their credentials are not as well established. Therefore, queues and delays may be caused, especially during peak times at the beginning of shifts, 5-7 am and 4-6 pm.

During the outage of February/March 2014 it became evident that waiting times of the larger flow of workers through the new security building were too excessive for permanent employees and temporary outage workers. In an attempt to reduce wait times and make waiting more comfortable security personnel implemented several changes to the security process. These changes included setting up a tent for the queuing lines outside the new building, where workers waited until adequate space became available inside the building. All processing stations inside the building were operated during peak times, and increased number of security officers manned these stations and directed the employees through the security processes. These changes resulted in significant additional operating cost, as well as security staff dissatisfaction due to higher levels of overtime work.

Our analysis of the security building internal layout design and processes revealed several areas for improvement, as follows.

1. Improvement of processes
2. Improvement of building layout and structure
3. Improvement of training
4. Improvement of signage and directions

The team created a number of deliverables: Facility redesign model using Visio, bin optimization policy, standard operating procedures (SOP), computer animated models that simulate existing and proposed processes using Simio modeling software, instructional video, effective signage designs, and a financial report that justified the costs of the recommendations. The proposed solutions achieve multiple objectives:

A. Decrease wasted time of employees at the security process
B. Decrease the number of security officers
C. Standardize the responsibilities of the security officers
D. Optimize asset usage, including inspection equipment and bins
E. Simplify the process via signage and video aids

The cost to implement these recommendations is approximately $275,265.06 and the savings are estimated to be $701,660. Therefore, net savings exceed $400,000. In addition, DCPP employee satisfaction should drastically increase, as the waiting lines will be eliminated or drastically shortened. Job satisfaction of security officers should increase as well, as a result of lower overtime and less stressful work environment.

EXECUTIVE SUMMARY

Diablo Canyon Power Plant (DCPP) recently built a new state-of-the-art security building that is used to perform security inspections on all workers entering the plant. However, the building's design is unable to accommodate the required number of workers and security process efficiency, due to floor space and layout and arrangement of equipment. The general access security process is as follows: workers enter the building, place belongings that should be X-rayed in plastic bins, and then place the bins on

an X-Ray machine's conveyor belt. The workers then enter the human "search train" that consists of an explosive detector and a metal detector. The current procedures and particular inspection equipment used in the security process are inefficient and not ergonomic.

Most of the time the building's operation is reasonably smooth, albeit at a high cost of security personnel. However, during the periodic outages temporary workers arriving at the plant increase (almost double) the number of workers that pass through the building to approximately 1,400 workers during the building's "rush hour", 5am–7am. The large number of people makes the building very noisy, negatively affecting officers' ability to communicate with the people they are supposed to guide, as well as among themselves. Temporary workers that are unfamiliar with the security process slow down the process and cause other workers to wait in queue longer.

Some of the signs used within the building to guide workers are ineffective while other signs are too small. The large TV screens present material that cannot be viewed or heard well, and is meaningless to the security process. Due to these problems DCPP increased the number of security officers and their overtime, making the new building less efficient and cost-effective than the old building.

The challenge for the senior project team was to find cost-effective solutions to the long queue problem, given the building structure and limited floor capacity. DCPP also requested that the team find a way to decrease the number of security officers required to run the security process and their average overtime rate.

After establishing the goals that DCPP wanted the project to achieve, the team had meetings with technical advisor, Dr. Tali Freed, about how the team should approach the project and what types of deliverables and industrial engineering topics would be suitable. The team completed relevant literature reviews to obtain more knowledge about the topics that would be applied in this project. The four main literature review topics were: inspection security systems, queuing theory, process simulation, and facility layout design. An initial list of proposed deliverables was made:

- Estimate the queue length and employee wait times using Queuing Theory and animated simulation models
- Determine the learning curve of new workers
- Redesign security process to decrease the processing time of workers
- Redesign the security floor layout to make it more efficient
- Optimize the number of bins and the process of bin replenishment

- Standardize the security officers' procedures
- Design effective signage and security process instructional video for new employees
- Reduce the number of officers needed for the process
- Reduce the noise in the building

The team performed many observations of the process and gathered necessary data for the analysis. The team also obtained data, such as blueprints and process descriptions, from the Director of Security, Shawn Kirven. The team then conducted experiments to determine what types of recommendations would be most effective.

The first experiment the team conducted was the learning curve fitting (estimated) experiment. This experiment simulated the metal detector portion of the security process since that portion is the most variable and dependent on the workers' knowledge of the process. The experiment indicated that the workers had a 92.3% learning curve rate. This result implies that as the worker experiences the security process repeatedly the processing time decreases to about half the initial processing time of this worker. Therefore, having separate lanes for temporary workers and permanent workers can be beneficial.

The next experiments that were conducted were performed using computer animated simulation modeling language called Simio. A computer animated model representing the current system and process was first created. This model's output was compared to the raw data collected and found to be statistically similar, thus validating the correctness of the model. This model was then used in comparison with several alternative variations of the recommendations the team had. The alternative models incorporated a third x-ray and separate lanes for the two types of workers: two lanes for temporary workers and one lane for permanent employees. Statistical hypothesis tests were done to compare the current process model results with the alternative model results to determine if there was a statistically significant change due to the proposed solution. In each case the alternative model resulted in a lower average time in system for the workers, and a statistically significant difference was found.

Therefore, our team strongly recommends that DCPP split up the search trains by worker type, with permanent workers occupying a single full search train (express lane), and temporary workers occupying two full search trains, where each full search train consists of one x-ray, one metal detector, and two explosive detectors.

In order to implement the above recommendation we suggest that a third x-ray machine will be used. The currently idle x-ray machine is older and has low imaging quality. However, it may be possible to dedicate this machine to permanent workers. The permanent employees have already had significantly more background checks and training than temporary workers, thus a higher level of trust may be warranted for them. With a separate search train the security process will be expedited for the permanent workers. **An additional security officer will be needed, and roller conveyor and table will have to be purchased to complete the lane.**

Activated (turning) conveyors are recommended since they have a higher capacity for bins. These conveyors should only be used for the temporary worker lanes since the area where the temporary lanes are located can accommodate these larger conveyors. Additional equipment such as x-ray conveyors and roller conveyors would be needed to help make the turning conveyors work effectively.

The security process uses plastic bins that are similar in shape and size to airport bins. Workers place their belongings in these bins and then place the bins on the X-Ray machine conveyor belt. The workers then enter the human search train of explosive detector and metal detector. The quantity of bins is important for smooth operation of the security process, since too few bins force workers to wait for empty bins for their belongings, while too many bins clutter the already challenged floor space. Determining the optimal quantity of bins is complex due to usage variability. A single worker may use 0, 1, 2, 3 or even 4 bins. Since worker arrival rate is also variable, the optimal number of bins required at the beginning of the security process is difficult to forecast.

Since workers collect their belongings at the end of the security process, empty bins must be returned from the end to the beginning of the process. Currently, this bin replenishment cycle does not have a standard operating procedure. Visibility of bin status is not satisfactory, either. An officer standing near the exit of the building cannot see the status of bins in the front. Therefore, sometimes workers must wait for empty bins before entering the search train.

In addition, the bin replenishment route is too narrow, cluttered, and requires non-ergonomic actions, such as bending over and lifting heavy, uncomfortable load, and opening a door and holding it ajar while pushing a bin cart through.

A Kanban bin replenishment system was created that efficiently cycle bins back to the front end as soon as they fill up the back end. The Kanban system incorporates ergonomic equipment that will be less strenuous for the employee in charge of bins compared to the current method.

A Visio layout of the Kanban system maps out the path the bins should take. In addition, a standard operating procedure (SOP) was developed to help officers perform the process.

Changes in security officers' responsibilities will result in a reduction of the workforce by 2-3 security officers (or the equivalent decrease in overtime), substantially decreasing labor costs and increasing officer satisfaction. The explosive detector officers will now have two responsibilities: they will be in charge of monitoring both the workers going through the metal detector and workers going through the explosive detector. They would have to stand in the area between the metal detector and explosive detector in order to monitor both. The 3 security officers at each of the metal detectors will no longer be needed. There still lies the issue of the explosive detectors going off. The explosive detectors go off on the side closer to the turnstile exits. The explosive detector officers will not be on that side of explosive detector to turn it off since their responsibilities have changed and they are monitoring the metal detectors from a different area where it is not accessible for them to turn it off. The solution is that the extra officer in charge of pat downs will have an added responsibility of turning off the explosive detectors that go off. In addition, the officers inside the isolated room who are monitoring the process will be an extra set of eyes that will notify the officer if he forgets to turn off one of the explosive detectors.

The team also researched products to control the noise in the building. Noise dampening panels and sprays can be purchased and mounted onto the building's ceiling. This will improve the officers' ability to communicate with one another and perform their duties more efficiently. Installation instructions for these panels were also included in the report.

A step-by-step instructional video was created to be shown during training sessions to workers. The video shows the entire security process and is concise. In addition, new effective signage was recommended to help workers better understand certain areas of the process where signage was originally confusing. Ergonomic changes were made to existing signs in order to decrease their wordiness and make them more concise.

The cost to implement these recommendations is approximately $275,265.06. However, the savings is estimated to be $701,660. Therefore, there is a net savings of $426,294.94 if DCPP decides to buy a new x-ray machine or $466,294.94 if the older x-ray machine is used. In addition, approximately 491.7 hours, or $26,949 of wasted time is saved per year (for 2 outages per year).

ACKNOWLEDGMENTS

The team would like to thank our technical advisor, Dr. Tali Freed, for all the guidance and support she has given us throughout our senior project journey.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. Introduction

Recently, Diablo Canyon Power Plant (DCPP) had designed and built a new Security building which assumed the responsibility for performing routine checks to prevent any incidents occurring at the power plant; such routine checks include the use of metal detectors, x-ray machines, and explosive detectors. The new Security building was opened for operational use within the last 18 months. Since the new Security building's grand opening, DCPP experienced its first outage in February/March 2014. DCPP experiences these outages periodically; during these times, reactors within the power plant may be shut down for maintenance, repair, and also re-fueling. Consequently, a large number of temporary outage workers are called in to perform these outage duties.

At the beginning of February/March 2014's outage, it was evident that waiting times to process through the new security building were too excessive for regular workers and new outage workers alike. In order to accommodate the larger flow of workers processing through the security building, security personnel began taking measures to reduce wait times by implementing changes to the current security process. Such changes included setting up both a tarp and queuing lines outside the new security building where workers were expected to queue up in until there was adequate space to process through the security process inside; this effectively restrained workers to wait outside to prevent any workers prematurely entering the building when it was already overcrowded. Additional changes included requiring almost all processing stations to be open inside the security building during peak times of the day and additional officer personnel to be present to man these stations according to regulations. There were effectively four hours observed in each work day that were considered peak times: 5am to 7am, and 4pm to 6pm. Unfortunately, running all processing stations during these peak times is very costly to man as most of these officers are having to work these shifts on overtime.

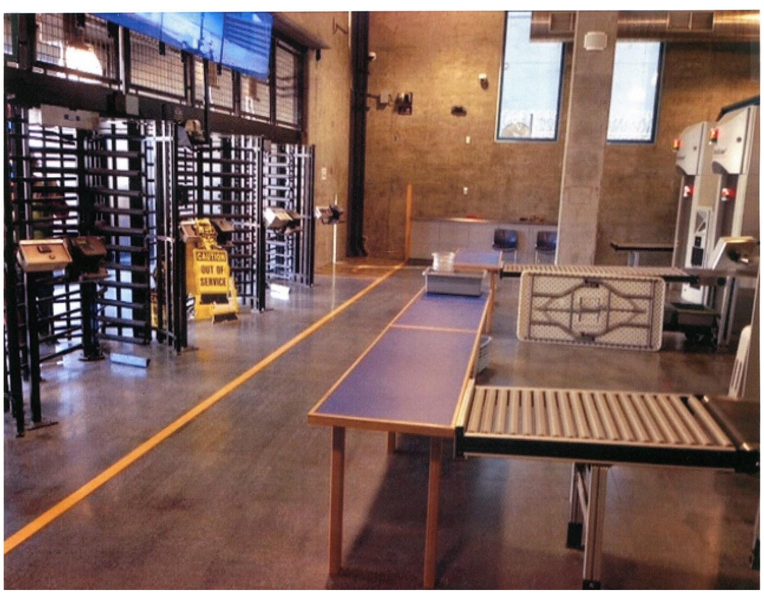

Figure 1 - Back End of DCPP's Security Building

The outage in February/March 2014 effectively highlighted the weak points in DCPP's security process. The facility was found to be too short (using their current process) to allow for comfortable moving range at both the check in and check out sides of the building. This issue was most prominent when high levels of congestion would occur as workers queued up on the check out side trying to grab and put back on their personal belongings from the x-ray machine, which can be seen in Figure 1. It was also seen to affect the check in sides as workers queued up to take off and place personal belongings onto the x-ray conveyor belt.

A competing problem complicating the congested areas was discovered to be the cycling of storage bins responsible for holding items that pass through the x-ray machine. With their current amount of storage bins, it is necessary to transfer bins from the check out sides back to the check in sides; otherwise, storage bins would run out on the check in side and effectively stop the security operation as no one could be processed through the x-ray operation. Currently, DCPP officers are having to manually push these stacks of storage bins through the congested areas within the facility to return them to their stored location on the check in side seen in Figure 2.

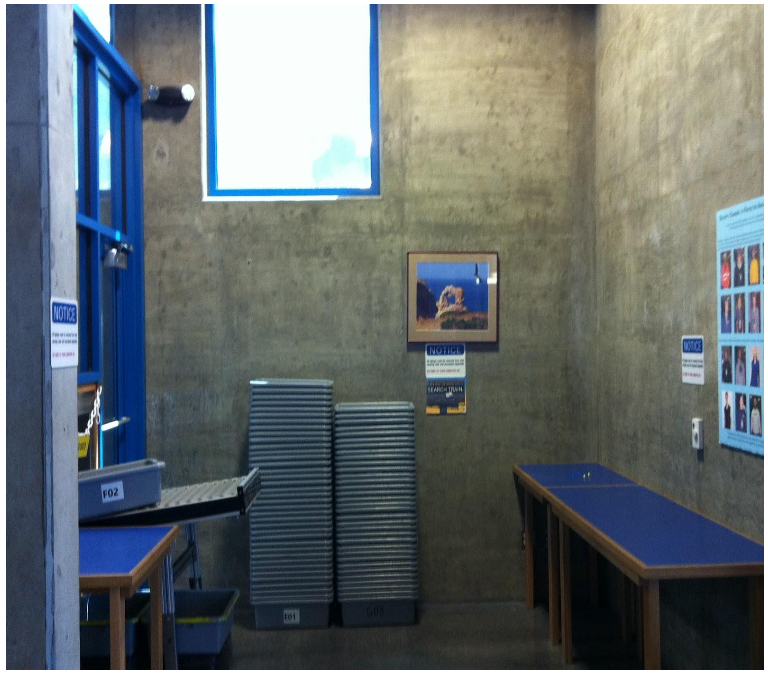

Figure 2 - Bin Storage Area at Front End of Building

Figure 3 - Signage Used at DCPP Security Building

The final imperative issue needing to be addressed is the ineffective use of signage throughout the Security system. Signs did not draw workers' attention and did not aid in efficiently directing workers through the process. Most signs were both small and static; the only dynamic signage was a digital display that cycled through unrelated screens that did not grab workers' attention or add value to the security process and an example can be seen in Figure 3.

Problem Statement

Diablo Canyon Power Plant's new Security Building was built without regards to their Security process. The space is very limited and the security officer staffing levels needed to facilitate the security process during outages are excessive. Some temporary workers that enter the security building during power outages are unfamiliar with the security process. The building itself is very noisy and adds difficulty to communication between security officers. The methods for cycling people and bins through the process are inefficient.

DCPP Project Requirements/Constraints

The project requirements defined by the DCPP stakeholders were to ultimately make the security process more efficient by getting workers through the security process faster, thereby increasing the number of workers that go through the process per hour, and to also decrease the number of security officers needed in the process. One of the constraints of the project is that the size of the security floor is unchangeable. The building was built without regards to the security process, and is a small floor area to work with. In terms of a budget for purchasing new search equipment or machinery that would make the process more efficient, there is no constraining budget.

Purpose

The general purpose of this senior project is to make cost-effective changes that will make the security process more efficient. The following objectives outline the goals the project plans to fulfill:

1. Determine the learning curve for the security process of new temporary workers that are unfamiliar with the process
    a. To analyze learning curve effects on the time study data, a learning curve fitting (estimated) experiment is proposed using students to process through an experimental security model similar to that of DCPP's security system. This experiment will use elements of process improvement and design of experiment. From this learning curve fitting (estimated) experiment, it is expected that results will provide a better understanding of how the learning curve could have affected the original time study data collected. The results from the experiment will be used to design experiments and the results from the latter experiments will be used to make recommendations to improve the system.
2. Create a simulation model to run different experimental scenarios to make the security building be able to serve more workers faster and decrease the time it takes for a worker to be processed through the security process
    a. As outages do not occur for long durations of time (usually lasting for about 1 month), further investigation of DCPP's security operations during overloaded conditions will be conducted using simulation models and queuing theory. The simulation models will be used to run different scenarios and determine what changes would make the security process more efficient and robust. Statistical analysis will be used to determine the statistical difference between the current system and the proposed solution.
3. Redesign a more robust and efficient facility layout

    a. The efficiency of the new security building's layout at DCPP will be examined through the use of facilities layout tools such as using raw time study data, learning curve fitting experimental data, and simulation models to analyze the process. Next, the space requirements of the machines and personnel in the building will be assessed. This data will be used to fully describe the facility layout for the purposes of analysis. Afterwards, process improvement ideologies will be utilized to perform a facility redesign.
4. Optimize bin usage and determine the number of bins needed and how often it needs to be replenished to the front
    a. Using the throughput data provided by DCPP, the optimal number of bins needed to accommodate the high number of workers during a power outage will be calculated. An efficient and standardized Kanban method to replenish the bins that will cause less strain on the officer in charge of bins will also be devised.
5. Decrease the noise in the building
    a. Effective sound absorbers and its installation process will be researched in order to improve communication methods between security officers
6. Create signage and an instructional video that serves as aids that will help temporary workers understand the process
    a. To address the issue of the ineffective use of signage in the facility, research into signage and applications of signage will be conducted. This research will be combined with consideration to human factors when looking into efficient sign designs. The requirements that the security team has for employees who are going through the security process will be incorporated in the application of signage via an instructional video that will be displayed as it pertains to the DCPP security process.
7. Create standard operating procedure (SOP) document that will explain the recommendations and walk the security officers step-by-step through the new procedures
    a. The recommendations made will be compiled into a standard operating procedure (SOP) document. This document will go over the improvements that the team has devised, explain how the improvements will be incorporated into the security process, and will include a step-by-step guide for the security officers to follow. The SOP is to serve as a guide to implement the recommendations and organize the recommendations into one document.
8. Make an economic justification for the recommendations
    a. A financial analysis will be completed to explain the monetary costs of the proposed solutions and recommendations. The recommendations made will take into consideration DCPP's requirements and will be financially feasible for DCPP.

Solution Approach: DMAIC Process

The Define, Measure, Analyze, Improve and Control (DMAIC) process was utilized to outline the steps necessary to complete the project. Throughout different parts of the report, the use of the DMAIC process and how it guided and organized the team's thought process will be discussed.

The define phase was completed by visiting the DCPP site and having meetings with the stakeholders to determine the goals and constraints of the senior project. These goals and constraints can be found

above and will be further discussed in the design section. After defining the constraints, specifications and requirements, the team and technical advisor for the senior project, Dr. Tali Freed, decided on deliverables that would help the team attain the solutions the DCPP stakeholders wanted.

The define phase was also completed when research was done on the topics that would be addressed in the senior project. Research on relevant topics and articles that solved similar problems defined for the senior project was done, which helped the team find some additional engineering concepts and tools that would be useful in formulating the solution. Literature reviews were completed for these articles in order to gain more knowledge on topics relevant to the project. The knowledge gained from doing the research and literature reviews was incorporated into the recommendations. The literature reviews also serve the purpose of giving the readers of this report background knowledge of the various topics that are discussed in this report just incase if they have never been exposed to it before.

The literature reviews is the next chapter of this report. It will be followed by the design, methodology, results/discussion and the conclusion.

II. Literature Review

Inspection security systems are needed in areas where high human traffic is a concern. Such need exists in airports, border checkpoints, nuclear power plants, and so forth. Inspection security systems serve two roles: to sufficiently check for any threat that could pose harm to the current environment; and to provide swift, quality service to the patrons processing through the system. It is important for inspection security systems to always remember both roles in order to be a successful, functional service provider. Consequently, there must be a balance between cost of providing the service, quality of service (how accurate inspection is in identifying possible threats), and efficiency of the system (measured by time patrons spend in the queue or in the entire system). In order to investigate how well a system is achieving this balance, methodologies such as simulation, human factors, queuing theory, facility layout analysis, and so forth can be applied to determine areas needing improvement. It is the design of this literature review to explicitly look into the effect of signage on the efficiency of an inspection system and to gain knowledge of how the real inspection system compares with that of its theoretical counterpart (extracted from queuing models, simulation models, alternate layouts, etc).

1. Inspection Security Systems

1.1. *Metal Detectors*

Most metal detectors are based on pulse induction (PI) systems. These systems function by utilizing a coil of wire as both a transmitter and receiver. The coil of wire then experiences pulses of current with each pulse creating a short magnetic field. At the end of a pulse, the magnetic field collapses abruptly leaving in its wake a sharp electrical spike. The spike then

induces a subsequent current to flow through the coil. The process repeats with another pulse being sent through the coil. When the metal detector detects a metal object, an opposing magnetic field is created within the object by the pulse. As soon as the pulse's magnetic field fades, the magnetic field that was created within the object forces the subsequent pulse to remain longer before it completely disappears.

1.2. X-rays

X-ray machines use highly energetic electromagnetic waves to penetrate a multitude of materials. Since different materials absorb X-rays at different levels, the image on the monitor lets the machine operator see distinct items inside the bins passing through on the conveyor belt.

2. Queuing Theory

To understand the theoretical implications for system performance, it is necessary to look into queuing theory and its applications in security systems.

2.1. Parkinson's Law

One consideration was how prevalent Parkinson's Law would be on Diablo Canyon's Security system and how it could affect the security personnel's service; Parkinson's Law considers the behavior of the worker speeding up their service when the worker perceives that the queue is longer. The repercussions then are a possible decrease in service quality.

To understand what potential effects this phenomenon could have on the Diablo Canyon Security System, a study titled *Human Factors Contributes to Queuing Theory: Parkinson's Law and Security Screening* conducted at a similar inspection system—an airport security system—was analyzed. An airport security system is ideal for comparison as it shares similarities with the Diablo Canyon Security System; specifically, they both utilize inspection machines such as x-rays and metal detectors for the purpose of identifying potential threats and maintaining a secure atmosphere.

The study broke down its experiment analyzing the effects of Parkinson's law perceived by studying airport security workers processing four types of bins: bins with clothing, keys, shoes, or cell phones; carry-on bags; small purses or camera cases; and laptop computers. The bins were titled bin 1, bin 2, bin 3, and bin 4 respectively. Of the four bins, potentially bins 1 and 3 would be applicable to DCPP.

The results showed that Parkinson's law affected only the speed of processing laptops through the x-rays due to the simplistic nature of inspecting laptops; all other items showed no difference in processing time, meaning that workers did not show an increase in speed when processing. Therefore, these results conclusively demonstrate that the Parkinson's law phenomenon was

only prevalent with laptops. Additionally, as laptops are not highly dominant items processed through Diablo Canyon's Security System, it can be deduced that Parkinson's Law will show little to no effect on Diablo Canyon's processing times and is outside the scope for a queuing model for DCPP's Security Building.

2.2. M/M/s Queuing Model

Determining an accurate queuing model is essential for producing representative results for any given system. A paper titled *Security Manpower Scheduling for Smart Airports* discussed how to accurately model an airport security system; their findings promoted the use of an M/M/s queuing model by the reasoning that the fundamentals of security checkpoints are "multi queuing lines and multi servers." The proposed queuing model assumes a Poisson distribution for arrival rates and an exponential distribution for service rates. The value of this finding is that their research suggests that an M/M/s queuing model would be applicable for the Diablo Canyon Power Plant security system on the same similarity principle between DCPP's inspection system/goal and an airport's inspection system/goal.

After obtaining results from the M/M/s queuing model, the researchers also suggest the possibility of determining minimum number of security personnel needed to maintain the security checkpoints by using integer programming. While DCPP and the airport in question do share similar peak times and principle, it is unclear as to the validity of extending their integer programming model onto DCPP's security system; further research between the varying personnel shifts would need to be conducted.

Lastly, while the study proposed two very intriguing ideas, their results remain purely hypothetical and assumed.

2.3. Reducing Waiting Time at Security Checkpoints

A queuing study completed at a security checkpoint, titled *Reducing Waiting Time at Security Checkpoints,* looked into problematic wait times for vehicles and buses who would queue up to be approved for containing no threat and then released through the checkpoint. At this particular security checkpoint, the ideology promoted giving priority to buses as each bus would contain a larger volume of people that could be serviced compared to an individual car. Although the actual scenario is not similar to DCPP's Security building, this paper does reflect good recommendations for when individuals are approaching queuing problems.

By the researchers' reasoning, information on inter-arrival rates, the nature of the queue, and the service rates were imperative to finding a solution to their queuing problem. Once data was collected, they confirmed an appropriate queuing model through identifying accurate distributions with a Chi-Squared test. The researchers considered two alternatives: add an additional security officer to lessen wait times versus open another lane that both current

security officers could service simultaneously. The results showed that the costs associated with adding an additional personnel did not make up for the slight decrease in wait times for vehicles and buses; however, by opening a new lane that could be serviced simultaneously, wait times improved dramatically at no cost to the security checkpoint!

The researchers suggest to always consider all options as the obvious adding additional personnel is not always the greatest solution to a queuing problem.

3. Simulation

To better understand the working behavior of DCPP's security system, an examination into applications of simulation modelling was performed.

3.1. Analysis of Airport Security Screening Checkpoints using Discrete Event Simulation

The study titled *Analysis of Airport Security Screening Checkpoints using Discrete Event Simulation* regarded external factors as a primary focal point. The researchers' reasoning was that most prior simulation models narrow-mindedly focused on internal behaviors. The specific variables of importance were as follows: arrival rates, baggage volume, service rates, and alarm rates.

This study also was conducted using an airport security system as the basis for discussion. Interestingly, arrival rates in this study followed a non-stationary schedule which permitted splitting the arrival times up and using a piece-wise distribution fitted to multiple Poisson curves based on a schedule. Then, to validate their model the researchers of this study completed an iterative sensitivity analysis until a validated model could be reached. The official findings were as follows: there is high sensitivity with alarm rates and little to no sensitivity associated with baggage volume.

As the study's results show a high sensitivity for alarm rates, these findings could be a good foundation for determining relative alarm rates for DCPP's security system.

3.2. Analysis of the Passenger Security Screening Process using Simulation Optimization

Identifying the appropriate approach to simulate an inspection security system is quintessential to pinpointing areas of improvement. One approach undertaken in the article *Analysis of the Passenger Security Screening Process using Simulation Optimization* used discrete-event simulation with the proposition of dividing airport passengers into two categories: registered travelers or regular passengers. Then the categorical divide continued throughout the security approach: registered travelers essentially went through a express lane that would only require checking once before cycling passengers and luggage through the system; regular passengers queued into a slower lane that required double checking of their luggage and careful consideration towards these passengers.

The mentality follows that registered travelers are given the benefit of the doubt and more trust whereas regular passengers are unknown to the system and are regarded with distrust. The possible benefits of using this approach would be to promote everyone to register into the system to maintain safety at a higher level as instant background information would be available to all security personnel; also, this would target utilizing expenses more efficiently as only the regular passengers who are foreign bodies to the system will need extensive searching. Consequently, there could be a cost-benefit and a security benefit resulting from this approach.

One implied application to DCPP could be to set-up two separate lines: one for outage workers and one for regular workers. The outage workers would be unfamiliar to the inspection system and naturally take longer to process through the system so there may result in a longer queue for outage workers. Conversely, the regular workers could process quickly through the inspection system and their familiarity will drive them to need less assistance from security personnel, potentially promoting less required security personnel for the regular worker line. Lastly, by using their suggested meta-heuristic simulation approach it may be possible to develop a richer solution to any optimization questions posed to a simulation study conducted for DCPP's security system.

4. Facility Layout Design

4.1. Psychology behind Facility Layout Design

Ascertaining how consumers respond to service providers can help service providers improve quality of service. Since service provided is intangible in some cases, consumers will draw upon cues within their environment to form a conceptualized idea of the quality of services being offered. Visual indicators such as signs can help to familiarize and orient consumers within a service environment; consequently, it is the construct of the study *Uncovering Dimensionality in the Servicescape: Towards Legibility* to determine consumer reactions to their service environment.

This study focuses on an airport terminal as it is seen as an illegible environment—meaning having no organized or coherent pattern to the facility layout. The response variables being considered then were primarily consumer moods to certain aspects within the airport terminal, gauged through the implementation of random questionnaires conducted at a single airport terminal. The results of the questionnaires indicate that the relationship between signage and spatial features with consumers' emotional responses towards a service setting can determine the legibility of a given service provider.

4.2. Signage

DCPP's security system currently has inefficient directional signs, thus requiring study into ways to improve these signs. As the purpose of signage is to aid in the development of wayfinding, it can be correlated that having more efficient signs could equate to needing less security personnel.

Signage is important in a servicescape as it directly affects behavior and is a "direct indicator of service quality and customer satisfaction". The paper being considered, *Towards an approach to signage management quality (SMQ),* discusses the importance of signage management quality and focuses on the customer's reception of the signs. As the focus is on the user, it follows that the sign's design should be oriented toward the user's needs. This paper suggests a signage management quality model should efficiently organize user needs (whether implicit versus expected/unexpected), determine the types of signage, and identify the targets of the service organization. Lastly, the researchers suggest integrating a feedback loop to attain valued understanding behind the reception of current signs.

4.3. The Facility Layout Design Problem

The facility layout problem (FLP) is defined to be the determination of the physical organization of a facility. Essentially, the FLP is concerned with "finding the most efficient non-overlapping arrangement of interacting departments with equal or unequal area requirements within a facility." Efficiency then is determined by the ability to minimize operational costs. Proposed solutions to an FLP (the outputs) are then block layouts specifying relative locations of distinct bodies within an operation.

The study titled *A comparative analysis of meta-heuristic approaches for facility layout design problem: a case study for an elevator manufacturer* looks at the FLP problem holistically and proposes an integration of Genetic Algorithm/Simulated Annealing. This approach offers a hybrid method to facility layout problems to identify the most effective solution. The argument behind using this hybrid approach is that both methods independently are great optimization techniques, however with their own specific benefits and weaknesses. Together, they can counterbalance their counterpart's weaknesses and offer a more in depth analysis to the FLP.

The applications of the proposed hybrid approach could potentially benefit any study conducted on DCPP's Security Building layout.

III. Design

Both the Define and Measure phases of the DMAIC process were used to outline the constraints, specifications and requirements of the project. The phases were also used to design the experiments that would yield results that would give important insight into the system's efficiency and ultimately help the team formulate effective recommendations.

As mentioned in the introduction, after the team visited DCPP, discussed the goals and constraints of the project with the stakeholders, saw the process, discussed the issues and brainstormed potential deliverables with Dr. Freed and completed the literature reviews, the team chose the experiments to be ran and deliverables to be completed that would bring them closer to solutions and recommendations. The following is the initial list of proposed deliverables that was mentioned in the introduction:

- Learning Curve Fitting (Estimated) Experiment
- Simio Model
- Facility Redesign Layout
- Bin Optimization
- Noise
- Signage
- Instructional Video
- Standard Operating Procedure (SOP)
- Financials

The initial proposed deliverables defined the measure phase. In later meetings and visits, the team measured and obtained the information necessary from the security process in order to run experiments and complete the deliverables. Time studies at DCPP's security building of workers going through the entire security process were done. These times were incorporated into the design of the experiments ran.

The Analyze phase of the DMAIC process was also fulfilled from the DCPP visits. The team members were able to see where bottlenecks occurred in the process and which areas needed the most improvement. The learning curve fitting experiment that will be mentioned in this chapter also had the goal of analyzing how long it takes for individuals to master the process of going through the metal detector without setting it off. A spaghetti diagram was made on Microsoft Visio to show the current layout and the flow of workers in order to better analyze the current process. DCPP also provided the team with blueprints, which was used to ensure that the designs of our experiments were representative of the facility. Any additional information that could not be extracted from the blueprint was physically measured during visits.

The next subsections of this chapter will cover DCPP's current system in detail and its influence on the design of experiments and the proposed deliverables.

1. Current Security Floor

1.1. The Current Security Process and Flow of Workers

The security process consists of an x-ray machine, a metal detector, two explosive detectors, and an exit. Three such processes are used in conjunction, two of the three processes share one x-ray machine. The first step is putting items in a bin and placing the bin on a Table to go through x-ray. Next, a worker walks through the metal detector and if they set it off, they have to repeat the step until they no longer set the metal detector off and are cleared. Afterwards, the

worker walks to one of two explosive detectors and stands in it for exactly 20 seconds every time. When the worker is out of the explosive detector, that person picks up their items from x-ray and goes to the turnstile exit. The process has 1 security officer per operational x-ray, 1 security officer per metal detector, 1 security officer per two explosive detectors, 1 security officer for bins, 1 security officer for pat downs and extra assistance for a total of 11 officers. This process can be seen in the Visio spaghetti layout below, Figure **4**. It is evident that there is a concentration of foot traffic towards the right side of the building as workers are trying to grab bins after workers enter the security building. There is also foot traffic at the back of the security building when workers pick up their belongings. These will be the areas that the team will focus on making more efficient. In addition, blueprints were provided by DCPP, which had the specific dimensions of the security building and its search train equipment.

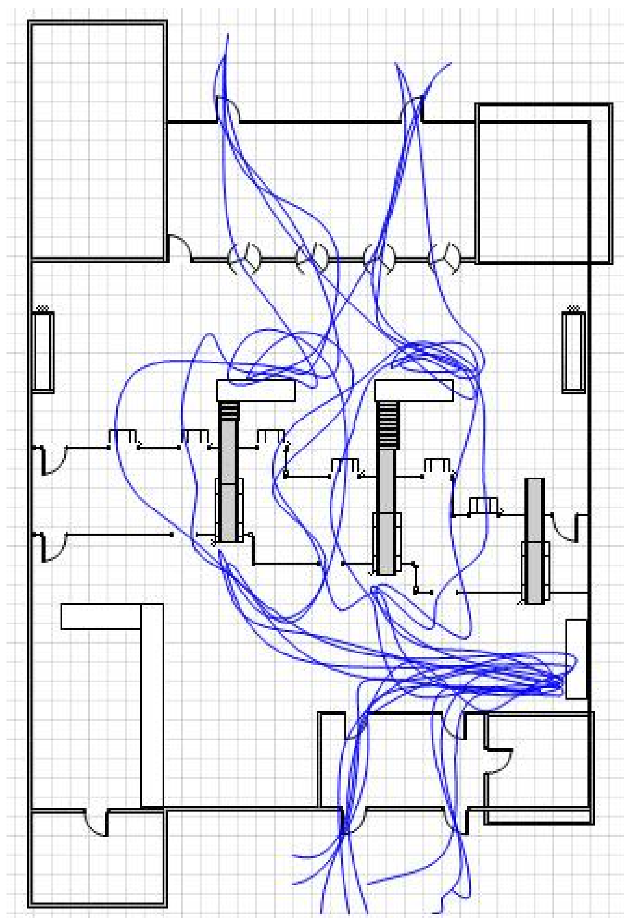

Figure 4 - Visio Spaghetti Diagram of Workers' Path

On regular days, a maximum of 700 workers are processed every hour. On outage days, the number doubles to a maximum of 1400 workers processed every hour. Some temporary workers have never been exposed to the security process and are unfamiliar with the process, which makes them take longer to go through the process. The people and process produce a high volume of noise in the building.

The current signs used at DCPP's security process are small and static. They do not draw the workers' attention, were not efficient at guiding the workers through the security process and did not add value to the security process.

The bins used to transport items through x-ray are stacked at the front and back of the process and one officer is assigned to move the bins from the back to the front as needed. The officer manually transfers the used bins in the back onto a transporting device and pushes it to the front for workers to use. The current method of moving bins is tedious, time-consuming and not ergonomic for the officer.

1.2. Current Security Process Constraints and Layout Constraints

The current system does not allow for any less than 11 officers who are all part of running the process. One of the primary goals is to reduce the number of officers as much as possible to reduce officer costs for DCPP.

The dimensions of the building housing the security process cannot be changed and is a limited floor space. The third x-ray machine is in an awkward placement and it is an older model that has low imaging quality and does not work as well, and therefore, is almost never used. There is also a cabinet blocking the flow of traffic near the third x-ray machine.

1.3. Time Studies

Times studies of the workers were completed in order to get raw data of the time it takes to get processed at two areas of the security process: metal detector processing time and explosive detector processing time. The time studies were taken during the third week of a power outage between the hours of 5am - 7am, which is the security building's busiest hours. Throughput data was also obtained, which allowed the team to determine the interarrival rate of workers. The raw data can be found in Appendix A: Raw Data.

2. Proposed System Designs

2.1. Facility Redesign

Based on the data mentioned in section 1.1, there were several improvement ideas that were devised specifically for the security floor.

2.2. Bin Volume and Optimization

One redesign idea is to improve the current layout include reorganization and optimization of the volume of plastic bins. The bins are crucial in keeping a steady and consistent pace within the security process and optimizing the volume of bins as well as the frequency of its replenishment to the front end will be important.

2.3. Addition of a Third X-Ray

The next solution is using existing equipment that is currently not being used, the third x-ray. This will help with accommodating more workers, which is vital during power outages when the number of workers entering the facilities doubles. This idea will first need to be justified by a simulation that will prove adding a third x-ray will make a significant difference and make the system more efficient. If a third x-ray is purchased, a conveyor belt and Table will also need to be purchased to complete the new lane.

3. General Potential Improvements for the Building

Some potential general recommendations to improve the security process also were devised.

3.1. Optimal Noise Level

Determining the decibel level of noise at the security process, researching the acceptable OSHA noise level and finding equipment that will help dampen the noise will make communication for workers entering the security building and officers that operate the building much easier.

3.2. Standardization Using Standard Operating Procedure (SOP) Document

Using process improvement fundamentals to create a standard operating procedure (SOP) for both the security officers and the workers going through the security process will standardize the process and change the dynamics of the system to make it more efficient. Any changes to employee responsibilities will be specified in this document.

3.3. Security Video Redesign

The security video will map out the entire security process each individual will go through: entrance, metal detector, explosive detector and exit turnstiles. It will mention specific details as to what individuals are not allowed to bring into the plant in hopes of decreasing the time a worker takes to be processed. The video can be shown during the training process for both permanent and temporary workers so that workers can become familiar with the process and decrease the time workers spend in the security process.

3.4. Signage Redesign

Ergonomics will be utilized to create new signs that will catch the workers' attention and clearly describe the security process individuals will go through. The signs will be large and will be straightforward in order to avoid any confusion and help the security process run more efficiently.

A student survey will be sent out in the Fall comparing DCPP's current signage with the team's signage. The survey will get students' opinion on its effectiveness, visibility and other ergonomic issues.

3.5. Reducing the Number of Employees Required

The facility redesign should also reduce the number of employees needed for the security process. This was one of the main criteria that the stakeholders wanted the project to achieve.

3.6. Separate Lanes for Permanent Workers and Temporary Workers

Permanent workers could potentially have a lane dedicated to them that would incorporate a quicker, more lenient security check process since they have had background checks done on them and have developed a sense of trust since they enter the building everyday. This idea originated from the literature review completed where regular travelers that traveled frequently had a separate express lane.

4. Simulation Design

The Simio model was made to scale with the DCPP's blueprint and images as the template. The model was made as closely as possible to the actual layout so that any statistical results gathered and any analyses made can be applied directly to the facility. The Simio model of the current layout and an alternative Simio model with brainstormed improvements will be created to determine if there are any statistically significant improvements in terms of time in system of workers and throughput of workers between the two models. Final recommendations will be made based off these results.

The current model of DCPP's security building was made in Simio. This model includes an entrance source for temporary workers, an entrance source for permanent workers, a bins source for the bins that process through the x-rays, three metal detector servers, three explosive detector servers, and four turnstiles as sinks. There is a queue line in front of each metal detector server, a queue line of 1 to 2 workers in front of each explosive detector, and a queue line in front of each sink.

The model represents the physical layout of Diablo Canyon Power Plant's Security Building according to blueprints of the actual Security Building. As this Simulation model will be used to provide detailed recommendations to the head of Security at Diablo Canyon Power Plant, it was necessary to make the simulation model as accurate by distances as much as possible; consequently, travel time of the workers were not neglected and paths with appropriate lengths were used.

Raw data was input into StatFit in order to determine the distribution (AutoFit) of the critical operations and then Goodness of Fit of each distribution: both entrance sources, metal detector servers, explosive detector servers, and the turnstile sinks.

4.1. Determining Distributions for Collected Data

During the third week of the outage, time study data was collected, consisting of times for both outage and regular workers processing through the Security Building. For the worker times recorded, times were split based on where the workers were in the system, e.g. at the front area, at the back area, and at the metal and bomb detectors. Additional data was then provided

by the Head of Security which logged throughput for each of the turnstiles that workers would pass through to exit the Security building. The provided turnstiles' throughput considers foot traffic of both outage and regular workers passing through the Security building during the two identified peak times (5am to 7am and 4pm to 6pm daily); of the two peak times, the more prominent peak time was during the 5am to 7am time period, with almost double the amount of foot traffic during this time period.

Subsequently, the data needed to be analyzed and its role in the project needed to be identified. Determining the appropriate distributions for the collections of time study data points and the provided turnstiles' throughput during peak times was recognized to be quintessential to having an accurate simulation model. The initial point of interest was the provided turnstile throughput.

Upon first attempting to determine distributions for the throughput data, each turnstile was considered separately and the program StatFit used. However, it was soon discovered that StatFit would not accept less than ten data points, and for each turnstile, only seven measurements of throughput were provided. The second attempt considered all throughput data as a whole and the measurements for each turnstile were compiled into StatFit. Unfortunately, due to the variation amongst the turnstiles, no distribution was feasible when considering all throughput data collectively. To determine the variation between the means for each of the turnstile's individual throughput, an ANOVA test and a Tukey-Kramer comparison of means test were conducted at a 95% confidence level using the statistical software JMP. For the ANOVA test, the following null hypothesis was proposed:

$$H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$$

$$H_1 : \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 ,$$

where μ_1 = average throughput for Turnstile 201, μ_2 = average throughput for Turnstile 202, μ_3 = average throughput for Turnstile 203, and μ_4 = average throughput for Turnstile 204

The results of the ANOVA test are below in Figure 5.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Turnstile Number	3	99168.29	33056.1	5.4118	0.0055*
Error	24	146596.57	6108.2		
C. Total	27	245764.86			

Figure 5 - ANOVA Test Results

The above ANOVA test image shows that at a 95% confidence level the P-value of 0.0055 is significant, and consequently the null hypothesis that all turnstiles' throughput is statistically similar can be rejected. Further investigation by the Tukey-Kramer comparison of means test identified which turnstiles were statistically different. The results for the Tukey-Kramer comparison of means test are seen below.

Connecting Letters Report

Level		Mean
Turnstile 204	A	291.85714
Turnstile 203	A	264.71429
Turnstile 202	A	262.85714
Turnstile 201	B	138.28571

Levels not connected by same letter are significantly different.

Figure 6 - Tukey-Kramer Comparsion of Means Test

At a 95% confidence level, it was concluded that Turnstiles 202, 203, and 204 were all statistically similar and that Turnstile 201 was statistically different from Turnstiles 202, 203, and 204. Returning to StatFit, only throughput data for Turnstiles 202, 203, and 204 were inputted. However, StatFit still returned no feasible distribution. Then the data from Turnstiles 202, 203, and 204 were inspected and one significant outlier was found within Turnstile 204's throughput data. Once this outlier was removed, the distribution was found to be Poisson(mu = 283.95) workers. The goodness of fit test and StatFit test results can be found in Appendix B: Simulation. This information will be used to determine the permanent and temporary worker's interarrival rate.

The distribution Poisson(mu = 283.95) is a generalized distribution that represents the number of workers that exit one turnstile in the 2-hour time frame between 5am - 7am. However, this was not useful for the simulation model. The distribution was divided in half to represent the throughput of workers per hour and then the value was multiplied by 4, representing the four turnstiles, to get the total number of workers exiting the building per hour. The value was 568 people per hour. This value was divided by 60 minutes to get the rate of people exiting the building per minute, which resulted in a rate of 9.47 people per minute. This rate was flipped in order to get the interarrival rate, which was 6.43 seconds between each worker for one source. The calculation can be seen in Figure 7.

$$Interarrival\ Time = \frac{\frac{283.92\ workers}{2\ hours}}{turnstiles} * 4\ turnstiles * \frac{1\ hour}{60\ minutes} = 9.464\ \text{people/min}$$

$$\rightarrow \frac{60\ seconds}{min} * \frac{1\ min}{9.464\ people} = 6.34\ \text{seconds/person}$$

Figure 7 - Interarrival Rate Distribution Calculation for both Permanent and Temporary Workers

However, since there are two entrances, the workers would be coming from two different sources and the 6.43 seconds value for two sources would be too high and cause a buildup in the Simio model. The interarrival rate would have to be doubled to 12.68 seconds between worker arrivals from two different sources so that it accurately represents the system.

Permanent Worker Entrance and Outage Worker Entrance: these were source objects. Using StatFit and calculations, it was determined that the interarrival time distribution is Random.Poisson(12.68) seconds.

Bins Container: this is a source object. Using an experiment in Simio and known knowledge on how many bins DCPP currently has, the team was able to determine the appropriate distribution for the bins.

Metal Detectors 1, 2, 3: these are server objects. Since most of their operations were less than 5 seconds in length during our raw data recording and since our explosive detector and metal detector times were grouped together during recording, it was determined that the metal detector processing times would be negligible in the model. Its processing time's distribution was set to a negligible distribution of Random.Triangular(0,2,4) seconds. Additionally, in the real system, queue lines are not allowed in between the metal detector and explosive detector forcing the queue to occur outside the three metal detectors. Consequently, the path was set to allow no passing and only permitted one individual to be processed through the explosive detector at a time with only one person allowed to be in the queue for the explosive detector.

In order to differentiate the time it takes for permanent workers and outage workers to be processed and to make the model representative of the real system, the path for outage workers had a higher rate of repeating the metal detector portion of the process. The assumption was that permanent workers repeated the metal detector 5% of the time.

For temporary workers, the percentage was based off the raw data gathered. It was assumed that any times that were unusually high meant that the worker repeated the metal detector. 2 out of the 9 trials had high times and this percentage, 22%, was used for temporary workers as the percentage of workers that have to repeat the metal detector portion.

X-Rays 1, 2, 3: these are server objects. Processing time was difficult to gauge as there were no recorded measurements for these servers. Therefore, the team relied upon online videos/research to determine a reasonable assumed processing time as 8 seconds.

Explosive Detectors 1-6: these are server objects. Using StatFit, the processing time's distribution was found to be lognormal(mu = 2.34, sigma = 0.5) minutes. Each explosive detector's capacity is 1 worker at a time, and their input buffer is 1, since there was space for 1 worker standing in each queue line in front of each station. The StatFit calculation results can be found in Appendix B: Simulation.

Turnstile 201, 202, 203, 204: these are sink objects. After the workers collect their items from the x-ray and return the used bin, they exit the Security Building through either Turnstile 201, 202, 203, or 204. The distribution for each turnstile was approximated based on similar hand screening tools used in the Cal Poly Recreation Center; it was decided that the appropriate distribution was Random.Uniform(5,10) seconds.

The completed Original Simio model can be seen in Figure 6.

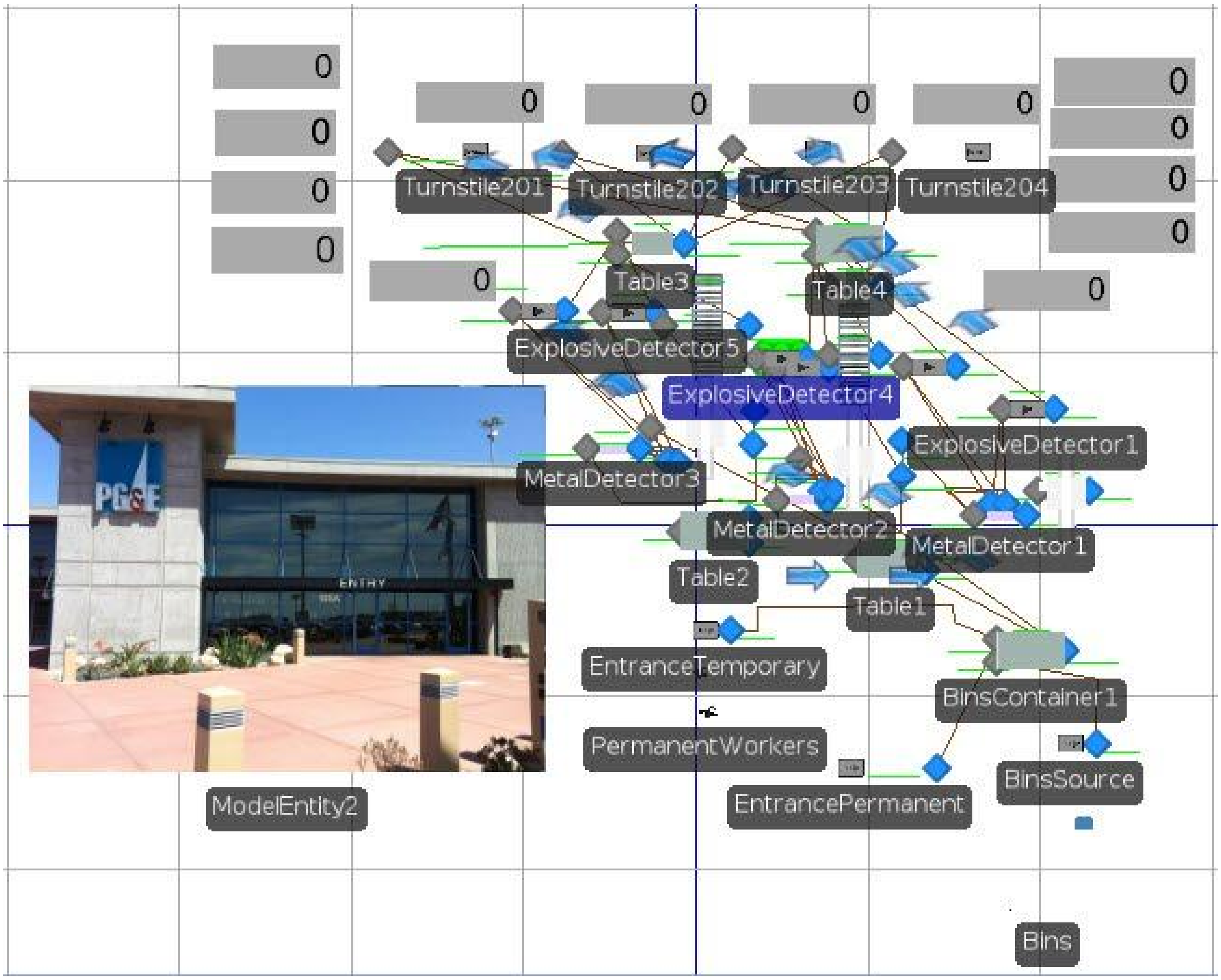

Figure 8 - Original Simio Model of Current System

4.2. Verifying Simulation Model with Queuing Theory

After the Simio model was completed the data produced by the model was checked by comparable calculations taken from Queuing Theory equations, seen in Appendix C: Queuing Theory, for an M/M/c process with all times assumed to follow exponential distributions. The time study data was used to find the arrival rate of workers, lambda, and service rate of the process, mu. The results of the Queuing Theory equations can also be found below in Table 1. The Simio model results were close in value to the results from the Queuing Theory calculations.

mu	0.5555555556	people/min	
lambda	1.991666667	people/min	
rho	0.89625		
c	4	sum	18.69031694
p(0)	0.01176089524		
Lq	26.95868654		
L	30.54368654		
W	15.3357422		
Wq	13.5357422		

Table 1 - Queuing Theory Results

5. Learning Curve Fitting (Estimation) Experiment

The proposed learning curve fitting (estimation) experiment will be a physical representation of the metal detector, x-ray and exit stages of the security process at DCPP. The purpose of this experiment is to collect data on the learning curve of new workers that go through the metal detector process. The team does not have info on how often the metal detector is set off normally and therefore, this will be the focus of the experiment. The other portions of the security process other than the metal detector are generally static and consistent. They are also not as dependent on the learning curve of the worker.

The students in IME 223, which represented new temporary workers, completed the experiment. A video will be created detailing the steps in the process that the students will have to complete and will be shown to the students prior to starting the experiment.

The team members, prior to the day of the experiment, will create 12 bags numbered 1 through 12 with 7 items in each bag. Some items will be metal and some will be non-metal to emulate workers' bags, which will have the same mix of items. The bag number and its specific contents will be recorded on a spreadsheet and printed to be used at the x-ray station. Metal items will be highlighted in the spreadsheet and the number of metal items in that particular bag will be shown at the bottom of its respective column.

IV. Methods (Experimentation)

Two project deliverables that incorporated actual experiments were the learning curve fitting (estimation) experiment and the simulation model. This chapter will cover the set-up of the experiments conducted for both deliverables.

1. Learning Curve Fitting (Estimation) Experiment

1.1. Set-Up

The students will be asked to get into team of two: One student will be the timer and recorder while the other will be going through the experiment. The time study sheet with one student's raw data can be

seen in Appendix D: Learning Curve Fitting (Estimated) Experiment. The student will go through the metal detector 10 times and their times will be used to determine their learning curve. Afterwards, the two students will switch places and complete another 10 runs.

There will be two sets of stations set up in a classroom beforehand. The first station will be bag station where students will grab bag for each run they do. Students will be instructed to try to grab a bag that they have not done a run with yet in order to ensure randomness. Having the students grab a different bag for each run will truly test if their learning of what items should and should not be going into the metal detector.

Then, there will be two x-ray stations and two metal detector stations that are parallel with one another and two exit stations. Each x-ray station will be a Table set up parallel to the metal detector station and a team member will man the station. Since a real metal detector cannot be present, a team member will be at each x-ray station with the spreadsheet that specifies all the items in each bag, which can be found in Appendix D: Learning Curve Fitting (Estimated) Experiment. The team will use the spreadsheet to check if all the metal items have been taken out. The team member will take the items from the student when they are ready to simulate putting the items in an x-ray machine. If there are some items on the spreadsheet are forgotten to be taken out of the bag, the member will tell the student to try again and that they still have metal items on them. This will simulate a metal detector going off. The remaining team member will be the security guard to answer any questions and help the simulation run. The pair will exit the station and go back to the bag station to repeat the run until a total of 10 runs have been completed before switching roles with their partner.

2. Simio Model

Experimentation Details:

A confidence level of 95% was used for all experiments. The t-distribution was used for Experiments 1 and 2 because the hypotheses are differences and the population standard deviation is unknown.

Each replication ran for 2 hours so that it simulates the rush hour period at DCPP from 5am to 7am.

Alternative Model

An alternative model as seen in Figure 2 was also made in Simio. The layout and model's objects are the same as the original model except that the temporary outage workers use the two leftmost search trains and the permanent workers use the rightmost search train and also incorporates an additional third lane. The team believes the alternative model is a more fair setup for workers as it will allow increased speed for both types of workers. The alternative Simio model can be seen in Figure 9 below.

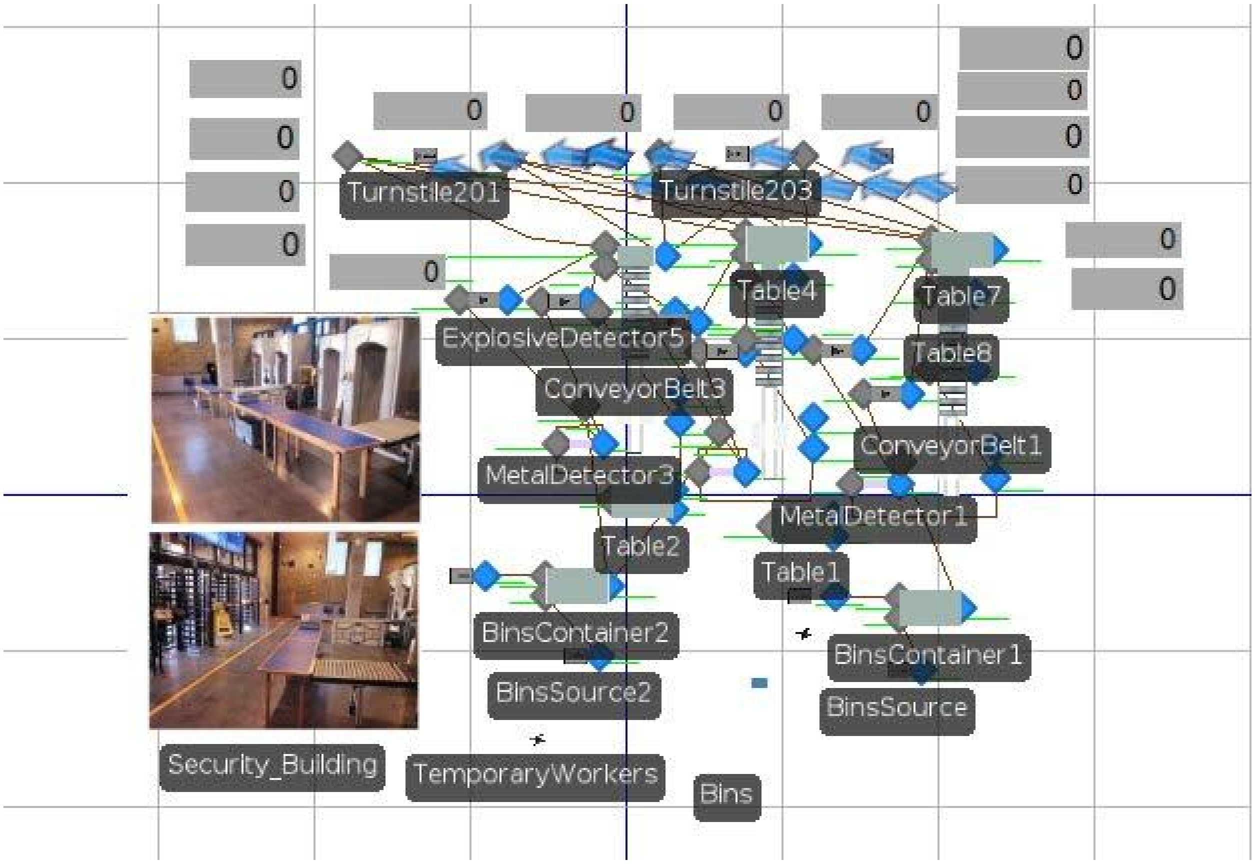

Figure 9 - Alternative Simio Model

There were a total of four types of experiments conducted on Simio. Some experiments compared multiple metrics.

Experiment 1:

The first experiment will compare permanent worker time in system (denoted as P) and temporary worker time in system (denoted as T) for three different distributions for interarrival time of bins. The experiment will determine if the process is sensitive to the interarrival rate of bins and if a certain rate of bins is required in order to optimize the security process.

1) Random.Exponential(.25) minutes
This distribution is standard for sources in the Simio program.

2) Random.Poisson(12.68) seconds
This distribution is double the interarrival rate of workers. In other words, it represents a situation where there are not enough bins to accommodate the rate of workers entering the building that was obtained from the throughput data.

3) Random.Poisson(6.34) seconds
This distribution is the same as the interarrival rate of workers. In other words, it represents a situation where there is enough bins available to accommodate the rate of workers entering the building that was obtained from the throughput data.

Experiment 2:

This experiment focuses on comparing the four turnstile throughputs, permanent worker time in system and (P) temporary worker time in system (T) difference between the Original model (model 2) and Real data (model 1).

Experiment 3:

This experiment focuses on comparing the four turnstile throughputs, permanent worker time in system and (P) temporary worker time in system (T) difference between Original model (model 2) and Alternative model (model 3)

Experiment 4:

The last experiment compares the permanent worker time in system (P) and temporary worker time in system (T) difference between three different worker interarrival times.

1) 100% Inter-arrival Time

This interarrival distribution is the standard Poisson(mu = 12.68) seconds that was derived from the throughput raw data provided.

2) 75% Inter-arrival Time

This distribution is 75% of the distribution derived from the raw data. This results in a distribution of Poisson(mu = 9.51) seconds, which is a faster arrival rate of workers than the derived interarrival distribution.

3) 90% Inter-arrival Time

Similar to the second distribution, this third distribution is 90% of the distribution derived from the raw data which is Poisson(mu = 11.41) seconds. This is also a faster arrival rate of workers than the derived interarrival distribution.

V. Results and Discussion

The results and discussion portion covered the improve and control steps of the DMAIC process. An alternative Simio model with improvements was created and experiments were done to determine if the improvements had a significant impact on the system. The recommendations and improvements made were incorporated into deliverables such as the Visio model and SOP to better control and standardize the security process and most importantly decrease the time it takes for workers to be processed.

1. Learning Curve Fitting (Estimation) Experimental Results

Raw data for each student was compiled into a spreadsheet and the experience curve function was used for each student's data. There were 24 students who participated, thus resulting in 24 data sets. The experience curve equation can be found in Appendix D: Learning Curve Fitting (Estimated)

Experiment and an example of its application on one student's data set of 10 runs can be seen in Figure 10 below.

			n =	-0.024	Learning Rate
Subject 12					
	Obs Time	Cum Time	Cum Ave	Learning Curve	
1	13	13	13	12.665	
2	10	23	11.5	12.45605	
3	13	36	12	12.33543	
4	15	51	12.75	12.25055	0.983502
5	13	64	12.8	12.18512	
6	10	74	12.33333	12.13192	
7	15	89	12.71429	12.08712	
8	15	104	13	12.04845	
9	9	113	12.55556	12.01444	
10	11	124	12.4	11.98409	

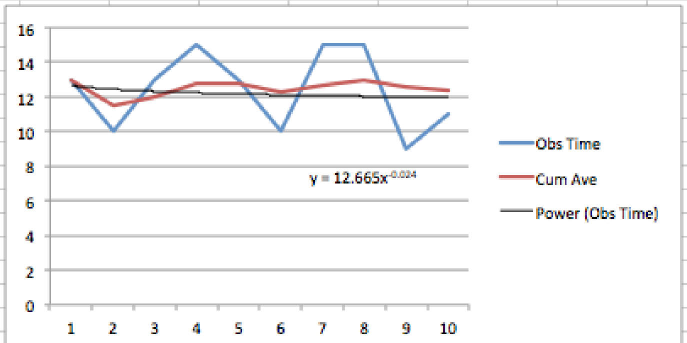

Figure 10 - Example of Experience Curve Calculation

The learning curve percentages for the 24 data sets were averaged to get a percentage that was representative of the metal detector process. The average learning curve percentage was 92.4%. A rate of improvement is calculated by subtracting 100% from the average learning curve percentage of 92.4%, which is 7.6%. In other words, 7.6% is the rate of improvement between doubled runs (i.e. comparing improvement of times between run 4 to run 8). This percentage indicates that there is a learning curve new temporary workers face at the metal detector.

After calculating the results of this experiment, the idea of having separate lanes for the two types of workers was supported. Its effectiveness will be investigated by conducting experiments in a Simio model, which will be discussed next.

2. Simio Model Experimental Results

Experiment 1:

Comparing three distributions for inter-arrival time of bins to the system.
1) Random.Exponential(.25) minutes
2) Random.Poisson(12.68) seconds
3) Random.Poisson(6.34) seconds

1 vs. 2 Permanent Worker Time In System
Ho: $\mu_{2P} - \mu_{1P=0}$
Ha: $\mu_{2P} - \mu_{1P} \neq 0$

1 vs. 2 Temporary Worker Time In System
Ho: $\mu_{2T} - \mu_{1T=0}$
Ha: $\mu_{2T} - \mu_{1T} \neq 0$

1 vs. 3 Permanent Worker Time In System

Ho: $\mu_{3P} - \mu_{1P=0}$
Ha: $\mu_{3P} - \mu_{1P} \neq 0$

1 vs. 3 Temporary Worker Time In System
Ho: $\mu_{3T} - \mu_{1T=0}$
Ha: $\mu_{3T} - \mu_{1T} \neq 0$

2 vs. 3 Permanent Worker Time In System
Ho: $\mu_{3P} - \mu_{2P=0}$
Ha: $\mu_{3P} - \mu_{2P} \neq 0$

2 vs. 3 Temporary Worker Time In System
Ho: $\mu_{3T} - \mu_{2T=0}$
Ha: $\mu_{3T} - \mu_{2T} \neq 0$

Confidence Interval Results:
$0.02329 < \mu_{1P} < 0.02826$
$0.50413 < \mu_{2P} < 0.51704$
$0.02487 < \mu_{3P} < 0.03843$

$0.02333 < \mu_{1T} < 0.02836$
$0.50033 < \mu_{2T} < 0.51966$
$0.02487 < \mu_{3T} < 0.03826$

μ_{1P} and μ_{3P} are not significantly statistically different because the confidence intervals overlap.
μ_{1P} and μ_{2P}, μ_{2P} and μ_{3P} are significantly statistically different because the confidence intervals do not overlap.

μ_{1T} and μ_{3T} are not significantly statistically different because the confidence intervals overlap.
μ_{1T} and μ_{2T}, μ_{2T} and μ_{3T} are significantly statistically different because the confidence intervals do not overlap.

Experiment 2:

Difference between Original model (model 2) and Real data (model 1)

Turnstile 1 Throughput
Ho: $\mu_{2.1} - \mu_{1.1=0}$
Ha: $\mu_{2.1} - \mu_{1.1} \neq 0$

Turnstile 2 Throughput
Ho: $\mu_{2.2} - \mu_{1.2=0}$
Ha: $\mu_{2.2} - \mu_{1.2} \neq 0$

Turnstile 3 Throughput
Ho: $\mu_{2.3}$- $\mu_{1.3=0}$
Ha: $\mu_{2.3}$- $\mu_{1.3}\neq0$

Turnstile 4 Throughput
Ho: $\mu_{2.4}$- $\mu_{1.4=0}$
Ha: $\mu_{2.4}$- $\mu_{1.4}\neq0$

Permanent and Temporary Worker Time in System
Ho: $\mu_{2.5}$- $\mu_{1.5=0}$
Ha: $\mu_{2.5}$- $\mu_{1.5}\neq0$

P-value Results:
P1=0.072
There is no statistically significant difference between turnstile 1 throughput in Model 1 and 2.

P2=0.140
There is no statistically significant difference between turnstile 2 throughput in Model 1 and 2.

P3=0.140
There is no statistically significant difference between turnstile 3 throughput in Model 1 and 2.

P4=0.754
There is no statistically significant difference between turnstile 4 throughput in Model 1 and 2.

P5=0.702
There is no statistically significant difference between worker time in system in Model 1 and 2.

The original Simio model (model 2) is not statistically significantly different from the real system, which means model 2 is a fairly accurate representation of the real system.

Experiment 3:

Difference between Original model (model 2) and Alternative model (model 3)

Turnstile 1 Throughput
Ho: $\mu_{2.1}$- $\mu_{3.1=0}$
Ha: $\mu_{2.1}$- $\mu_{3.1}\neq0$

Turnstile 2 Throughput
Ho: $\mu_{2.2}$- $\mu_{3.2=0}$
Ha: $\mu_{2.2}$- $\mu_{3.2}\neq0$

Turnstile 3 Throughput

Ho: $\mu_{2.3} - \mu_{3.3} = 0$
Ha: $\mu_{2.3} - \mu_{3.3} \neq 0$

Turnstile 4 Throughput
Ho: $\mu_{2.4} - \mu_{3.4} = 0$
Ha: $\mu_{2.4} - \mu_{3.4} \neq 0$

Permanent Time in System
Ho: $\mu_{2.5} - \mu_{3.5} = 0$
Ha: $\mu_{2.5} - \mu_{3.5} \neq 0$

Temporary Worker Time in System
Ho: $\mu_{2.6} - \mu_{3.6} = 0$
Ha: $\mu_{2.6} - \mu_{3.6} \neq 0$

<u>P-value Results:</u>
P1=0
There is a statistically significant difference between turnstile 1 throughput in Model 2 and 3.

P2=0.00000019
There is a statistically significant difference between turnstile 2 throughput in Model 2 and 3.

P3=0
There is a statistically significant difference between turnstile 3 throughput in Model 2 and 3.

P4=0.00000025
There is a statistically significant difference between turnstile 4 throughput in Model 2 and 3.

P5=0.0000089
There is a statistically significant difference between permanent worker time in system in Model 2 and 3.

P6=0
There is a statistically significant difference between temporary worker time in system in Model 2 and 3.

The alternative Simio model (model 3) is statistically significantly different from the original Simio model (model 2), which means model 3 has more throughput and less time in system of all turnstiles and types of workers.

Experiment 4:
Comparing three distributions for worker interarrival times to the system.

1) 100% Inter-arrival Time

2) 75% Inter-arrival Time
3) 90% Inter-arrival Time

1 vs. 2 Permanent Worker Time In System
Ho: μ_{2P}- $\mu_{1P=0}$
Ha: μ_{2P}- $\mu_{1P}\neq 0$

1 vs. 2 Temporary Worker Time In System
Ho: μ_{2T}- $\mu_{1T=0}$
Ha: μ_{2T}- $\mu_{1T}\neq 0$

1 vs. 3 Permanent Worker Time In System
Ho: μ_{3P}- $\mu_{1P=0}$
Ha: μ_{3P}- $\mu_{1P}\neq 0$

1 vs. 3 Temporary Worker Time In System
Ho: μ_{3T}- $\mu_{1T=0}$
Ha: μ_{3T}- $\mu_{1T}\neq 0$

2 vs. 3 Permanent Worker Time In System
Ho: μ_{3P}- $\mu_{2P=0}$
Ha: μ_{3P}- $\mu_{2P}\neq 0$

2 vs. 3 Temporary Worker Time In System
Ho: μ_{3T}- $\mu_{2T=0}$
Ha: μ_{3T}- $\mu_{2T}\neq 0$

<u>Confidence Interval Results:</u>
$0.01673 < \mu_{1P} < 0.02179$
$0.05210 < \mu_{2P} < 0.05925$
$0.02866 < \mu_{3P} < 0.03854$

$0.01408 < \mu_{1T} < 0.01739$
$0.04778 < \mu_{2T} < 0.05789$
$0.02608 < \mu_{3T} < 0.03422$

All the means are statistically significantly different because none of the confidence intervals overlap. A Table of the data used for the experiments can both be found in Appendix B: Simulation.

Summary of Results

Tests Performed	Test Statistic	df	P-value	Conclusion
Validated Turnstile 1 : Real Turnstile 1	2.181929971	6.040110803	0.0718698357	FTR Ho
Validated Turnstile 2 : Real Turnstile 2	1.697920842	6.032353405	0.1404421777	FTR Ho
Validated Turnstile 3 : Real Turnstile 3	1.699669026	6.034172679	0.1401036559	FTR Ho
Validated Turnstile 4 : Real Turnstile 4	0.3276716503	6.015382804	0.7542914984	FTR Ho
Validated Time in System : Real Time in System	0.3933003906	10.32485948	0.7023521838	FTR Ho
Validated Turnstile 1 : Alternate Turnstile 1	24.46489466	197.9509424	0	Rej Ho
Validated Turnstile 2 : Alternate Turnstile 2	5.414935503	184.9549862	0.0000001898102113	Rej Ho
Validated Turnstile 3 : Alternate Turnstile 3	8.349479417	194.9862617	0	Rej Ho
Validated Turnstile 4 : Alternate Turnstile 4	5.340364437	197.4936099	0.0000002543953739	Rej Ho
Validated Permanent Time in System : Alternate Permanent Time in System	4.562469596	197.3582366	0.000008879790397	Rej Ho
Validated Temporary Time in System : Alternate TemporaryTime in System	7.022109764	197.5820326	0	Rej Ho

Table 2 - Hypothesis Test Results

Hypothesis tests (see Table 2) in experiment 2 were used to compare the validated model results with the actual recorded and provided data. Each hypothesis test regarding a comparison between the validated Simio model and the real system data concluded a failure to reject the null hypothesis, meaning that there was no statistically significant difference between our validated model and the real system data. Therefore, it is believed that the Simio model accurately represents the behavior of the real DCPP system by a 95% confidence level.

Finally, hypothesis tests in experiment 3 were to compare the validated model results with the alternative model results to determine if there was a statistically significant change due to the proposed solution. In each case when the validated model results were compared against the alternative model results there was a statistically significant difference found. Then, by comparing the means between each circumstance, it was found that in each circumstance, the alternative model had a reduced time in system.

Evaluation and Recommendations

From the results of the experiments, the team came to several conclusions and recommendations:

- When comparing the original and alternative models in experiment 3, the time in system for both permanent and temporary outage workers were statistically significantly different with the alternative model. Both temporary and permanent workers had a time in system time of 116 seconds during the original model. The alternative model yielded 81 seconds time in system for temporary workers and 92 seconds time in system for permanent workers, which can be seen Appendix A: Raw Data. Therefore, the team strongly recommends that DCPP split up their search trains dependent on the type of worker with permanent workers occupying two full search trains and temporary workers occupying one full search train (one full search train consists of one metal detector, one x-ray, and two explosive detectors).
- In both models, the throughput was found to be statistically the same regardless of differing time in systems. The team believes that this could be due to a bottleneck inherent within the process

that sets a maximum throughput regardless of other variables. The time in system would change due to the formation of queues and throughput would remain constant.

- In the case of the bins, it was found that logically bins needed to be available at the same rate as workers coming into the process as demonstrated from experiment 1; when simulating, the team found this rate had to match exactly the rate of workers' interarrival times. In reality, these bins will need to be transferred from the back end of the security building to the front of the security building.
- In addition, experiment 4 demonstrated the significant impact varying worker arrival rates has on the time workers spend in the security process. Therefore, in order to maintain the equivalent flow of bins to workers, bin optimization is recommended to determine the number of bins needed and the optimal frequency to replenish the bins to the front of the building for various worker arrival rates.

An improvement that the team could have made would be to collect time data during non-outages hours to have a deeper understanding of how many permanent workers will be arriving during these peak times and how much faster are they than the temporary outage workers.

3. Recommendations and Improvements

The following subsections are finalized recommendations for the security team at DCPP. They were made based off either general observations of the security system, the simulation model experimental results, or a combination of both. The logic behind each of the recommendations will be specified.

3.1. Kanban Bin Replenishment System

A Kanban system was created to efficiently replenish bins. Kanban utilizes standardized cues and refined processes in order to reduce waste and maximize value. The team devised a Kanban system that can be implemented on the security floor in order to optimize bin replenishment. Four tasks must first be completed in order to implement the Kanban bin replenishment system.

3.1.1. Moving the Cabinet

The cabinet that currently sits against the right wall of the security building near the unused x-ray will have to be moved. During one of the visits, the security team mentioned that the cabinet was not being used. That space can be used to store bins before transporting them back to the front of the security building. Moving the cabinet will also allow security employees to walk freely to get from the front of the building to the back of the building, and vice versa.

3.1.2. Bin Optimization Using Self-Elevating Spring Lift Platforms

The use of self-elevating spring lift platforms, as shown in Figure 11, for the transportation and storage/retrieval of bins is highly recommended (“Self Elevating Spring Lift Platforms”). The platforms will be placed in front of the x-ray machines at the front of the building for workers to take bins from and the back end for workers to return the bins after use. It is recommended to put 45 bins in each elevator platform to keep the stack stable.

Figure 11 - Self-Elevating Spring Lift Platforms

These elevator plates have springs and allow bins to be placed inside. The more bins that are placed inside, the more the plate and its springs stretch downward to accommodate the accumulation of bins. This will help with any storage issues that may occur. As bins are taken out, the platform slowly rises and people do not have to bend down as far to get a bin. This is a more ergonomic alternative and makes it more efficient for workers to obtain a bin. These platforms also have wheels that make it easy for the employee to transport the bins back to the front of the building. The optimal quantity to purchase is 12 self-elevating spring platforms, which costs $526.40.

3.1.3. Additional Bin Purchase

DCPP currently has 200 bins available. However, 6 platforms need to be filled with 45 bins each for a total of 270, meaning that 70 more would have to be purchased in order to fill the necessary elevator platforms. The bins as shown in Figure 12 can be purchased from an online website called Globe Equipment Company (Rubbermaid 3349 Bus Box). The cost for 70 additional bins is $526.40.

Figure 12 - Storage Bins

F

3.1.4. Rope with Hooks to Transport Empty Elevator Platforms

Using ropes with hooks (B1AB180) shown in Figure 13 below will attach empty platforms together and can speed up the bin replenishment process. Two ropes would be sufficient for the bin employee to attach three platforms together. The cost of two ropes is $82.36.

Figure 13 - Rope with Hooks

The new alternative Visio layout in Figure 14 below shows the proposed Kanban replenishment system. There is enough space on the front end of the floor for 6 platforms, which can accommodate 270 bins. Due to limited spacing, only 3 platforms can fit at the back end to accumulate bins a total of 135 bins.

The platforms at the back will need to be brought to the front as soon as they are full so they do not take up limited space at the backend, which was a main reason behind creating the Kanban-like system. Although usage of visual signals is typical in Kanban systems, there are no visual signals used to notify the employee to move the platforms. The system is dependent on the bin employee to pay attention to the accumulating stacks of bins in the platforms at the back. Once one of the platforms is filled to approximately 45 bins, the replenishment process begins. An example of how the Kanban system works can visually be seen in the layout as indicated by the green and red lines. The specifics of the flow of the bins can be found in the SOP in Appendix F: Standard Operating Procedure.

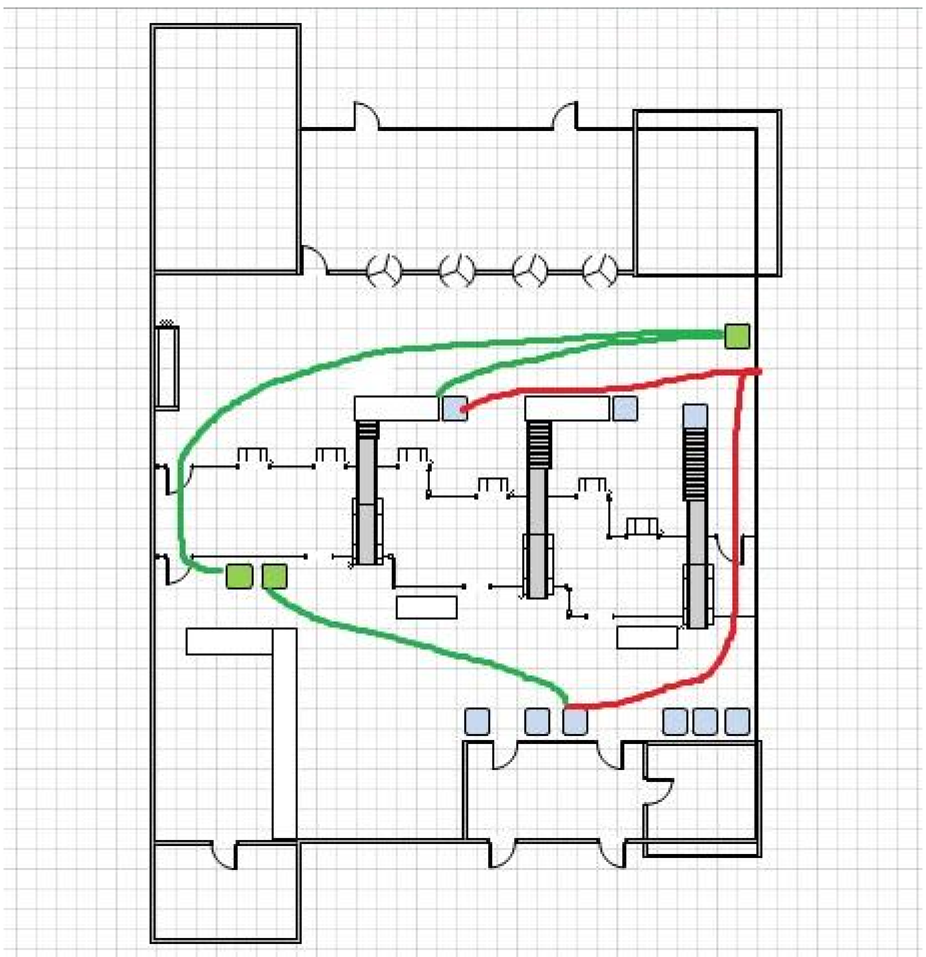

Figure 14 - Kanban Bin Replenishment System

The process of bringing platforms from the back to the front will therefore need to be repeated approximately every 10 minutes. Although the employee will have to repeat this process more frequently, it will be less strenuous on the bin employee because the elevator platforms are ergonomic and take away the task of him having to move the bins onto a fixture to transport them.

The benefit of using this system is that bins are replenished immediately and if the system is properly executed, there should always be enough bins to keep up with any interarrival rate and enough empty platforms to store used bins at all times. The rate of replenishment varies depending on the amount of people that enter. The process will need to be repeated more frequently if the rate of workers entering per hour is higher and less frequently if the rate of workers entering per hour is lower.

3.2. Having Separate Lines Dedicated to Permanent Workers or Temporary Workers

The alternative Simio model incorporated a third x-ray, which simulated a third available lane for workers to be process through. The model also specified lines for the two types of workers: 2 lanes for temporary workers and 1 for permanent workers.

One of the things that experiment 3 of the Simio model (which compared the original and alternative model) proved was that there was a significant difference in time in system for workers when these changes were implemented. In addition, according to the learning curve fitting (estimation) experiment done, it is estimated that the learning curve for the metal detector portion of the security process is 92.4%. This indicates that for every doubling of output, the cost of new output is 92.4% of prior output. This indicates that temporary workers are less familiar with the metal detector portion and will therefore take a longer time to be processed in comparison to permanent workers, especially for the first few days of the power outage. Therefore, based off experiment 3's results and the learning curve results, it is recommended to have separate lines dedicated to particular workers: 2 lines for temporary workers (from the security building entrance perspective, the left-most x-ray and the middle x-ray) and 1 line for permanent workers (the right-most x-ray).

Also, an additional x-ray will have a statistically significant increase on the amount of workers that will be processed through the security building and also decrease the time it takes for workers to be processed, as proved in Simio experiment 3. Therefore, it is also recommended that a third x-ray be utilized in order to improve the security process's efficiency. The two x-rays that are currently being used can be dedicated to temporary workers. For the third x-ray, DCPP can choose 1 of 2 options:

1. Utilize the older x-ray that is currently not being used
   a. It is understood that the older x-ray's imaging quality is lower and there are security risks the company runs if it chooses to use this x-ray. However, this x-ray can be used strictly for permanent workers since they have already had background check done on them and trust has been established since they come to work and go through the security process everyday.

2. Buy a new X-ray machine
   a. If the security team would rather have quality imaging for all three x-ray machines, the second option is to buy a new x-ray machine. The x-ray machine recommended is the Rapiscan 620 DV shown in Figure 15 because it is qualified by the TSA for checkpoint

screening (Rapiscan 620 DV). The cost of the x-ray is estimated to be approximately $55,000 after speaking to a technical salesman at the company.

Figure 15 - Potential New X-Ray Machine: Rapiscan 620 DV

If utilizing a third x-ray machine is agreed upon, another security employee will be needed to monitor the workers passing through. This will be an additional cost of $191,165 for the employee including benefits.

Figure 16 - FloStor Aluminum Roller Conveyor

As for the equipment needed after the x-ray, it is suggested to buy one Table and a longer roller conveyor to level out the Table with the other Tables at the temporary worker lanes. The roller recommended is from a company called FloStor and is shown in Figure 16 ("FloStor Online"). The roller is made of aluminum and is 5 feet long and 24 inches wide. The cost of this roller conveyor is $294.30.

An additional Table is the last piece of equipment needed to complete the new lane. The wooden Tables with the blue Table top that are currently used in DCPP's security building could not be found online, but the estimated cost for the smaller Table is approximately $250.

It is suggested that two conveyor belts parts that allow for turning to the right be purchased (see Figure 17 below) and used for the two newer x-rays at the temporary worker lanes. This addition is necessary in order to lengthen the amount of room for bins to flow the system at these two x-rays in order to increase capacity at both search trains associated with the newer x-rays. It may be required to purchase additional straight conveyor belt sections in order to achieve this lengthening of the x-ray conveyor belts. The turning conveyor belt may be purchased for roughly around $3,500. The additional straight conveyor belts prices will vary and depend upon the size required and how each x-ray part can connect to each other. It is recommended that these straight conveyor belt pieces allow the x-ray conveyor system to occupy as much length as is currently given for the rollers and Table in use in the present system. Two straight conveyor belt pieces the size of the current rollers at the newer x-rays is needed and one to two new rollers could be purchased to provide the same length as the Table currently in use.

Figure 17 - Conveyor Belt Piece That Allows for Turning to the Right

3.3. Implementing new Conveyor Belt System

The team considered implementing a conveyor belt system that would connect the x-ray conveyor belt to an additional conveyor belt (that would need to be purchased) which transports the bins through an opening above the turnstiles. This would allow the bins to move out of the congested back area and expedite the process of employees leaving the building.

Unfortunately, when this idea was proposed to the Diablo Canyon Security staff, it was met with much restraint. Further research into this idea suggested that it may be impractical to recommend such a conveyor belt system as there are security restrictions into how large an opening can be through the area above and beside the turnstiles; these restrictions, therefore, limit the capability of having the necessary space to allow for a conveyor belt to move the bins through to the other side.

In addition, this proposed conveyor belt system can pose a possible safety hazard. The conveyor belt would be placed over the employees traveling underneath. There is a slim possibility that the bins and the items inside the bin can fall off the conveyor belts and hurt the employees walking underneath them.

Due to the risky nature, the space restrictions and added cost it would take to implement, the team believes that this new conveyor belt system would not be feasible.

3.4. Cutting Employee Costs and Changes in Worker Responsibilities

3.4.1. Bin Employee

The employee that will be transporting the bins will be a lower-paid employee rather than an actual security officer. The rationale behind this recommendation was that since the person that moves the bins does not have to perform actual security procedures and is just in charge of

moving bins, the employee can just be a regular employee and not a trained security officer. The new employee would cost DCPP approximately $63,000, including benefits. This results in a savings of $128,165 per year.

3.4.2. Changes Affecting Explosive Detector Officers, Metal Detector Officers, Officer in Charge of Pat Downs/Extra Assistance and Officers Inside Isolated Room

The explosive detector officers will now have two responsibilities: they will be in charge of monitoring both the workers going through the metal detector and workers going through the explosive detector. They would have to stand in the area between the metal detector and explosive detector in order to monitor both. The officer can watch the light that clears the worker since there is a set of lights on both sides of the explosive detector machine. The lights on the metal detector and noise indicators on the explosive detector make it easier for the officer multi-task and to notice a warning. The 3 security officers at each of the metal detectors will no longer be needed.

The current process allocates 1 security officer at each x-ray, 1 security officer per two explosive detectors, 1 security officer per metal detector, 1 security officer for bins, 1 security officer for pat downs and extra assistance for a total of 11 officers. The recommendation is a reduction of 3 metal detector security officers and the addition of 1 security officer at the third x-ray machine (as mentioned in the previously), giving a new total of 9 security officers needed in the security building. The reduction of 3 security officers would result in a savings of $573,495. There still lies the issue of the explosive detectors going off. The explosive detectors go off on the side closer to the turnstile exits. The explosive detector officers will not be on that side of explosive detector to turn it off since their responsibilities have changed and they are also monitoring the metal detectors from a different area where it is not accessible for them to turn it off. The solution is that the extra officer in charge of pat downs will have an added responsibility of turning off the explosive detectors that go off. In addition, the officers inside the isolated room who are monitoring the process will be an extra set of eyes that will notify the officer if he forgets to turn off one of the explosive detectors.

3.5 Noise Control

As per a decibel measurement done during a visit to the site Appendix E: Noise Control - Decibels, the decibel levels in the front and back areas can reach up to 91 and 105 decibels respectively. These measurements are at a low traffic time, which means a high traffic time will have higher decibel levels. The measured decibel levels are comparable to freeway traffic and therefore are not conductive for easy communication between security officers. To reduce the decibel levels and allow for better communication between security officers acoustical absorbing material is suggested to be put on the ceiling of the security building. The two packs of panels Figure 18, four cans of spray adhesive Figure 19, and eight containers of PGPSA adhesive Figure 20 necessary to cover the ceiling will cost $778 total.

Figure 18 - Panels

Figure 19 - Spray Adhesive

Figure 20 - PGPSA Adhesive

3.5.1. Installation

The panels will be installed on the ceiling of the security building and the instructions on how best to install these panels are given in Figures 21 and 22.

Overhead Ceiling Installation – Adhesive

When installing Echo Eliminator to a ceiling it is recommended to use AGS12 Spray Adhesive in conjunction with PSA29 adhesive or PGPSA Adhesive.

1. Make sure that the surface to which the panels are being applied to is clean and free from dust in order to ensure a good bonding contact.
2. Using PSA29 or PGPSA Adhesive, cut the nozzle of the cartridge for a ¼" bead of adhesive.
3. Apply adhesive from corner to corner on the panel in an X zig-zag pattern, then a perimeter ¼" bead, ¾" from edges.
4. Apply a 6" circle of spray-on AGS12 Adhesive in each of the quadrants as shown below in the diagram.
5. Apply pressure to both the bead adhesive and the sprayed areas. The spray on adhesive will keep the panel in place while the bead of PSA29 or PGPSA Adhesive cures to provide a long lasting, permanent bond.
6. Before attaching the panel to the ceiling, make an X shape on the ceiling with the PSA29 or PGPSA Adhesive. This ensures a permanent bond. *Failure to add PSA29 or PGPSA Adhesive to the ceiling before attaching to the panel can result in the panels detaching from the ceiling.*

Figure 21 - Instructions for Panel Installation

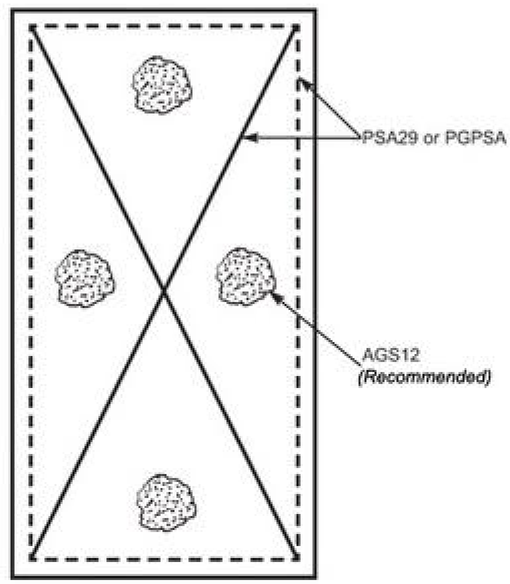

Figure 22 - Diagram for Panel Installation

3.6 Instructional Video

An instructional video was created to guide workers through the security process. This video will be shown at their training session in hopes of getting them acquainted with the process so that they will be more efficient when they arrive at the security building.

3.7 Standard Operating Procedure

This standard operating procedure (SOP) document created ties in all the recommendations and improvements made and explains how the recommendations will change the operations of the security building. It did not go into detail as to what the security officers learned in training. Any additional recommended changes to the duties of an officer were mentioned in the SOP. Otherwise, it is assumed that officers understand the responsibilities they have. In addition, a worker SOP was also created to walk through the steps worker should take to optimize their processing time. Officers can refer to this and make suggestions to the workers coming into the building on how to improve their processing methods. The standard operating procedure can be found in Appendix F: Standard Operating Procedure.

3.8 Signage

Signs were created based on the process described in the standard operating procedure to guide workers through the process and notify workers as to what is and is not allowed to pass through on their person. These signs were created to be easier to read and understand if replacing a current sign. A reversible open/closed sign Figure 23 on page 39 replaces a one sided closed lane sign for a better indication of whether a metal detector is open for use or closed for maintenance, the website that should be used to purchase these signs can be found in the work cited. The numbers on the explosive detector help the worker determine which of the stop/go signs to pay attention to when using the explosive detector, 1 for when to enter and 2 for when to exit. These signs should be a laminated numeral 1 and 2 similar to the one shown in Figure 24 on page 39 and should be attached to the indicated parts of the explosive detector, if the inside of the explosive detector cannot be changed the second laminated number may be attached to the outside of the explosive detector so long as the number can be seen from the inside of the explosive detector. Signs like those in Figure 25 and Figure 26 on page 39 have been changed to decrease the wordiness of the sign and focus on the important information that has to be received by the workers.

Figure 23 - Open/Closed Signs Used at Metal Detectors

Figure 25 - Improved Item Removal Sign

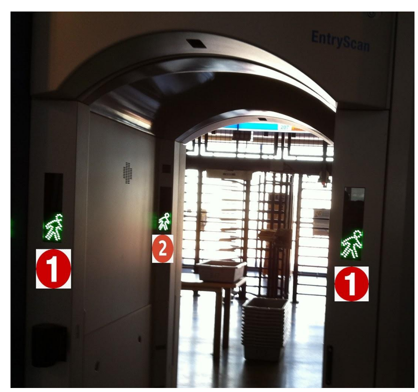

Figure 24 - Numerical Signs at Explosive Detectors

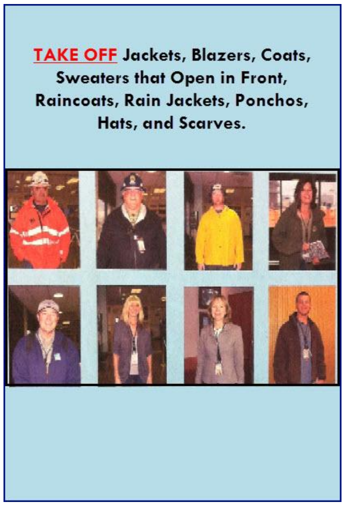

Figure 26 - Improved Search Train Sign

4. Financial Analysis

The Table 3 below is the cost breakdown of the recommendations made. All costs listed are one-time costs, except for the third x-ray security officer who is paid annually. The security officer cost was calculated by adding the average salary of $131,546.43 plus benefits. Benefits are valued at 40% of the salary. The total cost of all recommendations is $268,407.12.

COSTS	Quantity	Price Per unit	Price
Bins	70	$7.52	-$526.40
Self-Elevating Spring Lift Platforms	12	$56.70	-$680.40
X-Ray	1	$55,000.00	-$55,000.00
X-Ray Officer	1	$184,165.00	-$184,165.00
Conveyor Belt (Straight)	2	$8,000.00	-$16,000.00
Conveyor Belt (Curved)	2	$5,000.00	-$10,000.00
Roller	3	$294.30	-$882.90
Table	1	$250.00	-$250.00
Rope	2	$41.18	-$82.36
Noise Absorbing Panels and Adhesive	1	$778.00	-$778.00
Signs	3	$14.02	-$42.06
TOTAL COST			-$268,407.12

Table 3 - Cost Breakdown of Recommendations

The next Table 4 is the cost savings breakdown of recommendations made. All costs savings are related to worker costs and are therefore annual savings. The amount saved per worker for security officers was determined by taking the average salary of a DCCP employee, $131,546.43, and adding benefits cost (valued at 40% of the salary) to the worker salary.

Taking the cost of an officer and subtracting the estimated cost of a lower-paid employee calculated the amount saved for the employee dedicated to bins. The salary of the lower-paid worker is estimated to be $45,000. The 40% benefits cost would be $18,000. The total cost of the lower-paid worker would be $63,000. This value was subtracted from the amount DCPP would have spent on a regular security officer, $191,165. This yields the value of $128,165 saved as seen in the Table. The amount saved per year on employee costs would be $701,660 if the necessary changes are made.

SAVINGS	Quantity	Amount Saved Per Worker	Amount Saved
Security Officers	3	$191,165.00	$573,495.00
Employee Dedicated to Bins	1	$128,165.00	$128,165.00
TOTAL SAVINGS			$701,660.00

Table 4 - Savings Breakdown of Recommendations

The savings heavily outweigh the costs and is estimated to be approximately $433,252.88 if the security team decides to purchase a new x-ray machine. If the team decides to use the existing third x-ray machine, the net savings will be even higher at $488,252.88, as seen in Table 5.

Net Savings w/ New X-Ray Machine	$433,252.88
Net Savings using Old X-Ray Machine	$488,252.88

Table 5 - Comparison of Savings: Purchasing New X-Ray Machine vs. Using Old X-Ray Machine

The time saved if recommendations were implemented was also calculated and the breakdown can be seen in the Table 6 below. Assuming that there are 2 outages per year, the total time saved per year is approximately 491 hours.

	Permanent Worker	Temporary Worker
Time Savings (sec)	24	35.0
Time Savings in One Outage Period of 4 Weeks (min)	10	14.6
Time Savings for 600 Workers in One Outage Period (hours)	100	145.8
TOTAL TIME SAVED PER YEAR (hours)		491.7

Table 6 - Time Savings Assuming 2 Outages Per Year

Since time is money, the team wanted to take the time saved at the security process during a power outage and convert it to a monetary value. It was assumed that temporary workers make the same salary as permanent workers. By using the assumed average annual salary of $131,546.43 and

assuming that DCPP employees work 8 hours a day, 5 days a week, the hourly salary was calculated to be $56.67 as shown in Table 7 below.

Hours worked per year	2400
Yearly Salary	$131,546.43
Assumed hourly wage	$54.81

Table 7 - Estimation of DCPP Workers' Hourly Wage

Taking this value and multiplying it by the hours saved per year yields a savings of $26,948.75. The recommendations have the power to save DCPP employees precious time and DCPP employers a significant amount of money.

VI. Conclusions

DCPP built the new security building and focused attention on its aesthetics rather than considering the its functionality and how it will affect the security process's efficiency as the top priority. The building was built with a limited floor space, which causes people to process at a slow rate and creates a large queue at the front and back end of the building. The plant faces power outages, which doubles the number of employees trying to process through the security process to a maximum 1,400 people. The new outage workers are unfamiliar with the process. Some of the signs displayed in the building are not as effective as they can be. The large volume of people makes it difficult for officers to communicate. The power outages are a hectic time that can occur twice a year and can last 4 weeks.

The DMAIC process was used to guide the team through the steps they would take in order to get effective solutions. To evaluate the efficiency of the new Security building's layout at the Diablo Canyon Power Plant, the team started with visits to the DCPP security building to have meetings with the stakeholders to talk about the improvements they wanted and to analyze the security process in person.

After the team's met with the stakeholders, visited the facilities, and completed background research and literature reviews, the team came up with specific objectives for this project. They were to redesign the security floor layout to make it more efficient, optimize the number and process of replenishing bins, standardize the security officers procedures, create effective signage and instructional video, reduce the number of officers needed for the process, reduce the noise in the building during outages, decrease the time it takes for workers to be processed and determine the learning curve of new workers. The team made visits to the plant once again to collect relevant time study data that accurately represents the system and can be used in experiments.

The team decided to run experiments to determine the learning curve of the new workers and test the initial recommendations they had using simulation software. Several important results were gained using these two tools and recommendations were based off these results. The following are the most important conclusions made from this senior project:

- New temporary workers have a learning curve of 92.3%. Having separate lanes for the two types of workers decreases the time workers spend in the security process
- Utilizing the third x-ray for the permanent worker lane will significantly increase the number of people that are processed and decrease the time workers spend in the process. Although the low imaging quality on this x-ray appears to be a security risk, permanent workers should be trusted because they have extensive background checks done on them and they go through the security process everyday
- It is important for bins to keep up with the arrival rate of workers in order to decrease the time workers spend in the process
- Bins can be placed in self-elevating spring lift platforms. These platforms provide an ergonomic alternative to the current way of replenishing bins and put less strain on both the employee in charge of bins and workers using the bins
- The officers at the metal detector are not needed. The explosive detector officer can take over the responsibilities of the metal detector officer in order to reduce worker costs
- Approximately 490 hours of time and $26,947 in worker costs can be saved at the security process if these recommendations are implemented. Workers can get to their jobs earlier and utilize this time more productively

The team created a number of deliverables based off these results: Visio facility redesign, bin optimization policy, SOP, Simio models (representing the current system and an alternative system), instructional video, effective signage and a financial report that justifies the costs of the recommendations. The team was able to devise solutions that would decrease wasted time at the security process, standardize the responsibilities of the security building employees, devise a bin optimization plan, reduce the noise in the building, create aids that help new workers understand the process (video and signage) and decreased the number of employees needed in the security building.

The team learned how to apply various industrial engineering concepts learned in the classroom to a real life industry scenario. These concepts include simulation, queuing theory, statistics, ergonomics engineering economics, and process improvement techniques such as facility redesign, Kanban, time studies and learning curve. The team faced the challenge of finishing a senior project in one quarter. The time constraint made the team learn the importance of micromanaging, creating a thorough project timeline, making significant progress on the project weekly, having weekly meetings and establishing a clear line of communication between team members. If there was time, the team would like to come up with more recommendations and test them by running experiments on Simio to see its effectiveness. The team would also like to personally physically test the ergonomics and effectiveness of the recommendations made. The team recommends that DCPP's security team implements the recommendations made immediately in time for the next power outage in October.

Work Cited

"Acoustical Panel Spray Adhesive." *Acoustical Panel Spray Adhesive*. Web. 09 July 2014. <http://www.asistorefront.com/p-210-panel-spray-adhesive-wide-web.aspx>. AGS12 Spray Adhesive.

"ASI Store Front - Greenchoice™ Heavy Duty Adhesive." *Greenchoice™ Heavy Duty Adhesive*. Web. 09 July 2014. <http://www.asistorefront.com/p-330-greenchoice-heavy-duty-adhesive.aspx>. PGPSA Adhesive.

"B1AB180 1/2" LANYARD SMOOTH ROPE AdjusTable, Double-Braid, 3' to 6'" *: Amazon.com: Industrial & Scientific*. Amazon, n.d. Web. 08 July 2014. <http://www.amazon.com/dp/B00K24IOFW/ref%3Dasc_df_B00K24IOFW3202840?tag=thefind0272962-20&creative=395261&creativeASIN=B00K24IOFW&linkCode=asn>.

Bonfanti, Angelo. *Towards an approach to signage management quality (SMQ)*. Verona, Italy: University of Verona, 2012. 312-19. Web. 9 Apr. 2014.

"Cotton Acoustical Wall Panels." *Cotton Acoustical Wall Panels*. Web. 09 July 2014. <http://www.asistorefront.com/p-247-echo-eliminator.aspx>. Noise absorbing panels.

Dorton, Stephen L., and Dahai Liu. *Analysis of Airport Security Screening Checkpoints Using Discrete Event Simulation*. Daytona Beach, Florida: Embry-Riddle Aeronautical University, 2012. Web. 9 Apr. 2014.

"ECHO ELIMINATOR™." *Acoustical Surfaces, Inc.* Web. 09 July 2014. <http://www.acousticalsurfaces.com/echo_eliminator/wall_panel.htm?d=0>. Description, tests, and installation information.

"Flostor Online: SSR / SAR." *Flostor Online: SSR / SAR*. FloStor. Web. 08 July 2014. <http://www.flostoronline.com/buycon/category/20.40.11.0.html>.

Landauer, Edwin G., and Linda C. Becker. *Reducing Waiting Time at Security Checkpoints*. N.p.: n.p., 1989. 57-65. Web. 9 Apr. 2014.

Marin, Clara V., Colin G. Drury, Rajan Batta, and Li Lin. *Human Factors Contributes to Queuing Theory: Parkinson's Law and Security Screening*. New York: University at Buffalo, 2007. 602-06. Web. 9 Apr. 2014.

Melouk, Sharif H. *Analysis of the Passenger Security Screening Process using Simulation Optimization*. Miami, FL: The Air Force Institute of Technology, 2007. 209-14. Web. 9 Apr. 2014.

Newman, Andrew J. *Uncovering Dimensionality in the Servicescape: Towards Legibility*. Manchester: University of Manchester, 2007. 15-28. Web. 9 Apr. 2014.

Omni Power Belt Curve Conveyors. Advertisement. *globalindustrial.com*. Systemax, 2011. Web. 9 June 2014. <https://www.globalindustrial.com/g/material-handling/conveyors/power-belt/power-belt-curve-conveyors>.

Rapiscan 620DV. Rapiscan Systems. Web. 08 July 2014. <http://www.rapiscansystems.com/en/products/item/productsrapiscan_620dv>.

"Rubbermaid 3349 Bus Box / Utility Box Grey 15" X 20" X 5"" *Rubbermaid 3349 Bus Box / Utility Box Grey 15" X 20" X 5"* Globe Equipment Company. Web. 08 July 2014. <http://www.globeequipment.com/Disposals-and-Janitorial/Bussing-and-Warewashing-Supplies/Bus-Boxes/3349>.

"SELF ELEVATING SPRING LIFT PLATFORMS." *Canvas Trucks, Self Elevating Spring Lift Platforms*. L.K. Goodwin Co. Web. 08 July 2014. <http://www.lkgoodwin.com/more_info/self_elevating_spring_lift_platforms/self_elevating_spring_lift_platforms.shtml>.

Seo, Sangwon, Sanggyun Choi, and Chulung Lee. *Security Manpower Scheduling for Smart Airports*. Seoul: Korea University, 2012. 519-27. Web. 9 Apr. 2014.

Tuzkaya, Gülfem, Bahadır Gülsün, Umut R. Tuzkaya, Semih Onut, and Ender Bildik. *A comparative analysis of meta-heuristic approaches for facility layout design problem: a case study for an elevator manufacturer*. N.p.: Springer Science Business Media, 2011. 357-72. Web. 9 Apr. 2014.

Tyson, Jeff, and Ed Grabianowski. "How Airport Security Works" 20 June 2001. HowStuffWorks.com. <http://science.howstuffworks.com/transport/flight/modern/airport security.htm> 09 July 2014.

"U.S. Stamp & Sign Century Series Open /Closed Sign." *U.S. Stamp & Sign Century Series Open...* Web. 09 July 2014. <http://www.officesupply.com/office-supplies/boards-easels/boards/sign-message-boards/stamp-sign-century-series-open-closed-sign/p46889.html?device=c&network=g&matchtype=&ref=pla&cid=ad-pla-non-brand+&gclid=CjwKEAjwre6dBRC94d-Gma7g3wcSJACNatZeV6cqnUChiuXymjYwpch6-3YKf-Lf3bakstYSAd-HWhoCULzw_wcB>.

Appendix A: Raw Data

Metal detector to bomb detector	Duration in bomb detector
00:02.58	00:16.43
00:02.41	00:18.59
00:01.68	00:20.06
00:08.38	00:18.73
00:04.21	00:25.13
00:02.20	00:20.01
00:01.66	00:29.56
00:19.60	00:30.33
00:01.71	00:28.98
00:19.58	00:30.23

Date	Turnstile	0500-0700		Date	Turnstile	0500-0700
2/4/2014 Tues	201	100		2/10/14 Mon	201	98
	202	298			202	291
	203	302			203	296
	204	323			204	296
	Total	1023			Total	981
2/5/2014 Weds	201	128		2/11/14 Tue	201	123
	202	284			202	315
	203	296			203	273
	204	346			204	323
	Total	1054			Total	1034
2/6/2014 Thu	201	110		2/12/14 Wed	201	284
	202	236			202	298
	203	293			203	278
	204	345			204	352
	Total	984			Total	1212
2/7/14 Fri	201	125				
	202	118				
	203	115				
	204	58				
	Total	416				

Appendix B: Simulation

goodness of fit

data points	20
estimates	maximum likelihood estimates
accuracy of fit	3.e-004
level of significance	5.e-002

summary

distribution	Chi Squared
Binomial	no fit
Exponential	38.8 [3]
Normal	13.2 [3]
Poisson	5.77 [2]
Triangular	7.6 [3]
Uniform	19.6 [3]

Poisson

lamda =	283.9	
Chi Squared		
total classes		5
interval type		equal probable
net bins		3
chi**2		5.77
degrees of freedom		2
alpha		5.e-002
chi**2[2,5.e-002]		5.99
p-value		5.57e-002
result		DO NOT REJECT

Auto::Fit of Distributions

distribution	rank	acceptance
Lognormal[12.1, 2.34, 0.502]	87.7	do not reject
Exponential[16.4, 7.37]	55.4	do not reject
Normal[23.8, 5.3]	54.4	do not reject
Uniform[16.4, 30.3]	20.3	do not reject
Triangular[16.4, 35.6, 16.4]	17.4	do not reject

	For Verified to Alternate:						
	z = [(x-bar)1 - (x-bar)2 - 0] / sqrt(((s1^2)/n1) + ((s2^2)/n2))						
hw=s*z/sqrt(n)	standard deviation = hw*10/1.96						
	For Verified to Real:						
	t = [(x-bar)1 - (x-bar)2 - 0] / sqrt(((s1^2)/n1) + ((s2^2)/n2))						
	df = [((s1^2)/n1)+((s2^2)/n2)]^2 / [((1/n1-1)*((s1^2)/n1)^2)+((1/n2-1)*((s2^2)/n2)^2)]						
	Turnstile#1	**Turnstile#2**	**Turnstile#3**	**Turnstile#4**	**Permanent**	**Temporary**	
Verified	192	307	308	305	116	116	
n	100	100	100	100	100	100	average s
s	14.27346939	13.42908163	13.47244898	14.19132653	36.11989796	36.04540816	36.08265306
Alternate	241	295	291	294	92	81	
n	100	100	100	100	100	100	
s	14.0505102	17.62857143	15.26581633	14.92908163	38.24183673	34.42397959	
Real	138	263	265	292	121.5		
n	7	7	7	7	10		
s	65.37	68.47	66.84	104.9	42.72457		

Appendix C: Queuing Theory

Queuing Theory Equations

$$p(0) = \frac{1}{\frac{(c\rho)^c}{c!\,(1-\rho)} + \sum_{n=0}^{c-1} \frac{(c\rho)^n}{n!}}$$

$$L_q = \frac{\rho(c\rho)^c * p(0)}{c!\,(1-\rho)^2}$$

$$L = \lambda W$$

$$L_q = \lambda W_q$$

$$W = W_q + \frac{1}{\mu}$$

Appendix D: Learning Curve Fitting (Estimated) Experiment

Subject 1	Bag #	Number of times through Metal Detector	Time (sec)
1	12	0	19
2	7	0	7
3	3	0	9
4	6	0	7
5	9	0	8
6	10	0	12
7	8	0	9
8	1	0	14
9	2	0	10
10	5	1	23

	Bag 1	Bag 2	Bag 3	Bag 4	Bag 5	Bag 6	*indicates item that will set off metal detector
1	coins	metal mustang	lighter	lighter	earrings	earrings	
2	scissors	key chain	phone car charger	coins	earphones	metal lock	
3	batteries	coupon book	bouncy ball	pen	wallet	bouncy ball	
4	mechanical pencil	playing cards	coins	bouncy ball	bouncy ball	coins	
5	glue stick	highlighter	tissues	tissues	tissues	eraser	
6	book	sunglasses	bouncy ball	box	gloves	tape	
7	bread eraser	coins	gloves	notecards	eraser	post it notes	
Total metal items	4	3	3	3	3	3	
	Bag 7	Bag 8	Bag 9	Bag 10	Bag 11	Bag 12	
1	earrings	earrings	tiger broach	metal bead brace	metal hair tie	metal hair clip	
2	sewing needles	mechanical pencil	safety pins	post it notes	metal ruler	metal hair tie	
3	post it notes	button	coins	metal pen	protractor	pride ribbon	
4	gluestick	post it notes	post it notes	triangular ruler	coins	post it notes	
5	coins	white out	ruler	metal lock	post it notes	labels	
6	eraser	clear tape	triangular ruler	staple remover	cell phone	coins	
7	white out	ruler	post it notes	glasses case	notepad	notepad	
Total	3	3	3	4	4	4	

Experience Curve Equation:

$$Z_u = Ku^n$$

u = the output unit number

Z_u = # resource units to produce output unit u

K = # resource units to produce 1st output unit

s = learning-curve slope parameter (decimal)

n = log s / log 2

Appendix E: Noise Control – Decibels

	dB for Front Area	dB for Back Area
Max	91	105
		105
		105
Average	69/70	78
		82
		84
		87
Peak	75/81	80
		105
		95
		95

Appendix F. Standard Operating Procedure

Table of Contents

I. Introduction

Important Note

This standard operating procedure (SOP) document aims to explain how the recommendations will change the operations of the security building. It will not go into detail as to what the security officers learned in training. Any additional recommendation changes to the duties of an officer will be mentioned in the SOP. Otherwise, it is assumed that officers understand the responsibilities they have.

The Worker SOP is intended to walk through the steps worker should take to optimize their processing time. Officers can refer to this and make suggestions to the workers coming into the building on how to improve their processing methods.

Policy

The mission this SOP is trying to accomplish is to improve the efficiency of the officers that run the security process and to try to accommodate as many workers as possible through PG&E's security process while ensuring that thorough security checks are performed during the rush hours of 5 a.m. - 7 a.m. of a power outage period.

Purpose

The rationale behind this procedure is to make adjustments and recommendations to improve the security process so that both permanent workers and temporary workers can get to their jobs in a timely manner while still maintaining a high standard for security check. The suggestions will be mapped out in the standard operating procedure (SOP) so it is a standardized process that can easily be incorporated into the security process.

Scope

The team aims to use the environment available and make cost-effective adjustments that will make a large impact on the security process. The areas and individuals of the company that will be affected by this standardized process will be the security floor process, security officers that work in the building, permanent PG&E workers and temporary outage workers.

Responsibilities:

- The security officers need to have a thorough understanding of the SOP. The officers will have to help the workers to understand and make sure they abide by this new standard operating procedure in order to maximize its effects. The officers will guide the workers through the new procedure and address any issues or questions they may have.
- The permanent workers and temporary workers will have to comply with the SOP. There may be resistance the first few days but cooperation from the permanent workers will be helpful in ensuring a smooth transition to the new procedure.

II. Assumptions

- The specifics in regards to additional equipment that needs to be purchased, changes in the layout and changes in officer responsibilities can be found in the senior project report, Chapter IV: Results/Discussion, Section 3: Recommendations. It is recommended that the security eam read this portion of the report in order to understand the SOP.

Kanban Replenishment System

A Kanban system was created to efficiently replenish bins. The following bullet points map out the logic and reasoning behind the Kanban replenishment system so that the security team can better execute the system. The actual step-by-step instructions of carrying about the replenishment system are in Chapter III of this SOP. The Visio layout, Figure 1 in 2.1 Bin Employee's procedure, shows the flow of bins within the system.

- There are a total of 12 platforms used in this Kanban system: 6 in the front to pull bins from (4-5 available for workers to pull bins from and 1-2 used as safety stock), 2 empty platforms in the waiting area closest to the front desk waiting to be pulled to the back end when needed to replace a filled platform, 3 in the back end that are empty to collect used bins (1 at each conveyor belt) and 1 against the right wall which is used to replace a filled platform at any of the conveyor belts.
- There is enough space on the floor for 6 platforms, which can accommodate 270 bins. As previously mentioned, 780 bins will be needed per hour. However, only 3 platforms can fit at the back end to accumulate bins a total of 135 bins. This process of bringing platforms from the back to the front will need to be repeated approximately every 10 minutes. However, it will be less strenuous on the bin employee because the platforms are ergonomic and take away the task of him having to move the bins onto a fixture to transport them. It varies depending on the amount of people that enter. The process will need to be repeated more frequently if the rate of workers entering per hour is higher and less frequently if the rate of workers entering per hour is lower.
- The 6 blue elevator platforms in the front end of the building (which is the bottom half of the layout shown) contain 45 bins each, a total of 270 bins. 4-5 are available for workers to pull bins from and 1-2 are used as safety stock. Workers should be pulling from the 4-5 platforms in the front and the extra one(s) should be put to the side. The extra platform(s) is meant for emergencies where bins in the back are not brought back to the front in time. It is important that workers pull from just 4 or 5 platforms so that they are used at a steady rate that is consistent with the 3 platforms that are being filled with used bins in the back.
- The two green elevator platforms on the left are in the waiting area and are empty. They are waiting to fill the next designated spot, which is the green elevator platform against the right side of building. Only one empty platform should be against the right side of the building.
- The 3 blue elevator platforms at the end of each conveyor belt are where workers return bins.
- Using two ropes will attach three empty platforms together and can speed up the bin replenishment process to the waiting area.

An example of how the Kanban system works can be seen in the layout below as indicated by the green and red lines and will be explained step-by-step in section 2.1, the bin employee's procedure.

III. Standard Operating Procedure

1. PLAN (for security team)

1.1 Preparation before the days of the outage

- Have meeting with security officers and go over the SOP so that everyone has a thorough understanding of the process.
- Hold training meeting and show instructional video a few days prior to the outage to both permanent and temporary workers so that they have an understanding of what the new security process will entail.
- If using the older x-ray option is chosen, prepare and do a test-run several days prior to the outage period on the x-ray on the furthest right (that has been out of service).

1.2 Setting up on the days of the outage

- Set up Table for platforms with bins according to the Visio layout if it has not been done so already
- Display large signs that indicate where permanent workers will line up and where temporary workers will line up.
- All security officers will go to their designated areas to complete their duties.

2. PROCEDURE

2.1 All Security Officers

- All officers should be at their designated areas to complete their duties.

2.1 Bin Employee

IMPORTANT NOTES

- *In the diagram below, green platforms indicate that they are empty and blue platforms are filled with bins.*
- *For the example shown in the diagram, the lanes and its equipment will be referred to as number 1 through 3 from left to right.*
- *For simplicity, the path of replenishment is demonstrated for returning just one platform.*
    - *The particular process of bringing three filled platforms from the back to the front can be repeated for up to three times for three filled platforms. Full platforms from the back that are to be moved to the front are recommended to be pulled to the front either one at a time or two at a time. Any more than that at one time can become difficult to do, but it is up to the employee's discretion.*

PROCEDURE

- The bin employee is responsible for staying in the back end of the building and watch for the platforms to be filled.
- As soon as one of the platforms is full, the process begins.
- In the diagram, the blue elevator platform in lane 1 is filled to capacity after workers have returned approximately 45 bins. The employee will push the platform so it follows the red path to the right side of the building where it will wait to be moved back to the front of the building.
    - The employee will then take the green elevator platform against the right wall of the building and move it to take replace the blue filled platform at the first lane so that workers can return used bins.
    - The employee will take one of the green elevator platforms in the waiting area (on the left side near the front desk) and it will be used to replace the empty spot of the green elevator platform against the right wall.
- The bin employee will take the red filled platform from lane 1 that is now against the wall and replenish it back to the front.
    - At this point, one or more of the platforms in the front should be empty, or close to being empty. The filled platform will replace the empty platform in the front.
    - The employee will take the empty platform(s) and move it to the waiting area where the two green platforms were placed on the left side of the layout.
        - This process is repeated and adjusted as necessary. For instance, if there are three platforms that are empty in the front and can be moved to the waiting area, ropes with hooks on each end can attach empty platforms together. Using two ropes will attach three platforms together and can speed up the bin replenishment process to the waiting area. Two ropes would be sufficient for the bin employee to attach three platforms together.

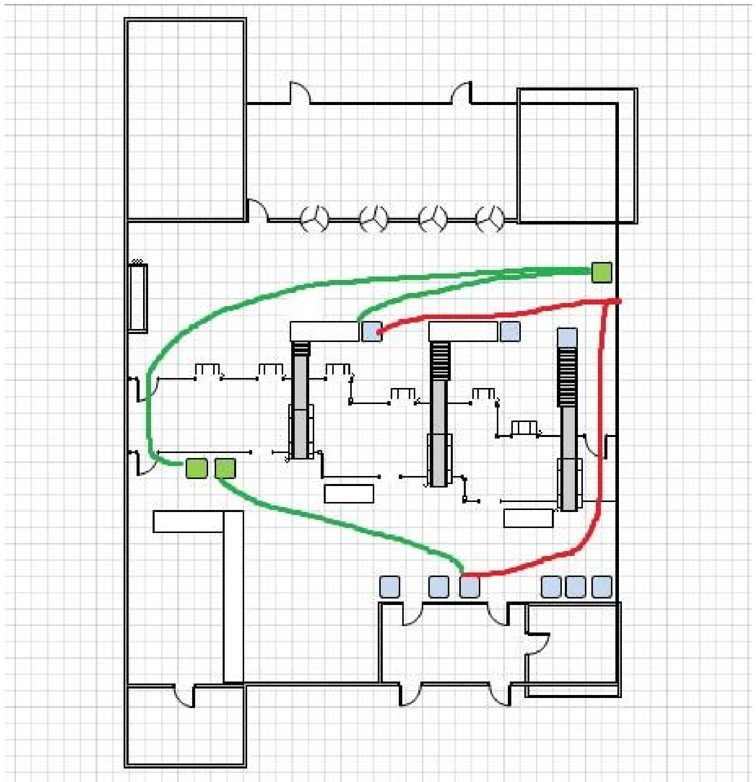
Figure 1 – Visio Layout

- Refer to the Table below for the approximate times to the platforms will be needed to be brought to the front. This Table only displays approximate times and should only be used as a guide. The Kanban replenishment system should start whenever the bin employee sees the one of the platforms fill up to about 45 bins.

Workers Per Hour	Number of Bins Needed	Replenishment Frequency Per Hour	Time of Replenishment (mins)	Day Type
350	455	3.37	17.80	Regular
400	520	3.85	15.58	
450	585	4.33	13.85	Outage
500	650	4.81	12.46	
550	715	5.30	11.33	
600	780	5.78	10.38	
650	845	6.26	9.59	
700	910	6.74	8.90	

Table 1 – Replenishment Rate

2.2 Explosive Detector Officers

- The explosive detector officers will now stand in the area between the metal detector and explosive detector. The officer will monitor and direct the workers through both the metal detector and the explosive detector.

2.3 Extra Security Officer

- The security officer for pat downs and extra assistance is in charge of turning off the explosive detectors when they go off and doing extra pat downs.

2.4 Officers in the Isolated Room

- An additional responsibility that the officers in the isolated room will have is to notify the extra security officer if an explosive detector has gone off and which one has gone off.

2.5 Workers

PROCEDURE

- Have worker badge out to speed up the time taken at the exit turnstile.
- Get into the respective lines for permanent workers and temporary workers.
- Grab a bin and place all items that would set off the metal detector in the bin (metal items, jacket, hat, steel-toed boots). More information on what items are permitted and not permitted is posted on the large blue poster.
- Place bin with the longest side of the bin faced forward onto conveyor belt in front of x-ray machine.
- Wait for officer's signal to walk through the metal detector
    - If the metal detector goes off, go back to the x-ray machine and take out items that you may have missed that set off the metal detector
- Proceed past the metal detector once you have rid of all metal items and the detector does not go off
- Wait for security officer to give signal to proceed through the explosive detector
- Wait in explosive detector for 20 seconds
- Wait for security officer to give signal to leave explosive detector
- Obtain your belongings from the Table that follows the conveyor belt of the respective x-ray you put your bin in. Leave the empty bin in the self-elevating spring lift platforms.
- Wait in line for any turnstile you wish to wait for and have your badge out and be prepared to scan it at the turnstile.
- Scan your badge at the turnstile and place your hand on the fingerprint identification machine. Follow the directions on the machine as displayed.
- Proceed through the turnstile and exit the security building.