PolyGAIT/DCPP Inventory Control System

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Contents

Table of Figures

Executive Summary

This report discusses a proposed system to improve upon inventory management issues experienced in the M&TE Tool room for the PG&E Diablo Canyon Power plant. Effective inventory tracking and management is an important characteristic of any organization handling physical assets, and without the proper system in place, companies may lose expensive items and waste time by not having equipment available when needed. The tool room is experiencing inventory shrinkage of M&TE equipment nearing $100,000 per year largely because of an inefficient checkout system that fails to keep employees accountable for the tools they check out. Even more costly than the shrinkage of inventory is the expense of downtime incurred by not having a tool ready when needed. Two main issues with the current system were identified as the reasons for the shrinkage and lack of accountability: 1 when no tool clerk is on staff, mainly nights and weekends, an unreliable paper-method for checkout is used, and 2, employees are not held responsible for checking their tools back in, resulting in tools being "handed-off" outside of the tool room. To combat these problems, a self-checkout/check-in system was developed, eliminating the need for the paper system, requiring an employee login for returning tools, and reducing the total number of steps in the process by 36%.

PG&E was also interested in using RFID (Radio Frequency Identification) technology to further increase accountability and improve the tracking of tools in and out of the tool room. A working proof-of-concept model was designed, built, and tested at Cal Poly's POLYGAIT Laboratory along with recommendations for a potential implementation at PG&E. The results of the portal testing indicate that the best RFID tags for larger items include the Confidex Ironside Slim or Xerafy Cargo Trak tags while the Confidex Captura G2XM should be used for cabled probes. In addition, a maximum of six tools should be carried through the portal at a single time.

An economic analysis for the proposed RFID system with revised checkout was performed along with two other alternatives: an increase in staffing on nights and weekends with the revised checkout and regular staffing with the revised checkout. All three alternatives were compared to the current state, which includes regular staffing without the revised checkout. The results of the economic analysis suggest that the RFID system paired with the revised checkout provides the lowest total cost solution, with a payback period of 0.046 years and a cumulative four-year return of $1,442,914.00. The second total lowest cost solution, which is the revised checkout method alone without an RFID system or increase in staffing, provides the fastest payback period of all the alternatives, in 0.019 years, but provides less of a return on an investment than when paired with the RFID system.

Introduction

Effective inventory tracking and management is an important characteristic of any organization handling physical assets. Without the proper system in place, companies may lose expensive items and waste time by not having equipment available when needed. However, there is also a cost associated with the labor required to accurately keep track of all the items in an inventory. Thus, it is very desirable to accurately manage physical assets in a way that is not overly labor intensive. Similar issues experienced at PG&E's Diablo Canyon Power Plant has led them to search for a cost-effective solution that will improve the inventory management system in their Measurement and Testing Equipment (M&TE) tool room, circled in layout shown in Figure 1 below. Currently, the tool room is experiencing considerable shrinkage of M&TE equipment nearing $100,000 a year largely because of an inefficient checkout system that fails to keep employees accountable for the tools they check out. Even more costly than the shrinkage of inventory is the expense of downtime incurred by not having a tool ready when needed. To alleviate these problems, an improved method of checking tools in and out needs to be developed to increase employee accountability. In addition to a revised checkout system, PG&E has chosen to pursue the justification of an RFID (Radio Frequency Identification) system to further improve the tracking of equipment in and out of the facility. A proposed RFID solution will be developed and compared to other tracking alternatives, including barcode and increased staffing. The goal of this Sr. Project is to develop this solution for PG&E, and to demonstrate its effectiveness by creating a working inventory tracking system in Cal Poly's PolyGAIT Center. PolyGAIT has a large amount of RFID equipment available for student use, however, no organized method exists for students to checkout the equipment or for tracking the inventory, making the lab an ideal place for demonstrating the proof-of-concept, and continuing multi-disciplinary student learning. In addition to the proof-of-concept, recommendations about the portal design, portal location, and number of checkout stations will be provided to PG&E for their own implementation along with an economic justification for the proposed solution.

The objectives of this project are as follows:

- Develop an improved, self-checkout system for the PG&E Tool Room
- Design and build a functional RFID-enabled door portal
- Provide recommendations to PG&E on implementation
- Provide economic justification comparing alternatives for increased inventory control

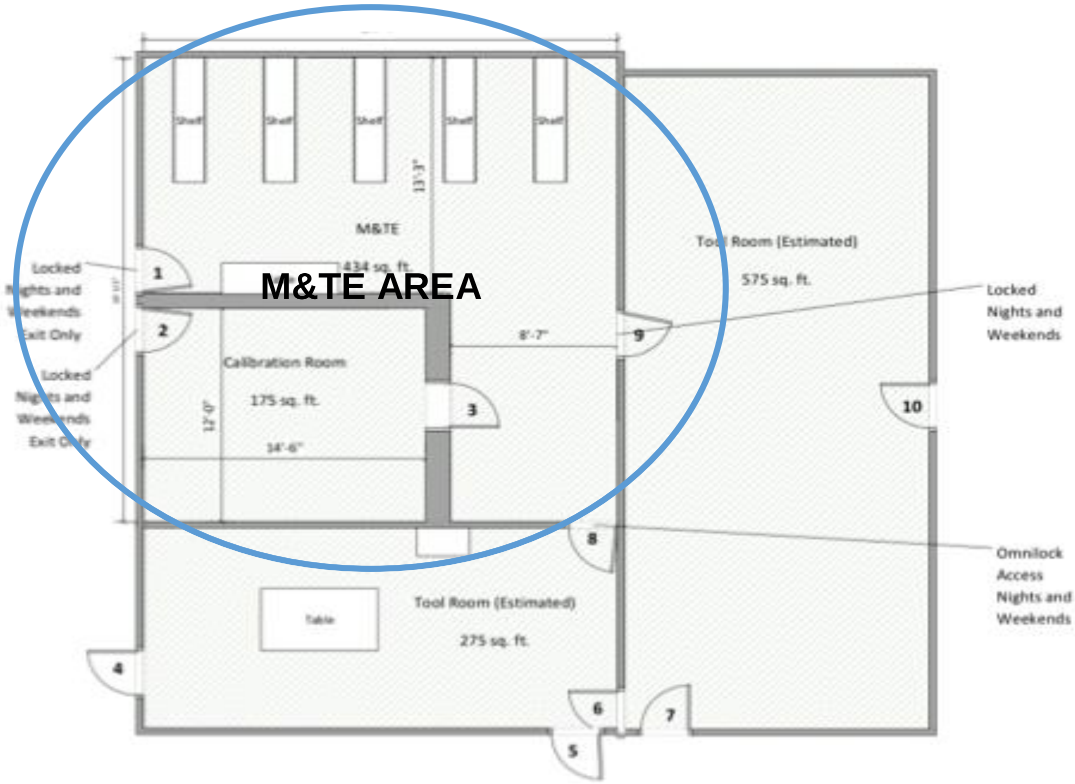


Figure 1: Layout of PG&E Tool Room with M&TE area highlighted

Background

Inside the tool room of the Diablo Canyon Power Plant, a wide variety of tools ranging from simple hand tools to expensive Measurement and Test equipment (M&TE) are stored for employees to check out so that they may perform their various jobs around the nuclear facility. Currently, the tool room is experiencing considerable shrinkage of M&TE equipment nearing $100,000 a year largely because of an inefficient checkout system that fails to keep employees accountable for the tools they check out. Even more costly than the shrinkage of inventory is the expense of downtime incurred by not having a tool ready when needed. The current checkout process for tools at PG&E involves the employee selecting their desired tool(s) and bringing the tools to one of the checkout stations, all located within the tool room, where a tool clerk assists in entering the necessary information required for checkout. This information includes the tool number, often entered by scanning a barcode, as well the employee number, work order number, and additional information about what the tool will be used for. The time spent on excessive manual data entry for each checkout results in wasted labor, and potentially longer checkout lines in the tool room. If these are too long, employees may avoid the checkout process altogether. However, the main concern for missed checkouts is on nights and weekends because the tool room is not staffed with clerks during these times. If a tool clerk is not available, the employees are supposed to write the information down on an "M&TE Checkout Form" that will be left for the tool clerk to enter in to the computer system later. While theoretically this form should increase accountability, realistically it increases the chances of a missed checkout and furthers the difficulty of tracking the equipment because of the hassles associated with a manual system. The concerns regarding lost or stolen tools and tool readiness also increase drastically during yearly scheduled outages, a time when nuclear reactors are shut down for a month for maintenance and repair purposes. During outages, which are held every 8 months, the number of employee's onsite doubles. The extra staff members required during outages are generally contractors rather than full-time PG&E employees, therefore they're often less inclined to use the proper tool checkout procedure. In addition, to emphasize the importance of tool readiness, it is estimated that one hour of downtime during an outage costs the power plant one million dollars.

The need for a reliable, effective way to manage these assets is apparent, but it is also desirable to do so at minimum cost. Frequently companies are choosing to utilize RFID technology to efficiently and accurately track physical assets throughout their property. Its adoption as an effective inventory management tool has become commonplace over the last decade, with major organizations including the US Department of Defense, the US Food and Drug Administration, large international retail firms ([24] Vijayaraman and Osyk, 2006), pharmaceutical firms ([2] Bloss, 2007), IT firms ([26] White et al., 2008) and automotive firms ([4] Coronado-Mondragon et al., 2006; [23] Strassner and Fleisch, 2003) exploiting its benefits. The difficulties of managing tooling inventory specifically are not felt by PG&E alone, as many companies from manufacturing and energy distribution sectors have experienced similar issues. One common solution is the use of automated tool cribs with embedded inventory management software, which are restricted to specific users and automatically track tool usage. (Bramlet and Jordan, 2005) (*Foundry Management and Technology*, 2010).

Literature Review

Inventory Management

Inventory inaccuracy is a major challenge for managers in various industries ([5] DeHoratius and Raman, 2008; [13] Kang and Gershwin, 2005). A cost-effective inventory management system balances the cost of tracking inventory with the costs incurred by having an inaccurate inventory record. In the case of PG&E's tool room, there are two main costs resulting from an inaccurate inventory record: increased shrinkage of tools and poor tool availability. Inventory shrinkage is when items are lost or are damaged beyond use. This can happen in tool rooms in many different ways including theft and misplacement. The problem arises when there is no system set in place to have accountability for an employee to a tool. In most situations, inventory is not being tracked in real time. This leads to the fact that employees do not realize that the inventory is lost or damaged until they need it, making it hard to find where it could have gone, in addition to wasted downtime not having the tool available for work. It is estimated that 2.41% of inventory industry wide is lost every year according to and ECR Europe's project report, which in total lost $31.3 billion industry wide (Bednarz, 2003). It was found in a study that even the best performing stores have only 70-75% of its inventory record that matches its actual physical inventory. For an average store it is about 51% (Gerswhin et al., 2005). Tool availability is about having the right tool at the right time and in the right place. According to a survey of over 50 UK manufacturing companies, 90% of companies acknowledged having tool management problems with 21% of those respondents indicating tool availability as their main tooling management issue. (Perera, T., & Shafaghi, M. 1995).

The costs of tracking inventory include the costs of labor, software, and any equipment involved in keeping inventory records. Many businesses rely on paper-based systems, Excel files, and/or traditional enterprise software, which are often resource-intensive and ineffective.

RFID Systems

To help improve inventory control and operational efficiency, many companies have begun to leverage RFID (Radio Frequency Identification) in conjunction with Web 2.0 tools for management of inventory (Mathaba ET. Al, 2011). An RFID system is normally comprised of a few pieces of technology: An RFID reader, its corresponding antennas, the RFID tags themselves, and normally a software component called middleware. In normal operation, a reader will transmit a signal through the antenna into the tag domain at regulated intervals, or as required by the middleware. Using backscatter, the tag will harvest energy to power itself, and then send back a signal to the reader. These signals are modulated using either Amplitude Shift-Keying (ASK) or Frequency Shift-Keying (FSK) to represent a bit-stream of zero's and one's representing it's Electronic Product Code (EPC) and any data that is contained on the tag's memory. By attaching passive or active RFID tags to assets and strategically placing reader antennas at certain "choke points", RFID systems allow for the tracking of moving items in real time, providing a labor-free and reliable way to track the location of assets (Amini et al.). At first, the costs of RFID tracking kept it from being applicable to businesses, since the goal of RFID is to reduce costs of tracking in the first place. With the decline of costs for RFID tracking, companies worldwide are seriously considering this emerging technology. Its adoption as an effective inventory management tool has become commonplace over the last decade, with major organizations including the US Department of Defense, the US Food and Drug Administration, large international retail firms ([24] Vijayaraman and Osyk, 2006), pharmaceutical firms ([2] Bloss, 2007), IT firms ([26] White et al., 2008) and automotive firms ([4] Coronado-Mondragon et al., 2006; [23] Strassner and Fleisch, 2003) exploiting its benefits. The difficulties of managing tooling inventory specifically are not felt by PG&E alone, as many companies from manufacturing and energy distribution sectors have experienced similar issues. One common solution is the use of automated tool cribs with embedded inventory management software, which are restricted to specific users and automatically track tool usage. (Bramlet and Jordan; *Foundry Management and Technology*, 2010).

Barcode Systems

Before the emergence of RFID, most organizations used barcode systems to assist in their inventory management. Barcode systems are a common form of data tracking technology that have been used for a very long time in retail stores and warehouses. They're often found printed on the box or bag of the item and consist of a unique design of bars and spaces that represent a certain data point in the data set. While the barcode system has been useful in the past and is still appropriate in many applications, RFID offers many benefits that barcode does not. For example, unlike barcode, RFID readers do not require line of sight to get data needed from a tagged item. A barcode has to either have an operator put the reader to the bar code or have the barcode pass the exact line of the reader on its way to inventory (Angeles). RFID technology also allows for a greater data collection than any other existing similar technology. However, barcode systems are cheaper than RFID systems. The price of RFID tracking can range by the type of accuracy wanted by the technology. Since most systems already have a barcode structure set up, the capital needed to set up the RFID infrastructure needs to be considered with the rate of return on the technology to see if it is worth the investment. The tags themselves also cost much more than barcode, which can become expensive when tracking a high number of items (Kapoor et al., 2009).

Portal Design

Another cause for concern when using RFID is that it is hard to achieve 100% read accuracy due to factors such as tag location and interference from miscellaneous objects (Rothfeder, 2004). When it comes to inventory tracking, a basic requirement is to track everything in and out of the inventory with 100% accuracy. Tool inventory tracking is especially tricky because of the different shapes that each tool can form, making it almost impossible to have a fixed location for tag placement. To maximize the read accuracy, it is possible to have multiple antennas or multiple readers in an RFID entryway. The success of an RFID system relies heavily on its level of read-accuracy, which depends on "the volume of the region that receives sufficient power from the reader," (Wang ET. Al, 2000). The factors affecting read accuracy include the distance/read-range of the antennas, relative orientations of the tags to the reader antennas and their polarizations, and the surface material of the tagged item. Wang ET. Al (2000) consider the first of these two to develop a model which can be used to find the optimal placement of reader antennas within a scanning portal by maximizing the powering region. The article is particularly useful because it incorporates the use of multiple reader antennas and addresses the situation in which tag locations are not fixed, both of which are applicable to the design of the portal in this project. Weighing the benefits of the time versus improved accuracy, it's really not necessary to use an optimization modeling approach such as theirs, especially considering the lengthy run-time for their solution was nearly four days long, but their results can be generally applied to the placement of antennas in the design of any standard portal.

Database Design

To drastically improve the speed and reliability of the checkout, a database may be designed to automatically populate the necessary information required for a tool and employee at the checkout. This will also allow for the checkout system to be self-use, eliminating the need for a tool clerk to facilitate the checkout. When creating, designing and implementing a database, the most important decision concerns the topology of the relational database, and its underlying table structure. A database with lots of redundancy in its structure will not only inflate in size, but can also lead to serious anomalies in your data (Roman Ch. 1). When exploring databases, we find that there are 3 types of data, or attributes of a table scheme. Those attributes are those for identification purposes, those used for informational purposes, and those used for both. For instance, a TagID is a unique attribute for identification in RFID systems, and a vendor name is used for identification. These attributes can be combined if needed to form a unique record for identification in the database, usually called a Super Key. This is called a Composite Key when made up of a number of attributes. A Candidate Key is the most minimal version of a Super Key, where no subset of the Candidate key is a Super Key. When this is used to identify unique record in a table and ER diagram, it is then a Primary Key. A key might take form of a composite key when the specific date and time of a transaction are recorded, or a primary key in the form of a Student ID number at a school, where both are unique and have no duplicates. In order to minimize redundancy, database designers are familiar with the idea of normalization in their databases, which identifies the special forms a table may possess. There are six normal forms in all, First, Second, Third, Boyce-Codd, Fourth, and Fifth, where each is stronger than the predecessor. While a high degree of normalization is desired in a database, adhering to very strong forms may require a loss of relational information, making data manipulation more difficult, and requiring some compromises.

First Normal Form

First normal form states that a table is in normal form when all attributes are indivisible. For instance, a table where every cell phone number has only one owner would satisfy First Normal Form, whereas a tuple with 2 Owners per cell phone would violate it.

Functional Dependencies

The concept of Functional Dependencies serve to define these normal forms and their relationships. An attribute is functionally dependent on another attribute when its value depends on the other attribute. For instance, a VendorID value of 1 would determine the VendorName Alien, while a VendorID value of 2 would determine the VendorName Sirit. In this case, the functional dependency can be illustrated as {VendorID} --> {VendorName}. This can be read "VendorID determines VendorName" or "VendorName depends on VendorID".

Second Normal Form

A table scheme is in second normal form when all of the strictly informational attributes (those not in a key) are attributes of entities in the table, and not some other class. For instance, the size of a city's population should not be included in a table with records designed to capture home addresses. A city population is dependent on the city, not any address.

Third Normal Form

Third normal form is a further step beyond Second Normal Form. While Second Normal Form means that no strictly informational attribute depends on the proper subset of a key, there are still undesirable possibilities that can occur. For example, consider the table scheme {Title,PubID, PageCount, Price}, and assume that no two books have the same title and publisher. The only key present in this schema is {Title, PubID}, with the others being purely informational attributes. Further assume that each publisher decides the price of their books based solely on the page count. The dependencies {Title} --> {PageCount}, {Title} --> {Price}, {PubID} --> {PageCount}, and {PubID} --> {Price} do not hold for this table Schema, showing us that it is in Second Normal Form. However, the relation {PubID, PageCount} --> {Price} does hold, which can introduce redundancy because Price depends on a proper subset of a key (PubID) together with another informational attribute PageCount). In other words, Price depends upon attributes that are: not a key, superkey, and not a proper subset of a key. Third normal form does not permit any strictly informational attribute to depend upon anything other than a superkey. While superkeys determine all assets, the point is made that strictly informational attributes depend only on superkeys.

Boyce-Codd Normal Form

Boyce-Codd Normal Form expands further on Third Normal Form. The difference is where Third Normal Form is for strictly informational attributes, Boyce-Codd says that an attribute is not allowed to depend on anything other than a superkey.

Normalization

While a high degree of normalization is normally a good thing for database designers, the process of normalization can still result in the loss of both information and dependencies. Loss of information can occur when decomposing tables into new schemes. For instance, when decomposing the table {AuID,AuName,PubID} with the dependency {AuID} --> {AuName} into two schemes {AuID,AuName} and {AuName,PubID}, the original table with two authors of the same name, yet different publishers, would expand to 4 records during a reconstruction in a query. While we have 4 records instead of 2, we have lost information since we no longer know which author produced for which publisher. As mentioned, normalization can also lead to a loss of dependencies in a database. When decomposing the table scheme {ISBN,PageCount,Price} with dependencies {ISBN} --> {PageCount} and {PageCount} --> {Price}, into the tables {ISBN,PageCount} and {ISBN,Price}, the dependency {PageCount} --> {Price} is lost as they no longer reside in the same table scheme. When normalization results in no information loss, it is called a lossless decomposition, and when it results in no dependency loss it is called a dependency-preserving decomposition. While we can show that any table can be losslessly reduced to Boyce-Codd Normal Form, we have no guarantee that our dependencies have been preserved. However, we can decompose losslessly while preserving dependencies if we decompose our schemes into Third Normal Form

While there is no law that specifies a database is more useful of efficient when under a high degree of normalization, it is still usually highly desirable. However, we must take care to not blindly apply the Normal Forms to our database designs, as a high degree of normalization can lead to less intuitive decompositions, along with the risk of information and dependency loss.

Middleware

Microsoft BizTalk Server is a Microsoft server product aimed at integrating Business Process Management, B2B Integration capability, Adapters, and an RFID platform into an enterprise-wide product. As with all Microsoft Server products, BizTalk Server was made to communicate with other Microsoft enterprise products, tie in with Active Directory and Domain products, and relies on Microsoft SQL Server, Microsoft Sharepoint, and others to develop a cohesive enterprise-wide system. The main purpose of BizTalk Server is to tie automation into various enterprise systems using adapters, and control the automation using Business Activity Management and Business Process Management.

Because of its wide compatibility, enterprise ready-nature, and RFID system support, BizTalk server seems to present a better solution for long-term implementation than a home-grown solution would. Further, with the eventual goal of implementation into nuclear power plants and other businesses, using a well-known and secure product platform as the base for our portal system should pay benefits in the future because of the level of support and interoperability available. As mentioned, devices and software connect to BizTalk through the use of Adapters. Fortunately, the Alien 9900 readers being used for this project support BizTalk server and the Alien Adapter software is provided. Again, by using an out-of-the-box, proven solution, we aim to reduce the set-up and configuration time of our portal, while enhancing the reliability, versatility, and ease-of-use of our portal system.

Queuing Theory and Simulation

In order to supplement the checkout revision with reducing wait times, we have developed an optimization model to determine the best number of checkout stations to have within the tool room. The final solution combines a mathematical queuing model to evaluate the flow of people through the checkout system with linear programming to minimize the total cost of the system. This section discusses previous literature on the topic of queuing theory and optimization models. While there is not much research available on the analysis of queues in an employee checkout environment, there is substantial research on customer line-waiting systems, and fortunately the two environments are similar and many principles of the customer line-waiting system are applicable to our scenario. The literature on these models encompass a wide variety of approaches, generally including some combination of either simulation or queuing theory with mathematical programming to either minimize costs or achieve a certain service level criteria. One well-researched example of staffing level optimization in a queuing system is the call center application where telephone agents serve a queue of incoming customer calls. Simulation techniques have been widely used in determining appropriate staffing levels for these types of problems. Saltzman and Mehrotra (2001) used simulation to model a fee-based technical support program prior to its launch to ensure sufficient staffing levels to support a proposed minimum on-hold guarantee to paying customers. Harrison and Zeevi (2005) combine a Monte Carlo simulation with linear programming to minimize labor costs and abandonment penalties at a large call center and Atlason et al. (2004), also minimizing staffing costs, used simulation to determine service level requirements that would serve as constraints to the objective function. Mathematical queuing theory models have also been applied extensively for scheduling problems. Andrews and Parsons (1993) discuss how L.L. Bean, a large telemarketer and mail-order catalog house for outdoor sporting goods and apparel, saved an estimated $500,000 per year after optimizing their staffing levels that had previously been determined using a service-level criteria. The solution used a mathematical queuing theory in combination with an expected total-cost objective function, similar to the approach used in our model. Comparable literature discussing call center staffing and scheduling applications using queuing theory and mathematical programming include Alfares (2009) and Busco and Jacobs (2000). Also inspired by the call center application, Cezik et al. (2001) discusses several solution approaches to a weekly tour-scheduling problem under highly variable demand changing significantly within a day and between days of the week while also combining shift scheduling constraints into a network flow structure.

In a practice case particularly useful in assisting our model formulation, Mehri et al. (2006) analyze the waiting line model of an airport, performed for the A.I.M.H.B airport in Tunisia. A queuing theory model is used to evaluate the cost of service versus the cost of customers waiting in line. In this case, the goal of the objective function is to minimize the total cost per hour by finding the optimal number of travel agents. Identical to our model, a single-phase, multi-channel, FIFO queuing model (M/M/s) was used to analyze the queue, which is discussed in greater detail in the next section.

Additionally, the concept of customer balking may be drawn from customer-waiting models and applied to ours. Balking refers to customers' impatience with excessively long lines, and therefore choosing not to enter the line. This concept could be applied to our formulation as a way of analyzing a scenario in which an employee, balking at the length of the checkout line, chooses not to engage in properly checking out a tool. (Manoharan)

IP Security Camera Best Practices

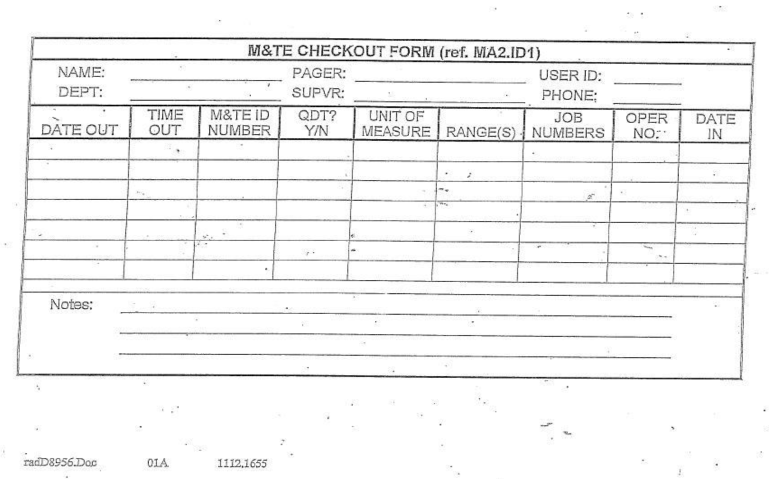
IP Security Camera Best practices cover all aspects of implementation ranging from network design, to physical placement of camera assets. While a large corporation may have many issues relating to camera placement, network load planning, and more, our installation is relatively straightforward as it only depends on a single camera and single data storage point. When placing your camera, careful attention must be paid to the movement of the subject. If placed where a subject moves vertically in the frame, the frame rate of the camera can be lowered than if the subject was moving side-to-side. Velocity of your subject is also a consideration, as fast-moving objects will require a higher frame rate to properly capture.

Another key aspect of any video surveillance system is the amount of physical data storage needed for the system to continuously function. Since even small implementations can require above 30 camera installations, lots of data must be continuously handled by the network and then stored for later review or archiving. The data requirement can be calculated by knowing just a few simple parameters of the camera. Newer security camera's support video recording based on the MPEG-5/H.264 Codec. For his standard, the data storage needed can be calculated by: MPEG4 storage = Bit rate (kbps) x duration. For cameras supporting the MJPEG Codec, storage can be calculated by: MJPEG storage = Average Frame size x Frame rate x duration.

Design

Check-in/out Process Re-Design

As previously mentioned, the M&TE room at Diablo Canyon is not staffed during non-normal working hours and weekends, even though work is still being performed. During these off-hour times, employees are held accountable for M&TE tool checkouts by recording 14 Pieces of information down on an M&TE Checkout Form, such as the tool number, Job number, and the employee's contact info. This form is shown Figure 2 below. While the form contains the critical pieces of information required for accountability, it is often not filled out by employees, and tools are often handed off to other employees without being checked-in first, because of the steps and info required for tool check-in/out.



M&TE CHECKOUT FORM (ref. MA2.ID1)

NAME: PAGER: USER ID:
DEPT: SUPVR: PHONE:

DATE OUT	TIME OUT	M&TE ID NUMBER	QDT? Y/N	UNIT OF MEASURE	RANGE(S)	JOB NUMBERS	OPER NO:	DATE IN

Notes:

radD8956.Doc 01A 1112.1655

Figure 2: M&TE Checkout Form

By incorporating electronic check-in/out tied to a database, the team hoped to vastly reduce the number of steps by eliminating the repetitive inputting of information needed in each check-out through the use of database dependencies.

For instance, currently an employee must write down their Name, UserID, Phone number, and many other pieces of information. In the new process, an employee would simply swipe their badge to login. Their personal information is already in the database, and necessary information would be auto populated by the dependency {BadgeID} → {UserID}, and {UserID} → {First Name, Last Name, Dept, Supervisor, Phone, Pager, Admin}. The other Dependency used is {ToolID} → {S/N, Range, Units, Model#, Manufacturer, Description}. These dependencies should drastically reduce the number of steps and information required for the Check-Out process, as 9 out of 15 elements would have the same information recorded for each employee's checkout.

Database Design

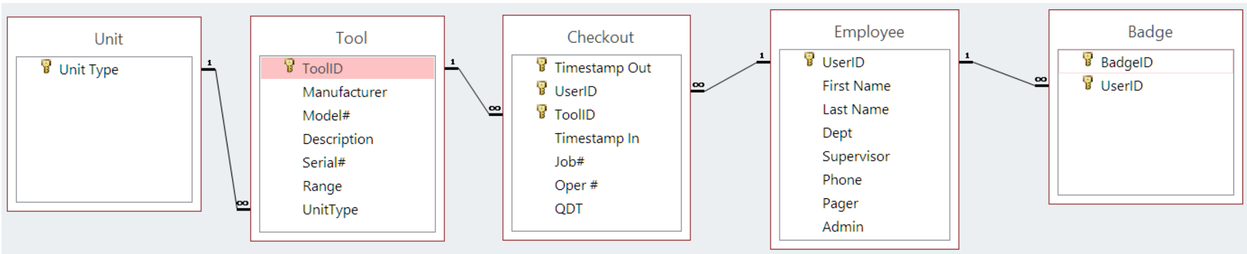


Figure 3: Entity Relationship Diagram and Table structure for the database design

Figure 3 presents the overall database design for this project. The Badge Table holds the pairings of each UserID and BadgeID in order to link the two upon Check-Out/In. The UserID is then used as the primary key in the Employee Table. The relationship {UserID} → {First Name, Last Name, Dept, Supervisor, Phone, Pager, Admin} associates all the necessary personal info to the UserID. Checkout records are then stored in the Checkout table once a checkout has been completed. Here a composite key is composed of the Checkout Timestamp (date and time), the UserID, and the ToolID. This allows every checkout record to have a fully unique identifier upon creation, and does not depend on a Check-In timestamp in order to be found in the table. This key, along with the Check-In timestamp, Job #, Operation# and QDT store all the relevant information needed for each tool checkout. The Tool Table stores all relevant info for each tool, such as its ToolID, which is the primary key, along with information such as the manufacturer, serial #, and Unit Type. Lastly, the Unit Table identifies the types of units available for each tool in order to maintain the data uniformity through each tool record.

Checkout Station Design

Due to the knowledge gained in IME 312, Microsoft Access was used to develop a working database and user interface in a single package. After creating the database topology, a user interface was designed for the checkout system. As the UI was designed with touch-screen use in mind, care was taken to make all buttons and selections sufficiently large. Large, and relatively high-contrast text was also utilized in an effort to improve readability. The basic UI consisted of 4 different pages, or forms. The LoginForm is the first form the user sees upon accessing the database, and can be seen in Figure 4.

Figure 4: Checkout Station LoginForm

The user is prompted to swipe their badge to log in, taking them to the MainForm. After swiping their badge, the user will chose to checkout a tool or check a tool back in. After making a selection, for a checkout, the user is prompted to swipe the tool(s) they would like to checkout. After doing so, the user would input their Operation#, Job#, and QDT reference, and select Checkout tool. The CheckoutForm can be seen in Figure 5.

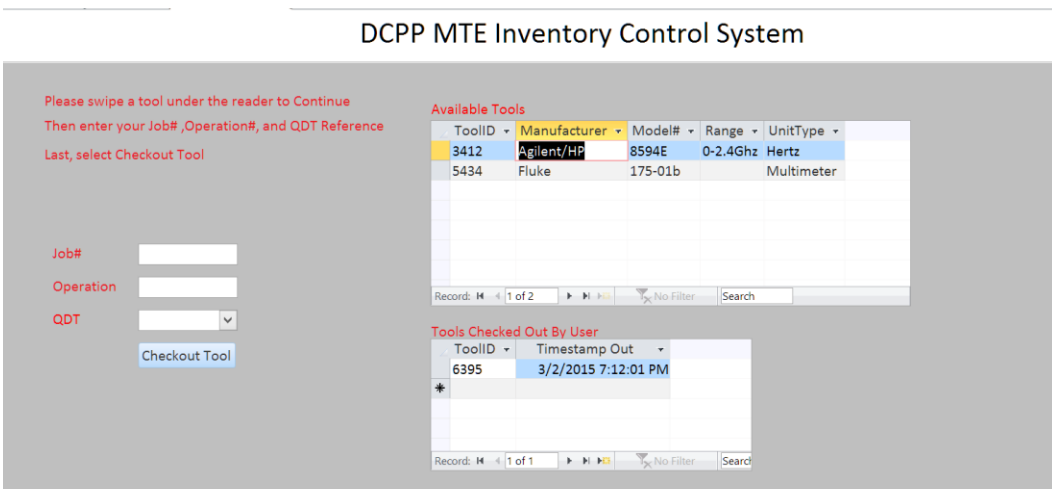


Figure 5: Checkout Station CheckoutForm

RFID Portal Design

This section discusses the design of the RFID system used to supplement the revised checkout process with tracking tool usage. A functional proof-of-concept portal was designed and built at Cal Poly's PolyGAIT laboratory.

The purpose of an RFID system in this case is to serve as a backup for incidences in which tools are not properly checked out with the checkout station, especially during nights and weekends when the M&TE room is not staffed. The goal in designing the system was to achieve the highest level of tracking with the minimum amount of hardware and cost. To do so, the layout of the facility and the flow of employees carrying tools in and out of the area had to be considered. Figure 3 below shows the layout for the tool room. For the scope of this project, only the tools coming in and out of the M&TE area needed to be considered, limiting the area of focus to that area only. It was decided to place antennas only at the entryways to focus only on capturing tools entering or leaving the area and to avoid any false reads of tools moving within the tool room. With four possible entryways, labeled 1-4 in Figure 6, to the M&TE area, it had to be decided how many and which doorways should be used as portals. As the only doorway with access during nights and weekends, when the concern for missed checkouts is greatest, Entryway 1 should be used as the portal.

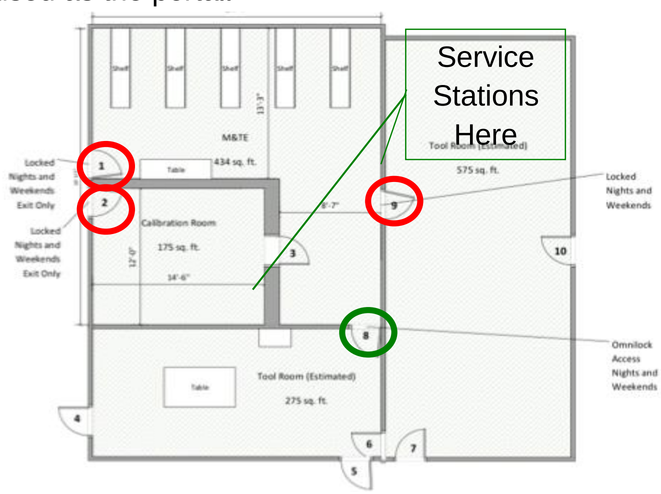


Figure 6: Floor Layout of the PG&E Tool Room. The four doorways, labeled 1-4, designate the possible entryways to M&TE area

After establishing the location of the portal, the best number, placement, and orientation of antennas at that portal had to be determined. For an RFID system to be successful it must achieve a high level of read-accuracy, which depends on "the volume of the region that receives sufficient power from the reader," (Wang ET. Al, 2000). The factors affecting read accuracy include the distance/read-range of the antennas, relative orientations of the tags to the reader antennas and their polarizations, and the surface material of the tagged item. In *Placement of Multiple RFID Reader Antennas to Maximize Portal Read-Accuracy*, Wang ET. Al (2000) consider the first of these two to develop an optimization model which can be used to find the best placement of reader antennas within a scanning portal by maximizing the powering region. The model they develop is complex and has a runtime of almost four days, so rather than attempt to use their optimization technique with the PolyGAIT door frame dimensions, it was decided to use their results to guide the decisions regarding the number and placement of antennas for the proof-of-concept portal at PolyGAIT. It was assumed that a comparable read-accuracy could be achieved using these results, as the conditions of their model are similar to the PG&E scenario. In their model, all possible antenna orientations are given equal weight, which is assumed to be the case for employees carrying tools through the M&TE room. Additionally, the dimensions of the door frame at PG&E were assumed to be similar enough to the model door dimensions to not have a significant effect on the outcome of the results. Figure 7 below shows the design of the door frame used in the model, with 18 possible antenna locations, each with 3 possible orientations: -45, 0, or 45.

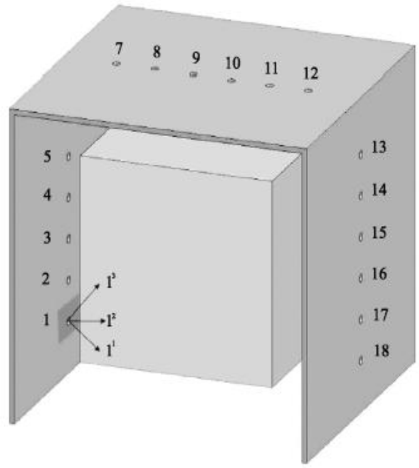


Figure 7: Portal dimensions used in the optimization model in Placement of Multiple RFID Reader Antennas to Maximize Portal Read-Accuracy, (Wang ET. Al, 2000).

In a scenario with two antennas, the optimal locations are at 3 and 16 with the optimal orientation of both antennas being 0 degrees. With three antennas, the optimal placements are 3, 16, and 9, all at 0 degrees. Figure 8 shows the coverage fraction percentage with the corresponding number of reader antennas, which shows the improvement in coverage fraction beginning to plateau at three antennas. Weighing the read-accuracy benefits of additional hardware versus the costs, it was determined to use three antennas for the proof-of-concept portal at PolyGAIT. Using the results of Wang ET. Al's model, antennas were placed halfway up the door frame on each side and one antenna was placed in the middle, directly above the door frame, as shown in Figure 9 below.

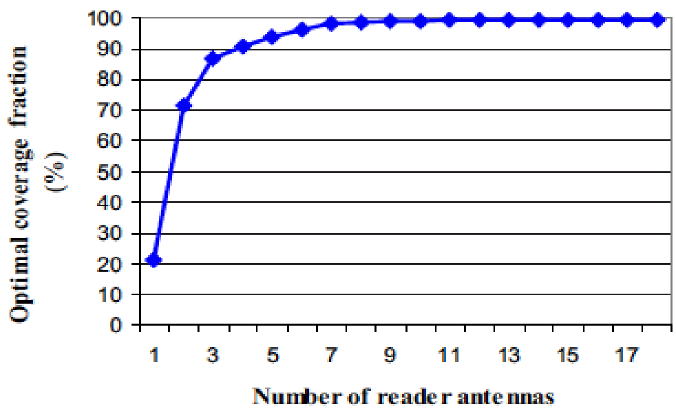


Figure 8: Graph of Optimal Coverage Fraction of the portal area for the number of reader antennas used in the portal, as determined in Placement of Multiple RFID Reader Antennas to Maximize Portal Read-Accuracy, (Wang ET. Al, 2000).

Figure 9: Completed Portal Design in PolyGAIT Room 112

In selecting the hardware to be used, the cost and read range had to be considered. RFID systems can be passive, meaning the tags don't use a battery for transmitting their signal, or active, where tags do rely on a battery. Passive tags are cheaper than active tags and never require battery replacements, but they also have a shorter read range. Within the passive category, RFID systems can also be LF (Low Frequency), HF (High Frequency), or UHF (Ultra High Frequency). The higher the frequency, the greater the read range. Passive UHF RFID technology was selected because it met the minimum desired read range for the portal and is much cheaper than active RFID. A UHF Alien brand RFID reader was selected for the proof-of-concept portal because it supports up to four antennas, can capture direction of tag movement, and also interfaces with Microsoft BizTalk server, a product aimed at integrating Business Process Management, B2B Integration capability, Adapters, and an RFID platform into an enterprise-wide product. Chosen for its wide compatibility, enterprise ready-nature, and RFID system support, BizTalk server seems to present a better solution for long-term implementation than a homegrown solution would. Further, with the eventual goal of implementation into nuclear power plants and other businesses, using a well-known and secure product platform as the base for our portal system should pay benefits in the future because of the level of support and interoperability available.

With just the portal, the system is capable of capturing a tool's ID entering or leaving the tool room, as well as the time and date, but there is no way of identifying which employee has taken it. To increase employee accountability, two alternatives have been considered. The first alternative is to reference the entry time and date information of the Omnilock access door (see Figure 6 above) and match it with the nearest time and date info captured at the portal. This is the simpler option, but is only applicable during the nights and weekends when the Omnilock door must be used and may not be 100% accurate depending on how many employees are accessing the room during these times. The second alternative is to use a security camera with the portal to record video of employees entering or exiting the portal. This would increase the costs of building the portal, but would ensure a greater level of security and employee accountability. A security camera was not used in the PolyGAIT portal, however, information on the best practices of security camera placement and video storage was collected and is presented in the literature review section under IP Security Camera Best Practices.

Portal Testing and Validation

Tag Selection

In order to validate the design of the portal, a proper design of experiments was constructed to guide tag testing and eliminate any possible confounding variables. Four UHF RFID tags of different sizes and configurations were selected for testing, as seen in Figure 10 below. On-metal tags were chosen given that M&TE tools normally feature a metal chassis, and would offer improved performance, and in some cases read-range when placed directly on-metal. The Captura tag was chosen because of its design for hanging on metal structures, which is similar to hanging a tag off of probe-type cables.

Picture	**Tag Name**	**Manufacturer**	**Size (in)**	**Type**	**IC Type**	**Advertised Read Range (On-Metal)**	**IP Rating**
	Cargo Trak	Xerafy	3.94 x 1.02 x 0.35	On-metal ruggedized tag	Alien Higgs-3	Up to 39 ft.	IP68
	Dash-On XS	Xerafy	0.48 x 0.12 x 0.09	Small On-metal ruggedized tag	Alien Higgs-3	Up to 6.6 ft.	IP68
	Ironside Slim	Confidex	3.31 x 0.83 x 0.39	On-metal ruggedized tag	Impinj Monza 4QT	Up to 26 ft.	IP68
	Captura G2XM	Confidex	2.26 x 0.75 x 0.79	Hanging tag for metal structures	NXP UCODE G2XM	Up to 26 ft. (US)	IP67

Figure 10: UHF RFID Tags selected for testing

As part of the design-of-experiments, the same tool was used for every orientation measurement, with the exception of the Captura tag (since it was for probe use), as to not introduce another factor into our experiment. Tag placement was consistent for each tag, as seen in Figure 11 through Figure 15 below. Each tag was secured with electrical tape before testing, as this is done to tags on PG&E tools to prevent FOD.

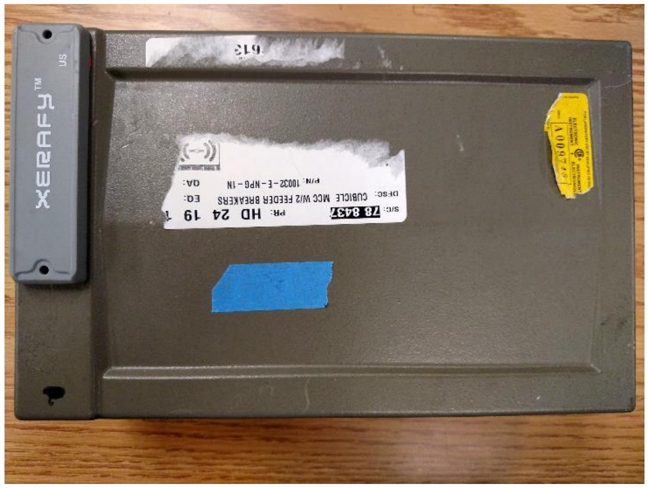


Figure 11: Xerafy Cargo Trak Tag Placement

2

Figure 12: Confidex Ironside Tag Placement

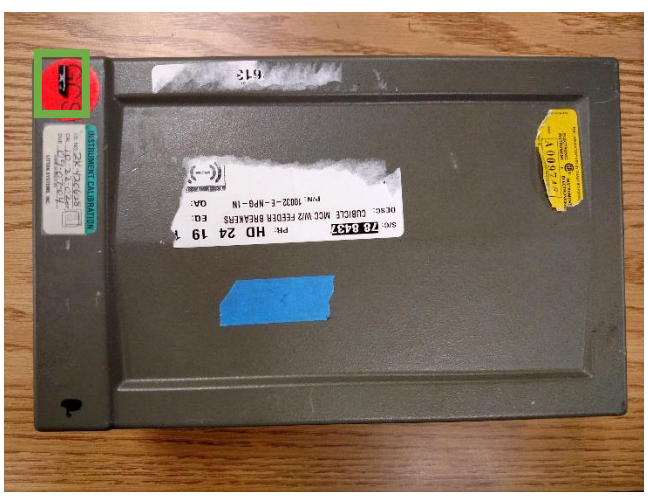


Figure 13: Xerafy Dot-on XS Tag Placement

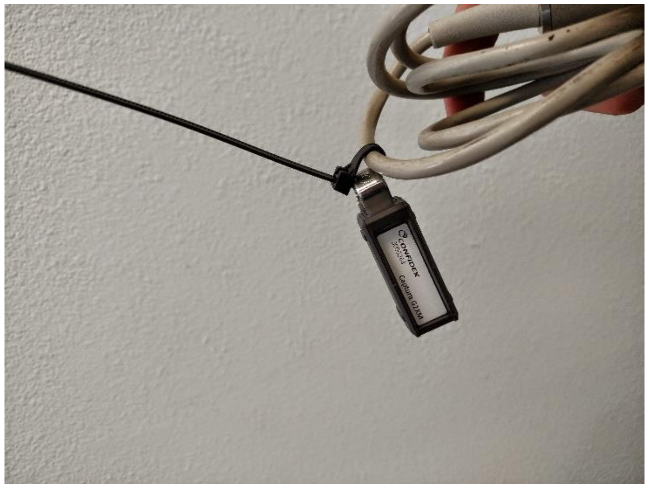


Figure 14: Confidex Captura G2XM Tag Placement (Orientation 0)

Figure 15: Tool Height during Tag Testing

Portal/Tag Testing

During testing, each tag permutation was walked through the portal at walking speed and a height of 4 ft. from the floor. An example of this can be seen in Figure 15. Each tag would be moved through the portal at orientations from 0 (top of tag facing left towards antenna 2) to 360 degrees in 45 degree increments. This would be repeated 3 times for each orientation in order to build an average number of reads for each antenna (zero through two). The average reads for each antenna were then added together to develop the total average portal reads per tag orientation. Testing results can be seen in the results section, as well as in Figure 40 through Figure 43 in the Appendix.

Multiple Tag/Tool Testing

In order to ensure the portal could accurately track more than one tool at a time, six tools were simultaneously moved through the portal in a shopping cart as seen in Figure 16. Due to limitations of tag inventory, Omni-ID Pipe Tags and Xerafy Data Trak II tags were used to supplement the tags selected for testing. The team decided to test 6 tools, as it was more than could be easily carried, and would provide an adequate safety factor, given a checkout of 6 tools is highly irregular. This test was repeated 3 times. Results can be seen in the results section and Figure 44: 6 Tool Tag testing Data in the Appendix.

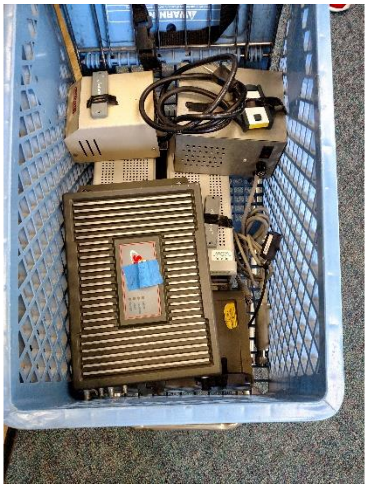


Figure 16: 6 Tool Cart Testing Configuration

Number and Placement of Checkout Stations

This section discusses the optimization model used to determine the required number of checkout stations within the tool room. The goal of the model is to minimize the total costs of employees waiting in line and the costs of implementing and maintaining a checkout station.

Model Formulation

The Objective Function:

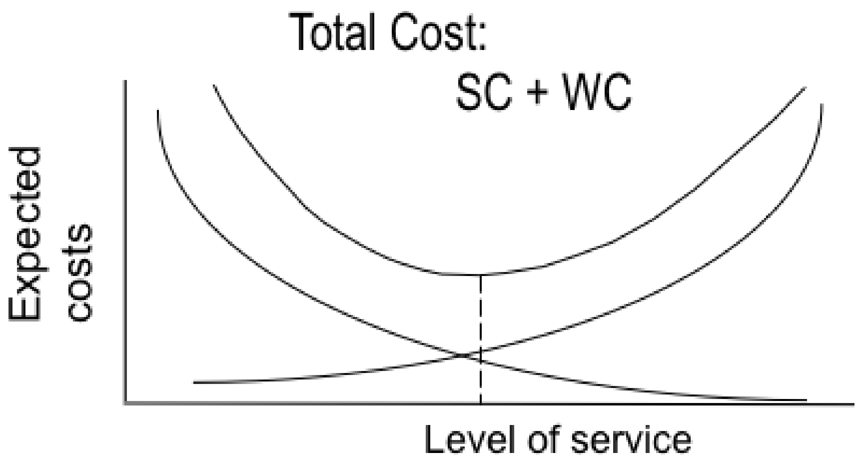


Figure 17: Graph depicting service, waiting, and total costs as a function of service level

Like with any type of checkout system, the tool room checkout creates a line of people waiting to checkout tools, also known as a queue. In a queuing system, there are the costs associated with providing the service, in this case the checkout station, and costs associated with waiting, which is the cost of employees waiting in line. As the level of service increases, meaning the cost of service increases, the time and cost spent waiting goes down. Likewise, if the service level decreases then the waiting cost increases, as shown in the graph in Figure 17. The goal of this model is to find the optimal balance of service and waiting costs so as to minimize the total cost, thus, our objective function is as follows:

Min TC = SC + WC

TC = Total Cost
SC = Service Costs
WC = Waiting Costs

The Service Costs (SC)

SC = (C_s) (S)
SC = Cost of service
C_s = Maintenance cost (in dollars per hour)
S = Number of checkout stations

The cost of service for the self-checkout station (C_s) included an estimate of the annual maintenance costs required for the database and checkout as well as the annual middleware costs of the Microsoft BizTalk server. The software maintenance costs were determined using an Intermediate COCOMO (Component Based Software Development Model) software maintenance estimation model (C.V.S.R, Syavasya), which equated to about $1,000 annually. Microsoft BizTalk Server costs $620 per core, with a minimum purchase of four cores per computer, totaling $2480 per checkout station annually. The total annual cost of $3480 per checkout station was divided by the number of working hours per year in order to obtain an estimated service cost in dollars per hour, as shown below:

Cs = $3480/year * (250 working days/year) * (8 hours/day) = $1.74/hour

Waiting Costs (WC):
The waiting costs refer to the amount of time employees spend waiting to check out a tool. The cost of waiting is determined, in dollars per hour, by the average number of employees waiting in the system multiplied by the employee wage, and the equation is as follows:

$WC = C_w(L)$

WC = Cost of waiting

C_w = Employee wage (in dollars per hour)

L = Average number of employees waiting in the system

Taking into account additional benefits, the employee wage, C_w, was assumed to be $60 per hour.

To determine the cost of waiting, we first needed to decide on how to model the flow of employees through the checkout system. Generally, there are two types of ways to construct mathematical models of operations: queuing theory and simulation. Simulation, the most common approach, involves creating a simplified imitation of the real system, which allows you to trace individual items through the system, observe queues build up, and to analyze the state of the system over time (de Treville). Alternatively, queuing theory involves constructing mathematical models to evaluate characteristics of a queuing system. Simulation is often used when a problem is too complex for optimization techniques and can be used without applying “strict assumptions,” which are necessary for analytical models like queuing theory in order to find a tractable solution (Proctor). Queuing theory models, although generally less accurate than simulation models, offer a quicker way to obtain system parameters that are often suitable depending on the desired level of precision. Given the checkout system is a relatively simple model, we chose a mathematical queuing theory model for our solution because of its ease of use, especially when serving as an input to the integer-programming model. It was also decided that a queuing model provided a sufficient level of precision. Using queuing theory, we were able to determine how many employees, on average, were waiting to checkout out a tool, therefore allowing us to determine the average cost per hour of employees waiting in line.

The Queuing Model:

There are three parts of a queuing system: 1. the arrivals into the system, 2. the service station, and 3. the queue itself. Mathematical queuing models are an effective tool for evaluating these systems because, as long as you know some information about the system, such as the service and arrival rate, you can determine several other characteristics such as the probability that there is no item in the system, the average number of the items in the system (the items in the waiting line and the items being served), the average time an item spends in the waiting line, the average time an item spends in the system, and more. In our formulation, we are only concerned with the average number of employees waiting in the system. Queuing systems can vary in terms of their number of channels and phases, arrival and service patterns, and queue disciplines in processing new arrivals, and the complexity of the mathematical models grows significantly with the complexity of the queue. The tool checkout queuing system will be single-phase, where the employee receives service from only one station then exits the system, and multichannel, meaning it's possible to have multiple checkout stations available for service. Additionally, to evaluate the queue of the tool checkout process, some assumptions need to be made. The first is the queue discipline, which we assume operates as first-in, first out (FIFO), meaning the order of arrival corresponds to the order of service. Second, we assume the arrival rate of employees follows a Poisson distribution, meaning the arrivals occur at a known average rate and each arrival is random and independent from another. Third, we assume a constant service time for each checkout station. Lastly, we assume the length of the line and the population of arriving employees to be potentially infinite and that the total service rate must be faster than the rate of arrivals, otherwise the line would grow to infinity. Using this model, we were able to determine the average number of employees waiting in the system, by inputting the constant service rate and average arrival rates. The equations used for finding the average number of employees in the system are presented below:

$$L = L_q + \frac{\lambda}{\mu}$$

$$L_q = \frac{\lambda\mu\left(\frac{\lambda}{\mu}\right)^s}{(s-1)!(s\mu-\lambda)^2}P_o$$

$$P_0 = \frac{1}{\left[\sum_{n=0}^{n=s-1}\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s\left(\frac{s\mu}{s\mu-\lambda}\right)}$$

L= Average number of employees in system

L_q = Average number of employees waiting in line

P_o= Probability there are zero employees in the system

λ= Arrival Rate

μ= Mean Service Rate

S= Total number of checkout stations

The Mean Service Rate is assumed to be 5 minutes, serving 12 customers an hour.

S= Total number of staffed checkout stations

Constraints

The first constraint is that the number of service stations be greater than or equal to one. This is required in order to make sure that there is a service station that serves an employee at any given moment.

$S \geq 1$

The second constraint is that the number of service stations has to be an integer value. This allows for one task employee per service station.

S = Integer

The third constraint is that the number of service stations multiplied by the service rate needs to be greater than or equal to the arrival rate.

$S * \mu \geq \lambda$

Solving the Model

As previously stated, the goal of the objective function is to find the number of stations, S, that minimize the total cost.

Min TC = SC + WC

The team solved the model several times, analyzing varying levels of arrival times to serve as inputs to the queuing model. One major limitation of queuing theory is that it must be assumed the arrival time of people entering the system follows an exponential distribution, which is unrealistic and likely not the case. However, without having the opportunity to collect data on arrivals at the site to determine a more appropriate distribution, using queuing theory was the next best possible option. In addition, the arrival times are significantly higher for outage times than non-outage times, introducing an even greater challenge to the validity of the model, which assumes a constant arrival time. Therefore, to provide a more realistic picture, varying degrees of arrival times were evaluated using a combination of excel solver and solver table. Solver table is an extension of the excel solver add-in that generates a table of multiple optimal solutions corresponding to varying inputs to the model, which in our case, was the arrival rate of employees as well as the service rate of the checkout station. Solutions were generated for arrival rates between 2 to 20 employees per hour in increments of 2 as well as service rates from 10 to 30 employees per hour, also in increments of 2. The results are shown in Figure 18 below.

		Service Rate (Employees/hour)										
	s	10	12	14	16	18	20	22	24	26	28	30
Arrival Rate (per hour)	2	2	2	1	1	1	1	1	1	1	1	1
	4	2	2	2	2	2	2	2	2	2	1	1
	6	3	3	3	2	2	2	2	2	2	2	2
	8	3	3	3	3	3	2	2	2	2	2	2
	10	4	3	3	3	3	3	3	2	2	2	2
	12	4	4	3	3	3	3	3	3	3	3	2
	14	4	4	4	3	3	3	3	3	3	3	3
	16	5	4	4	4	3	3	3	3	3	3	3
	18	5	4	4	4	4	3	3	3	3	3	3
	20	6	5	4	4	4	4	3	3	3	3	3

Figure 18: Optimal Number of Service Stations from Solver Table

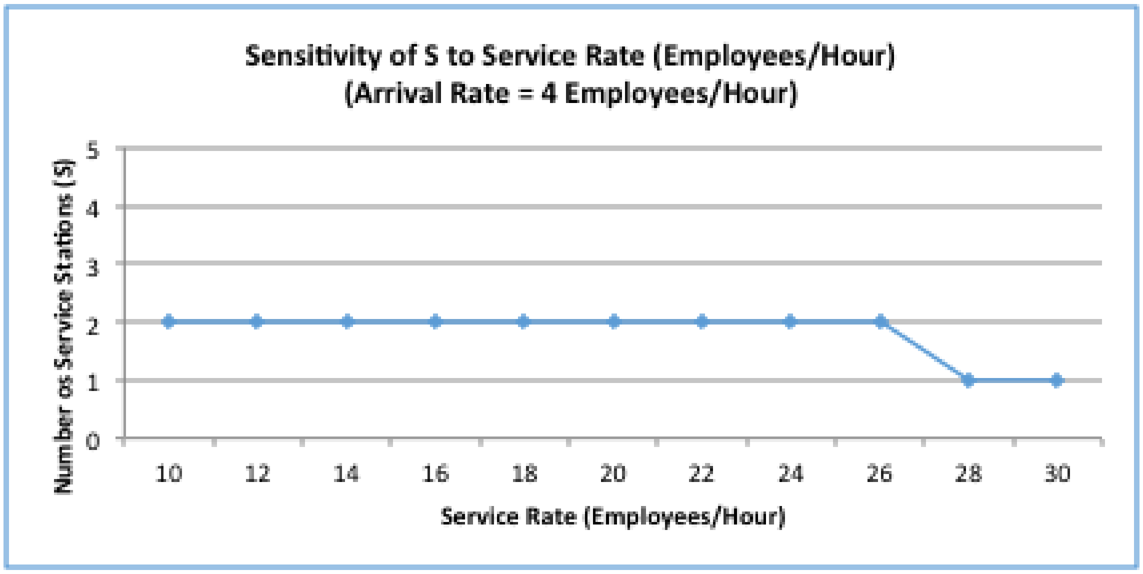


Figure 19: Sensitivity of S to Arrival Rate

Figure 20: Sensitivity of S to Service Rate

The expected service rate for the system is about 28 employees/ hour, or a little over 2 minutes per checkout, and based on conversations with the tool room manager, the expected arrival rate is between 2 to 4 employees/ hour. Figures 16 and 17, above, demonstrate the sensitivity of the optimal number of service stations, S, using these values that are expected to be the closest to the true case. Figure 26 shows the sensitivity of the optimal number of service stations to a varying level of service rate using an assumed arrival rate of 4 employees per hour while the graph in Figure 27 shows the sensitivity of S to varying arrival rates, with an assumed service rate of 28 employees per hour. Given these results, the two best options are to use either 1 or 2 service stations, depending on what the rate of employee checkouts PG&E expects. To help make a final recommendation, using a conservative service rate of 24 employees per hour and an arrival rate of 4 employees per hour, the difference in the variable total cost for using 1 service station versus 2 service stations was compared to the fixed cost of a service station to see if building an additional station was economically justifiable. Referring to figure 18, below, which summarizes the total cost per hour for all of the arrival rate-service rate pairs; the optimal total cost of this scenario is $13.55 per hour using two service stations. If a single station were used instead, the total cost would be increased to $13.74 per hour. The estimated fix cost of building a service station, including the computer, monitor, and additional materials was assumed to $1,400. At an improvement of only 20 cents per hour, it would take approximately 4 years to earn the money back spent on the additional service station; therefore, we recommend that PG&E build only one service station for tool checkout.

		Service Rate (Employees/hour)										
	$	10	12	14	16	18	20	22	24	26	28	30
Arrival Rate (per hour)	2	15.60121	13.54993	11.74	10.31143	10.16731	8.406667	7.74	7.194545	6.74	6.355385	6.025714
	4	28.48	24.05143	20.98	18.7181	16.98	15.60121	14.48	13.54993	12.76571	11.74	10.97077
	6	41.58986	35.40182	31.03395	26.79984	24.05143	21.89432	20.15368	18.7181	17.51298	16.48645	15.60121
	8	54.35525	45.77749	39.81158	35.40182	32.00153	28.48	26.0441	24.05143	22.38909	20.98	19.76959
	10	67.36816	56.55177	48.8066	43.15359	38.82742	35.40182	32.61812	29.6143	27.44313	25.61439	24.05143
	12	79.91271	67.36816	58.13566	51.10235	45.77749	41.58986	38.20246	35.40182	33.04539	31.03395	28.48
	14	92.90828	77.79592	67.36816	59.33228	52.90361	47.89422	43.86692	40.55144	37.77037	35.40182	33.35894
	16	105.4309	88.5134	76.29103	67.36816	60.26836	54.35525	49.63891	45.77749	42.55126	39.81158	37.4538
	18	118.0668	99.64508	85.41504	75.16601	67.36816	61.02074	55.55042	51.10235	47.40426	44.27529	41.58986
	20	130.9805	109.6083	94.81428	83.11141	74.29308	67.36816	61.63871	56.55177	52.34784	48.8066	45.77749

Figure 21: Total Optimal Cost from Solver Table

Figure 29, below, shows the recommended location for the service station. The placement of the service station was based on available space as well proximity to the portal. First, the location had to have enough room for employees to wait for checkout. The suggested location is close enough to the portal to facilitate operators through that door after checkout, but far enough away to avoid any unintentional reads from tags at the checkout station.

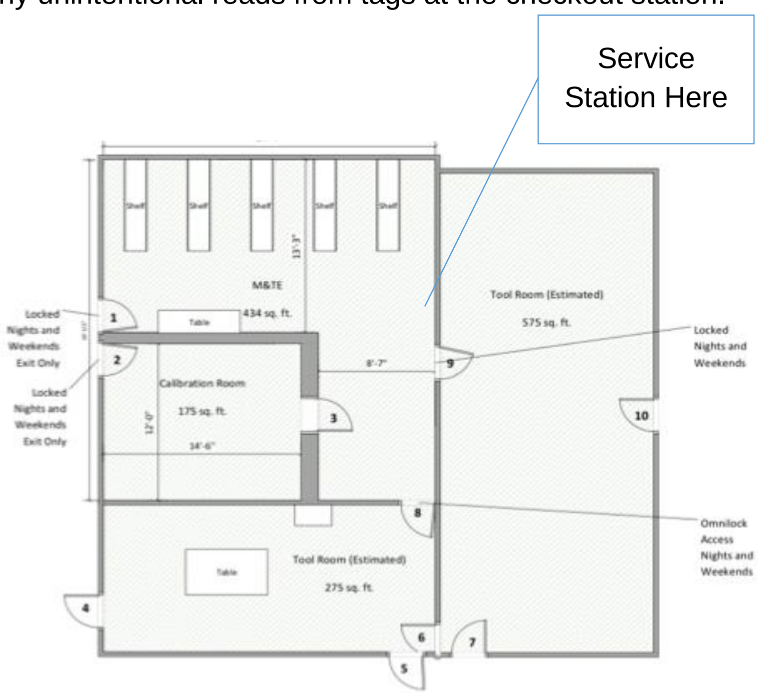


Figure 22: Layout of tool room showing recommended location for service station

Cost Benefit Analysis

This section describes the cost benefit analysis that was performed to evaluate the benefits of the proposed system and to also compare with other possible alternatives. In total, 3 alternatives are considered and compared against the current state. These three alternatives include the following:

1. RFID enabled system with the door portal and redesigned checkout system
2. Increase in staffing on nights and weekends and the redesigned checkout system
3. Regular staffing with the redesigned checkout system

The current state of the tool room is the scenario with regular staffing and with out the revised checkout system. Five main improvements to the current state were identified, including reductions in the following areas:

- Average search time per tool (min)
- Percentage of checkouts missed or not properly recorded
- Percentage of missed Checkouts resulting in a lost tool
- Percentage of successful checkouts resulting in a lost tool
- Number of Tool Clerks required for checkout

These improvements are quantified and summarized in the table below, which were used in evaluating the costs of each scenario.

Estimated Improvements for Each Alternative

Improvement	RFID w/ RC	Increased Staffing w/ RC	Regular Staffing w/ RC	Current (Regular Staffing w/ out RC)
Average Search Time per Tool (min)	60	90	120	120
% Checkouts Missed	0.10%	0.05%	0.10%	1.00%
% of Missed Checkouts Resulting in Lost Tool	2%	12%	12%	12%
% of Successful Checkouts Resulting in Lost Tool	1%	1%	1%	1%
# of Tool Clerks (staffed normal hours)	3	3	3	4

Figure 23: Estimated Improvements for Each Proposed Economic Alternative

For all three alternatives, the percentage of missed checkouts and percentage of lost tools are reduced as a result of the revised checkout system, which has three main benefits:

- Eliminates the use of the unreliable paper system, which has been identified as the primary source of missed checkouts.
- Enforces an employee login for in the tool check-in process, reducing the number of hand-offs outside of the tool room, which has been identified as a primary cause of lost tools and tool unavailability.
- Potentially releases one of the tool clerks for other tasks in a new area. The economic justification was performed twice, once with the assumption of reduced staff and once without, in case the assumption was invalid.

The reductions in average search time per tool and percentage of missed checkouts resulting in a lost tool for the RFID system are because this system automatically sends an alert anytime a tool leaves without being properly checked out, significantly reducing the number of times a missed checkout goes unnoticed or a tool goes missing without a record of it leaving the tool room. The increase in staffing on nights and weekends has an even lower percentage of checkouts missed than the RFID system because a tool clerk on staff is capable of holding employees accountable for using the checkout whereas the RFID system only serves as a backup in the case where a checkout is negated. However, the benefits of increased staffing come at a considerable cost, especially because nights and weekends are paid at 50% more than the normal rate.

Cost-Benefit with Reduced Staffing

This section covers the results of the economic analysis with the assumption that a tool clerk staff member could be released for tasks in a different area as a result of the self-checkout system. With low development and implementation costs for the revised checkout system, the possibility of reducing the tool clerk staff from four to three provides immense benefits, as illustrated in Figure 31, below.

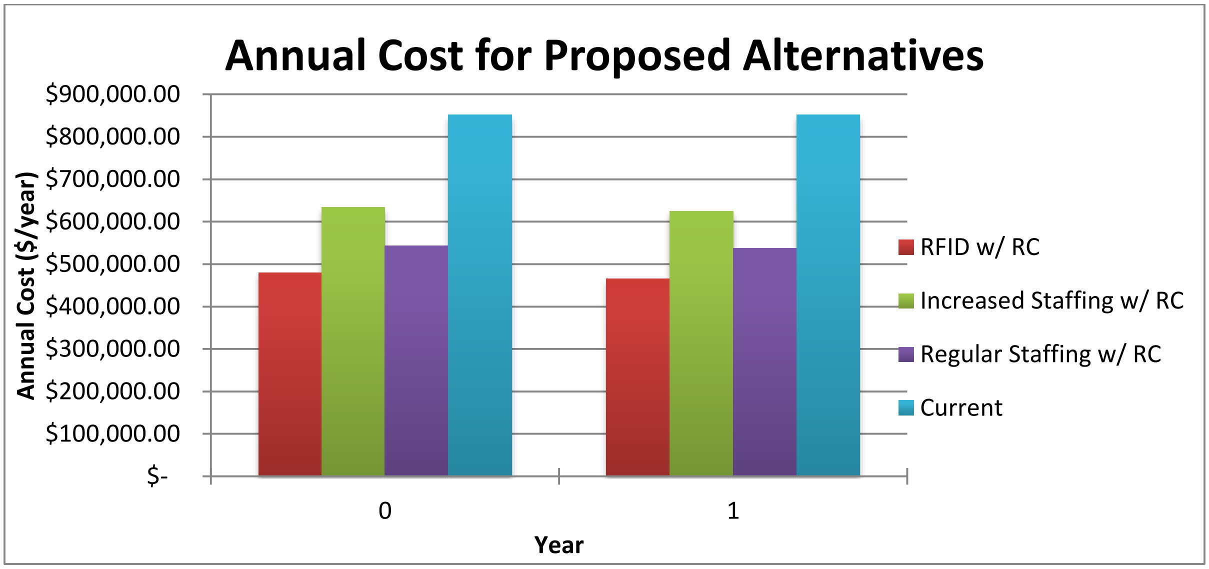


Figure 24: Annual Costs for Proposed Alternatives in Year 0 and Year 1 assuming reduction in staff

Our results indicate that the RFID system paired with the revised checkout provides the total lowest cost solution and that the revised checkout system without the RFID system provides the second lowest. The estimated benefits for these two alternatives are summarized below:

RFID w/ RC versus Current

Year	Money Spent	Money Saved By RFID	Cashflow	Cumulative Cashflow
0	$ (479,471.00)	$ 372,889.00	$ (106,582.00)	$ (106,582.00)
1	$ (464,986.00)	$ 387,374.00	$ (77,612.00)	$ 280,792.00
2	$ (464,986.00)	$ 387,374.00	$ (77,612.00)	$ 668,166.00
3	$ (464,986.00)	$ 387,374.00	$ (77,612.00)	$ 1,055,540.00
4	$ (464,986.00)	$ 387,374.00	$ (77,612.00)	$ 1,442,914.00

Total Implementation Cost	$ 17,165.00
Money Saved In Year 1	$ 372,889.00
Payback Period Year:	**0.046**

Figure 25: Cumulative cashflow and payback period for RFID system with revised checkout assuming reduction in staff

Regular Staffing w/ RC versus Current

Year	Money Spent	Money Saved By RC	Cashflow	Cumulative Cashflow
0	$ (542,610.00)	$ 309,750.00	$ (232,860.00)	$ (232,860.00)
1	$ (536,610.00)	$ 315,750.00	$ (220,860.00)	$ 82,890.00
2	$ (536,610.00)	$ 315,750.00	$ (220,860.00)	$ 398,640.00
3	$ (536,610.00)	$ 315,750.00	$ (220,860.00)	$ 714,390.00
4	$ (536,610.00)	$ 315,750.00	$ (220,860.00)	$ 1,030,140.00

Total Implementation Cost	$ 6,000.00
Money Saved By RC In Year 1	$ 309,750.00
Payback Period	**0.019**

Figure 26: Cumulative cashflow and payback period for regular staffing with revised checkout assuming reduction in staff

While the revised checkout system alone provides a faster payback period, the addition of the RFID system provides a greater return on investment over time.

Cost-Benefit without Reduced Staffing

This section covers the results of the economic analysis without any reduction of tool clerk staffing. Figure X below shows the estimated annual costs for each alternative in the first two years.

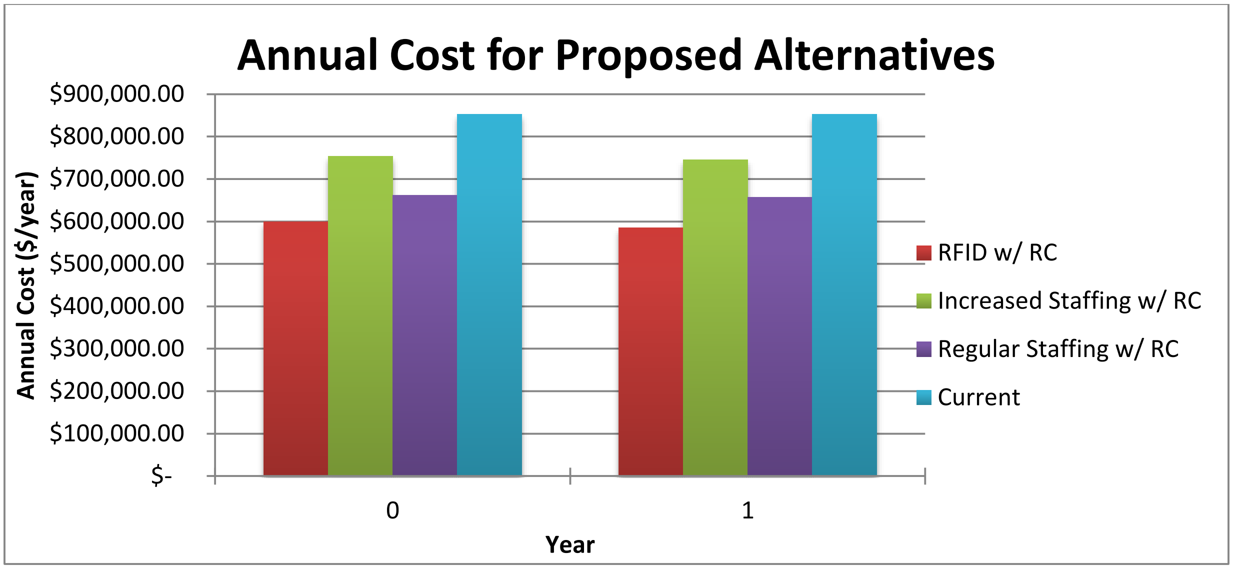


Figure 27: Annual cost for proposed alternatives in Year 0 and Year 1 assuming no reduction in staff

The results of this analysis led to the same conclusions as the analysis with reduced staffing, with the two best alternatives as the RFID system with the revised checkout and the revised checkout system alone. The results are summarized below:

RFID w/ RC versus Current

Year	Money Spent	Money Saved By RFID	Cashflow	Cumulative Cashflow
0	$ (599,471.00)	$ 252,889.00	$ (346,582.00)	$ (346,582.00)
1	$ (584,986.00)	$ 267,374.00	$ (317,612.00)	$ (79,208.00)
2	$ (584,986.00)	$ 267,374.00	$ (317,612.00)	$ 188,166.00
3	$ (584,986.00)	$ 267,374.00	$ (317,612.00)	$ 455,540.00
4	$ (584,986.00)	$ 267,374.00	$ (317,612.00)	$ 722,914.00

Total Implementation Cost	$ 17,165.00
Money Saved In Year 1	$ 252,889.00
Payback Period Year:	**0.068**

Figure 28: Cumulative cashflow and payback period for RFID system with revised checkout assuming no reduction in staff

Regular Staffing w/ RC versus Current

Year	Money Spent	Money Saved By RC	Cashflow	Cumulative Cashflow
0	$ (662,610.00)	$ 189,750.00	$ (472,860.00)	$ (472,860.00)
1	$ (656,610.00)	$ 195,750.00	$ (460,860.00)	$ (277,110.00)
2	$ (656,610.00)	$ 195,750.00	$ (460,860.00)	$ (81,360.00)
3	$ (656,610.00)	$ 195,750.00	$ (460,860.00)	$ 114,390.00
4	$ (656,610.00)	$ 195,750.00	$ (460,860.00)	$ 310,140.00

Total Implementation Cost	$ 6,000.00
Money Saved By RC In Year 1	$ 189,750.00
Payback Period	**0.032**

Figure 29: Cumulative cashflow and payback period for regular staffing with revised checkout assuming reduction in staff

Again, while the revised checkout system alone provides a faster payback period, the addition of the RFID system provides a greater return on investment over time.

Results and Conclusion

Check-in/out Process Re-Design

As stated in the design section, the team hoped to vastly reduce the number of steps by eliminating the repetitive inputting of information needed in each check-out through the use of database dependencies.

When these dependencies were applied to the Checkout process, the result was an almost 65% reduction in the amount of information required, along with a 50% reduction in steps, as can be seen in Figure 30 below.

Old Checkout Process	New Checkout Process	Percentage of Original
14 Pieces of Info	5 Pieces of Info	35.7%
14 Steps	7 Steps	50%

Figure 30: Number of steps and pieces of information required for input in the old checkout process versus the new checkout process

The new checkout process, as seen in Figure 31, requires none of the repetitive information as seen in Figure 2: M&TE Checkout Form. This information is now stored in the database where it can be accessed as needed, not during every checkout. The BadgeID, UserID, Job#, Op#, and QDT reference are the only required pieces of information needed at each checkout, and therefore are the only pieces of information in the new process.

1. Scan Badge
2. Select Check In
3. Scan Tool
4. Input Job Number
5. Input Op Number
6. Input QDT Y/N
7. Select Finish Check Out

Figure 31: New Checkout Process

Unfortunately the same savings are not seen in the check-in process by virtue of the design of the checkout station. The changes to the process can be seen in Figure 32 and Figure 33. Under the old paper form system, an employee was only required to record the time the tool was returned. With the new Check-In system, an employee must login with their badge and rescan or select the tool they checked out. While a system design that does not require a login for check-in could be implemented to further reduce these steps, it was chosen not to pursue this in an effort to curb tool hand-offs, as it would allow any employee to check a tool back in.

Old Check-In Process	New Check-In Process	Percentage of Original

1 Piece of Info	2 Pieces of Info	200%
1 Step	4 Steps	400%

Figure 32: Number of steps and pieces of information required for input in the old check-in process versus the new check-in process

1. Scan Badge
2. Select Check-in
3. Scan Tools
4. Select Finish Check-In

Note- Only employee who checked tool out or approved staff can check it back in

Figure 33: Number of steps and pieces of information required for input in the old check-in process versus the new check-in process

In total, even with the slight increase of steps for check-in, the new processes are much improved when compared to the old paper system. As seen in Figure 34 below, the total information required is 33.33% of the original, and steps needed have been reduced by over a quarter. Further, the addition of a database should keep checkout data uniform, and remove any errors due to legibility, transcription or issues with Database Normalization. Once fully implemented, an employee would only require their badge, tool, job #, operation #, and QDT reference to checkout and check-in a tool, compared to the 15 pieces of information previously required.

Old Process Total	New Process Total	Percentage of Original
15 Pieces of Info	5 Pieces of Info	33.33%
15 Steps	11 Steps	73.33%

Figure 34: Number of steps and pieces of information required for input in the old process versus the new process

Portal/Tag Testing

After completion of all testing trials, the average reads for each antenna were added together to develop the total average portal reads per tag orientation. This information can be seen in the figures below.

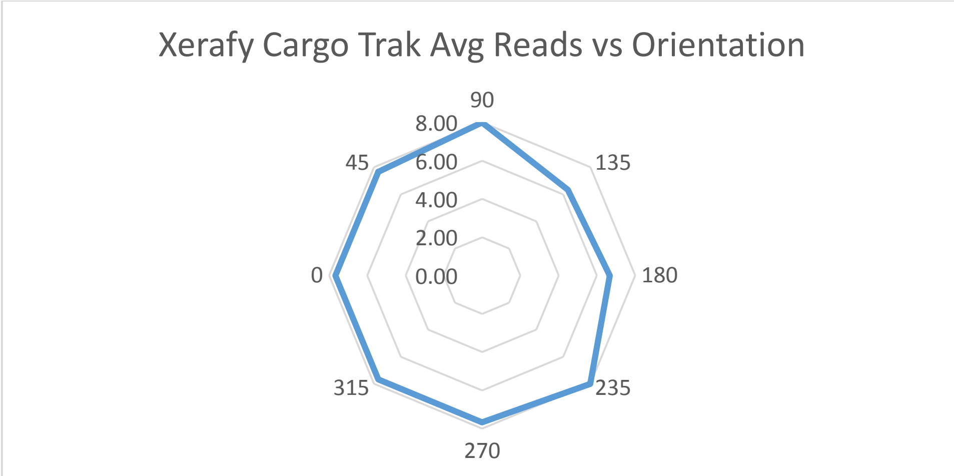


Figure 35: Xerafy Cargo Trak Average Reads vs Orientation

As seen by the circular shape of its reads vs orientation graph in Figure 35, the Xerafy Cargo Trak tag exhibited the most uniformity in reads throughout all orientations. The Cargo Trak tag also achieved the second highest number of average reads for all tested tags. As such, this tag is recommended second to the Confidex Ironside Slim tag, which has the highest number of reads.

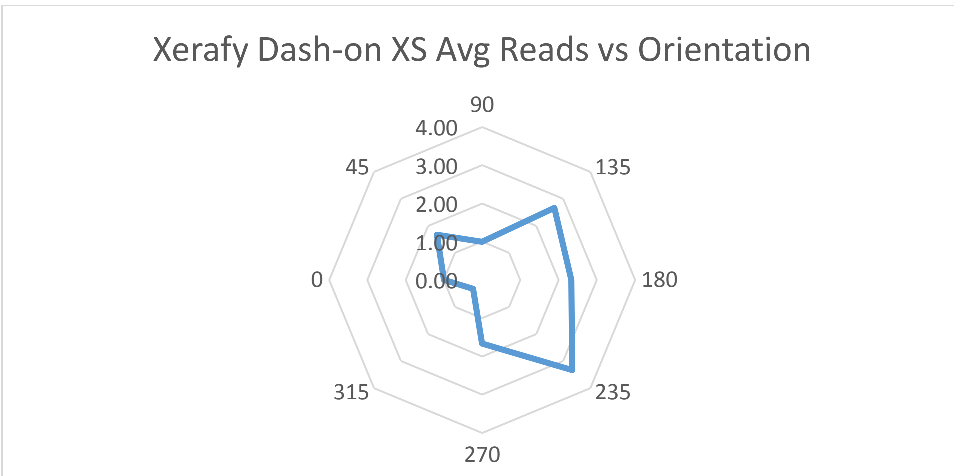


Figure 36: Xerafy Dash-on XS Average Reads vs Orientation

The Xerafy Dash-on XS was not a uniform performer, however. As seen in Figure 36, it achieved low read totals for most orientations, including an average under 1 for 315 degrees. As such, it is not recommended to use this tag for tool tracking in this implementation, as there is little guarantee it will be read every time. Max reads can be seen in orientations 135 through 235, when the tag was closest in position and orientation to antenna zero. This suggests that the tag requires very close proximity to the antenna, even though it has an advertised read range of 6.6 ft.

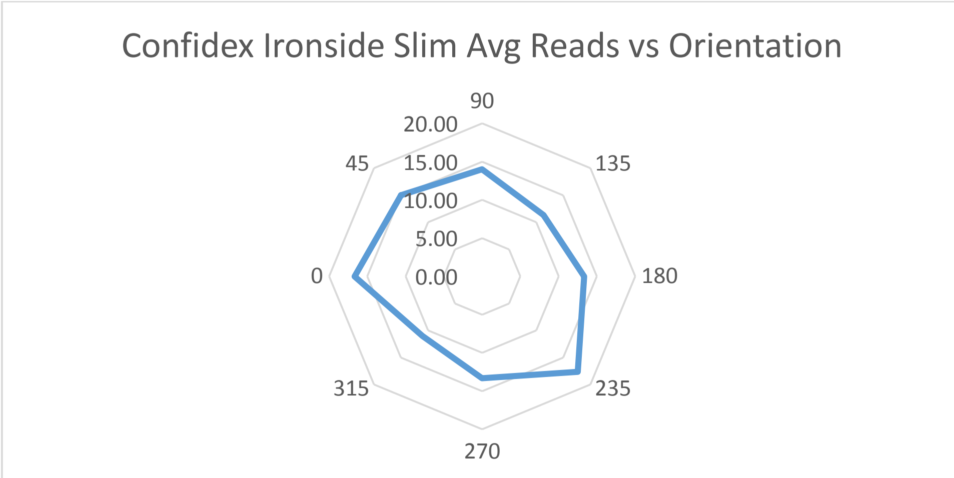


Figure 37: Confidex Ironside Slim Average Reads vs Orientation

The Confidex Ironside Slim Tag, shown in Figure 37, was the highest performer of the tested tags with respect to Total average reads. The tag routinely achieved 10 or more reads throughout each trial. While it may not have the high uniformity of the Xerafy Cargo Trak tag, the Ironside Slim recorded on average 1.88 times the amount of reads. Therefore, this tag is recommended for implementation as it is smaller than the Cargo Trak and achieved higher reads in every orientation.

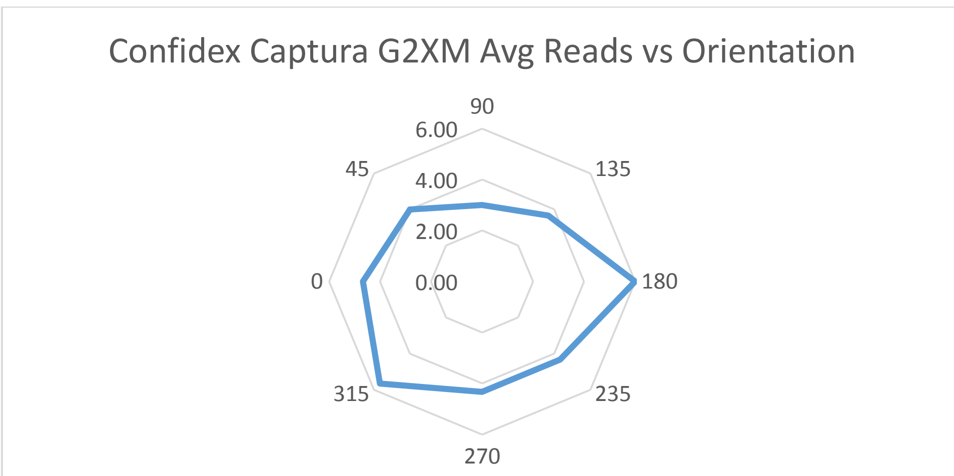


Figure 38: Confidex Captura G2XM Average Reads vs Orientation

Lastly comes the Confidex Captura G2XM, seen in Figure 38. This tag was chosen to be used with probe type tools not suitable for larger tags, and would be secured to a cable with its clasp and a zip-tie. While relatively uniform, at its worst it achieved 3 total reads at 90 degrees orientation. While this tag achieved consistent reads, other tags may require investigation if more reads can be achieved.

Multiple Tag/Tool Testing

Throughout the 3 testing trials, all tags achieved 100% readability with the exception of the Confidex Captura tag in trial 2, as seen summarized in Figure 39 and Figure 44 in the appendix. Though this tag exhibited the same sum of reads performance in these trials as in individual testing trials, these results are not consistent throughout each trial, again verifying that other tags should be researched for probe-style tools. However, the data does prove that our portal is capable of tracking 6 tools simultaneously, and would likely do so with 100% read accuracy had only recommended tags been used for testing. Recommended tags achieved read totals of 11 and 14.67, for the Xerafy Cargo Trak tags, and 15 for the Confidex Ironside Slim tag. As such, it is recommended that employees do not checkout more than 6 tools at a time, as our portal was not tested for 7 tools or more simultaneously.

Tag	Sum of Reads
Xerafy Cargo Trak	11
Xerafy Data Trak II	4.66
Omni-ID Pipe Tag	11
Xerafy Cargo Trak	14.66
Confidex Ironside Slim	15
Confidex Captura G2XM	3

Figure 39: 6 Tool Testing Summarized Data

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Appendix

Figure 40: Confidex Ironside Testing Data

Trial	1			2			3			Average			Sum
Antenna	0	1	2	0	1	2	0	1	2	0	1	2	
0	16	1	1	11	3	0	14	3	1	13.67	2.33	0.67	16.67
45	11	2	0	13	1	1	16	1	0	13.33	1.33	0.33	15.00
90	8	2	2	11	1	2	8	0	8	9.00	1.00	4.00	14.00
135	7	2	3	5	4	2	9	0	2	7.00	2.00	2.33	11.33
180	11	1	0	14	0	1	12	1	0	12.33	0.67	0.33	13.33
235	15	1	4	15	1	0	16	0	1	15.33	0.67	1.67	17.67
270	9	0	6	10	1	3	7	0	4	8.67	0.33	4.33	13.33
315	7	3	1	8	2	2	7	0	3	7.33	1.67	2.00	11.00

Figure 41: Confidex Captura G2XM Testing Data

Trial	1			2			3			Average			Sum
Antenna	0	1	2	0	1	2	0	1	2	0	1	2	
0	4	0	0	3	1	0	6	0	0	4.33	0.33	0.00	4.67
45	4	0	0	4	0	0	3	1	0	3.67	0.33	0.00	4.00
90	3	0	1	1	1	0	1	2	0	1.67	1.00	0.33	3.00
135	4	0	0	1	0	2	2	0	2	2.33	0.00	1.33	3.67
180	3	1	3	2	2	2	3	2	0	2.67	1.67	1.67	6.00
235	3	0	1	2	2	0	3	1	1	2.67	1.00	0.67	4.33
270	2	4	0	3	1	0	2	1	0	2.33	2.00	0.00	4.33
315	5	0	0	6	1	0	5	0	0	5.33	0.33	0.00	5.67

Figure 42: Xerafy Cargo Trak Testing Data

Trial	1			2			3			Average			Sum
Antenna	0	1	2	0	1	2	0	1	2	0	1	2	
0	2	2	3	0	3	4	3	3	3	1.67	2.67	3.33	7.67
45	5	1	2	4	3	0	2	3	3	3.67	2.33	1.67	7.67
90	3	4	0	4	4	1	3	2	3	3.33	3.33	1.33	8.00
135	6	1	0	6	0	0	3	3	0	5.00	1.33	0.00	6.33
180	8	0	0	4	1	0	6	1	0	6.00	0.67	0.00	6.67
235	8	0	0	9	0	0	7	0	0	8.00	0.00	0.00	8.00
270	7	0	0	8	0	0	7	0	1	7.33	0.00	0.33	7.67
315	0	3	4	0	2	6	0	2	6	0.00	2.33	5.33	7.67

Figure 43: Xerafy Dash-on XS

Trial	1			2			3			Average			Sum
Antenna	0	1	2	0	1	2	0	1	2	0	1	2	
0	0	0	1	0	0	1	0	0	1	0.00	0.00	1.00	1.00
45	0	0	2	0	0	2	0	0	1	0.00	0.00	1.67	1.67
90	1	0	1	0	0	0	1	0	0	0.67	0.00	0.33	1.00
135	0	3	0	0	3	0	0	2	0	0.00	2.67	0.00	2.67
180	0	3	0	1	1	0	0	2	0	0.33	2.00	0.00	2.33
235	3	0	0	4	0	0	3	0	0	3.33	0.00	0.00	3.33
270	1	0	0	3	0	0	1	0	0	1.67	0.00	0.00	1.67
315	0	0	0	0	0	0	0	0	1	0.00	0.00	0.33	0.33

Figure 44: 6 Tool Tag testing Data

Trial	1			2			3			Average			Sum
Antenna	0	1	2	0	1	2	0	1	2	0	1	2	
Xerafy Cargo Trak	6	5	1	4	5	1	4	6	1	4.67	5.33	1.00	11.00
Xerafy Data Trak II	2	1	1	1	3	0	2	4	0	1.67	2.67	0.33	4.67
Omni-ID Pipe Tag	7	3	1	4	4	1	7	1	5	6.00	2.67	2.33	11.00
Xerafy Cargo Trak	10	3	2	7	4	3	12	0	3	9.67	2.33	2.67	14.67
Confidex Ironside Slim	11	0	2	10	1	1	14	2	4	11.67	1.00	2.33	15.00
Confidex Captura G2XM	0	0	1	0	0	0	2	6	0	0.67	2.00	0.33	3.00