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Passive Radio Frequency Identification (RFID) and Museum Collections

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by
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Abstract

Keeping a collection organized and accounted for is a never-ending struggle for museums of every type. New to museums and the collections management field, Radio Frequency Identification is a growing technology that museums can implement to keep track of the location, status, condition, and movement of their objects. Objects are labeled with RFID "tags" which enable them to communicate custom information to a reader and ultimately a database. This implementation would save time, money, and stress among collections staff members. Using the Perot Museum of Nature and Science in Dallas, Texas, as my subject museum, I propose implementing a pilot program to test the viability of this RFID technology within the confines of a museum collection. A period of four months will be used to install and test an RFID system within a portion of the collection, after which data gathered will be used to determine the viability of the RFID system.

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Chapter 1: Executive Summary

For my museum studies capstone, I created a pilot project for RFID implementation at the Perot Museum of Nature and Science in Dallas, Texas. The Perot museum has a mission to "inspire minds through nature and science" and their collection reflects that. The Perot currently houses eleven permanent exhibit halls covering everything from gems, minerals, engineering, energy use, physics, and dinosaurs.

For my capstone project, I created a pilot project for the Perot that would allow them to test the viability of an RFID system within their collection without expending the resources normally required for such an implementation. In my pilot project, the Perot will tag and test over a period of months, specific objects within the collection. Namely objects from the ornithology, paleontology, mammalogy, and minerology collections. Though only samples of each collection, these objects represent a wide range of storage conditions and locations. Data from this initial pilot project can then be extrapolated to estimate the pros and cons of further and/or full scale implementation.

This document contains the detailed description of my capstone project. Chapter 2 contains a literature review of the current research on RFID tech as it applied to museums. Peer reviewed research is scarce so I have included research on libraries and RFID as well, drawing analogies between the two similar types of institutions. Chapter three contains my project proposal along with the goals and objectives of the pilot project. While chapter four contains a detailed action plan, laying out a timeline of actions and who will perform said actions. I have also provided a Gantt chart. Chapter five details my criteria for success in the pilot project as well as expected outcomes, and a few personal reflections on this capstone project as a whole. An annotated bibliography and bibliography follow chapter five to conclude my capstone.

Chapter 2: Literature Review and Background

Introduction

In order to explore the issue of RFID implementation in museum collections, this literature review will look at texts about associated costs, methods, case studies, and the technology behind RFID. In the first part of this paper, I will explain the technology behind RFID and its ability to improve the field of collections management. In the second part I will focus on case studies of libraries and museums with RFID implementation. Libraries, as a whole, are in front of the museum world in terms of RFID adoption for their collections management. Because so many parallels can be drawn between the two, and because relatively few museums have implemented RFID (and subsequently written about it), libraries will be looked at in respect to the costs, installation time, long-term viability, benefits, and potential issues faced. For the third and final part, I will discuss the current situation between RFID and museums, and their future.

The Tech Behind RFID

RFID technology was first developed in World War II as a method for detecting aircrafts (of any allegiance) from the ground. The British later refined this technique by adding a transmitter to their planes in order to identify friend and foe (Huang, 2009, p. 1). Though in its infancy, this early RFID system contained the same basic components as today's modern systems. All RFID systems contain two main parts, a radio frequency (RF) reader and a transponder, which work together to allow RF tagged objects to identify themselves through the use of radio frequencies (Ward & van Kranenburg, 2006, p. 4). Disregarding till later in this review the topic of data storage limits on RFID tags, the most basic RFID system is able to link a physical object to its history and information stored on a network or database. This can be seen as a third part and in describing this relationship between the components. Ward and van Kranenburg (2006) say,

> In principle, and on the very simplest level, RFID tags allow objects to say, “Hello, I’m here and my name is…”. When discussing digital ‘intelligence’ with regard to an object or environment we have to keep in mind that although there are different sorts of tags with different levels of computing capability, the main intelligence resides in the network or application connected to the RFID system. The main purpose of an RFID tag is to act as ‘glue’ to a digitally mediated world (p. 4).

These systems can work with either passive or active tags, but because passive tags are cheaper and better suited for museum applications than active ones (Zhu, Mukhopadhyay, Kurata, 2012, p. 153), we will focus on them in this review.

All passive RFID tags communicate in the same manner. The tags are comprised of an integrated circuit and an antenna that can send and receive radio waves. The circuit stores unique identifying information and the antenna provides the communications (Ward & van Kranenburg, 2006, p. 4). Passive tags contain no independent battery or power source and so only communicate when a signal is sent out by an RF reader. This communication is called backscatter and is limited in passive tags to ranges of up to a few meters. The three frequencies for passive tags are low, high, and ultra-high (UHF), which give typical read ranges of 30cm, 1m, and 3-5 meters (Roberts, 2006, p. 20).

RFID in Libraries

Libraries, just like museums and corporate businesses, benefit from greater asset control and improved efficiency. Thus, it makes sense that they would be some of the first institutions to adopt and employ RFID technology. “When libraries first began using RFID, the only viable tag for item-level tracking was an HF tag. This is because the read range of UHF is longer and more unwieldy than HF tags, and because early UHF tags encountered problems around metal and water (Ayre, 2012, p. 11).” UHF tags have since improved thanks to a mandate by Walmart requiring all major suppliers to implement UHF RFID into their supply chain systems (Zhu, Mukhopadhyay, Kurata, 2012, p. 153), but virtually all American library RFID systems are based off HF tags (Ayre, 2012, p. 11). Often, RFID tags are used as simple substitutions for barcodes, replacing the old technology with the new, but keeping the use the same. In these instances, the only data put onto the tag itself is a barcode number, effectively narrowing down RFID’s potential usefulness to that of an ‘any orientation, no line-of-sight required’ barcode.

Besides being a barcode replacement, current literature suggests that the usefulness of RFID can be greatly expanded in libraries. One use involves increased accuracy in inventories, providing a real-time look at the collection and its location. Hand held RFID readers have been used to perform accurate shelf reading, locating items that are on the wrong shelf. It has even been suggested that ‘open shelf’ libraries use RFID to monitor how often periodicals and magazines get read. Once removed from the shelf, a periodical’s or magazine’s tag can no longer be read by the permanent reader on the same shelf. By looking at these gaps in the data, libraries can see which items are used the most (Yu, 2007, p. 61). Self-service kiosks are also a potential use for RFID technology in libraries and using data from a survey from 2012, Ayre (2012) found that 98% of libraries using RFID were using it in part for self-checkout. However, of that 98%, only 35% saw patron self-checkout account for over 85% of checkouts (p. 12-13). As Ayre’s research shows, adoption of new technology will not always immediately lead to changes in visitor preferences. Therefore, says Curran & Porter, there should be dual options for the initial changeover period, and this may be phased out when customers become more comfortable with the new system (Curran & Porter, 2007, p. 603). The use of RFID in libraries shows great potential and the large-scale implementations across the globe are proof of this potential.

While museums have suffered from slow adoption rates of RFID, several very successful library implementations have been completed around the world. TAGSYS, an RFID manufacturing company, was behind the Shenzhen Library in China, the second largest library in the world, tagging over two million books (Curran & Porter, 2007, p. 603). The public library systems of Seattle, Washington, and New Orleans, Louisiana, also have tagged the majority if not all of their collections. Per Ayre, “One of the reasons RFID has not been more widely adopted in libraries is the lack of standards. Without standards, libraries couldn’t be assured that their significant investment would be worthwhile (Ayre, 2012, p. 20).” Such standards, thankfully, were adopted in 2012 in the US National Information Standards Organization (NISO) finalized standards that would see interoperability between libraries, publishers, and suppliers throughout the life of the book, regardless of which RFID company was used (Ayre, 2012, p. 22). With such standards now in place, libraries will not have to be hesitant about to committing to a technology with an uncertain future and because of this, we should expect to see the number of libraries implementing RFID technology to grow. This growth will show museums that RFID within non-profit collections can be a viable and important tool for collections management.

RFID Applied to the Cataloguing of Historical Plaster Moulds

RFID use is still in its infancy in the museum world. Most museums find that implementing new technology has costs associated with the hardware or software that are just too expensive for the perceived benefit (Buck & Gilmore 2010, p. 246). When RFID is implemented into a collection, benefits can range from decreased inventory times to the ability to track objects in real-time and more. Inventories can also be completed without having to touch, move, or handle the objects, something which was important to the Richard-Ginori porcelain factory in Sesto Fiorentino, Italy.

An article by Ciofi, Zappia, Balleri, & Gherardelli (2016) details the process of cataloging a large collection of plaster moulds belonging to an Italian porcelain factory (p.1). The collection, gathered over time, now consists of several thousand pieces, and serves as a valuable resource for those studying the sculptors of the 17th and 18th centuries. This cataloging process sought to create *smart objects* out of its moulds for better management of its warehouse. In this way, the digital information of a collection or catalogue can be bound to the physical objects (Ciofi, Zappia, Balleri, & Gherardelli, 2016, p. 2). The RFID system created for the porcelain warehouse involved tagging individual sets of moulds with an UHF RFID tag which could then be read with a mobile reader, bringing up the information from the database for viewing on the reader. The reader also has the capability to work with or without Wi-Fi access. The warehouse has no Wi-Fi and the cell service is spotty so it was decided that the system would adopt the approach of *eventual consistency* (Ciofi, Zappia, Balleri, & Gherardelli, 2016, p. 3), meaning that whatever information was gathered on the mobile reader or main server would be synced with the main data base once a Wi-Fi connection was established or the reader was docked to a computer. To monitor and avoid conflicts, the database can keep track of any conflicts and what was done to resolve them. Over a two-month period, 200 sets of moulds, were tagged with RFID tags as well as QR codes. (Ciofi, Zappia, Balleri, & Gherardelli, 2016, p. 5).

The benefits of an RFID system at the Richard-Ginori porcelain factory are multiple and aid in the long-term storage and management of the moulds. The system not only allowed accurate inventories to be completed but reduced the need to handle the fragile moulds. It was able to physically attach the digital object information to the moulds themselves in a manner which could not fade or be covered by dust, and reduced the risk of injury or object damage due to moving moulds to and from shelving. The system works with or without a wireless connection, and maintains consistency between the physical collection and the digital database in a manner faster and more efficient than previous methods. Museums can study this implementation and its successes in order to build on them and apply them to their own collections.

Tracking Museum Objects in Turkey

Research by (Çayırezmez, Aygün & Boz, 2013) suggests that Turkey would be an ideal country for RFID technology to be applied to monitoring inventories, tracking collections, and interactive museum displays (p. 315). This research states that while there are no globally standard methods for marking museum objects, common methods exist in Turkey, each carrying their own flaws. Recently, museums in Turkey have started to update their records into digital collections management systems through individual initiatives of staff members (Çayırezmez, Aygün & Boz, 2013, p. 316). Most importantly, this article lays out several points on why RFID is superior to barcode scanner systems. RFID offers unique identifiers for each object, they do not need to be visible or have a line of sight to be read and can be read simultaneously with other tags. Because a line of sight is not needed, RFID tags can work in rougher, dirtier conditions that a barcode would be obscured in. RFID tags have a larger storage capacity and are able to contain information on the object itself rather than just a simple ID number directing you to an entry in a database. The only negatives mentioned by the authors is the cost, and the relatively difficulty in obtaining blank tags compared to simply printing off more barcodes on site. RFID tags, meaning the circuit and accompanying antenna, are currently able to be printed on paper using conductive ink, but like all new technologies, the price has so far limited its feasibility (Curran & Porter, 2007, p. 597).

The areas in which Nurdan Çayırezmez, Hakan Aygün, and Levent Boz suggest implementation of RFID are several, but their main focus is on storing object associated data on the tags, and RFID tracking for museum artifacts (2013 p. 317). The article does make a point to mention that at the time of writing, no current applications of RFID systems exist in any of the museums run by Turkey's Ministry of Culture and Tourism. The authors suggest that collaboration between the museums, universities, and private companies will be the way forward towards bringing RFID into the Turkish museum world.

RFID Data Storage

As mentioned above, data storage on RFID tags is one of the major benefits of RFID technology. Not only can data be stored on a tag, but tags also can be made to offer read-write capabilities, giving the user the flexibility to modify the information stored on the tag as they see fit (Pais & Symonds, 2011, p.1). Passive UHF tags, which are becoming the most commonly used tag can store up to 32 Kilobytes of information which translates to roughly one thousand characters. Currently that is not enough storage space to entirely replicate every database entry on a tag, but it is a start, and the technology is only getting more efficient every year. Due to the advancing nature of RFID technology, standards have been put in place to ensure interoperability between current and future applications of RFID.

Design and Standards

Ayre (2012) mentions that early adopters of RFID technology have now been left behind as new standards are set (p. 20). However unfortunate this may be, the development of standards is a long term positive for RFID. One such standard is the frequency and power at which RFID readers are allowed to emit. Three main regional standards are used worldwide for the regions of Europe, the Americas, and Asia. Governing bodies regulate these standards. In the United States the standards are set by the Federal Communication Commission (FCC) (Bolic, Athalye & Li, 2010, p. 24). Though these radio wave frequency standards might appear different, they are actually close enough to allow for one tag to be suited for all ranges. Research on a Printed Dipole Antenna with a CPS Matching Circuit and Inductively Coupled Feed proved that is was possible for one tag to cover the whole spectrum of standards (Popović, 2011, p. 33).

Security

RFID by its very nature operates in a wireless capacity. Because of this, it is vulnerable to several kinds of security threats. Research by Huang (2009) details the various methods by which an RFID system's integrity might be compromised. RFID systems can be encoded but the signals are still sent wirelessly and therefore can be intercepted. This intercepted signal can be potentially decoded and read. Signals can also be sent out en masse in order to purposely disrupt a target signal, a method called jamming (Huang, 2009, p. 7). In a reverse type of jamming, signals can also be sent back to the reader en masse to create a tag collision. Tag collision happens whenever more than one tag responds at the exact same time as another, and purposefully overloading the number of backscatters to the reader can exaggerate the problem. When a tag collision happens, the reader is unable to receive the data from the tag, therefore this method of forced tag collision can render an RFID system inoperable. This method is also a type of Denial of Service attack (DOS), with a more common example being when 'hackers' flood a website with so much traffic that the servers can't keep up, shutting it down for as long as the attack goes on.

Thankfully, solutions exist that solve these security issues. Kill commands exist that would render a tag useless once it's initial purpose was fulfilled. This method is not suitable for museum collections as they need their tags to last as long as possible, but tags also can come with something called a modifiable bit (called a privacy bit). The privacy bit can either be activated or deactivated, allowing only authorized, recognized readers to communicate with the tag when active (Huang, 2009, p. 11).

For museum collections using passive UHF tags, the chances of having signals intercepted are avoidable due to the relatively short read ranges of passive tags. The strength of the reader does not matter when the backscatter from a passive tag is at most a few meters. This means that someone would essentially need to already be inside of the collection in order to begin reading tags, which would be larger security issue. Lastly, information needs to be on the tag in order for it to be vulnerable. If a museum has objects within their collection of high value they can simply use the RFID tag as an ID number linking it back to the system but without any object data on the tag itself. It also is an option to not tag certain highest value objects, while tagging the rest of the collection.

Cost

Cost is by far the primary issue that contemporary research on RFID mentions regarding mass implementation across all industries.

> Tag cost is often a key point of comparison among the various technology types. However, a complete RFID system also requires interrogators, label printers, software, and networking technologies to provide the value sought. Other cost components also include the manual labor to install, integrate, apply, and use the technology. (Bolic, 2010, p. 47)

This can seem like a daunting undertaking for museums. Museum budgets have trended towards public programs and exhibitions while cutting back on collections and conservation budgets (Nicks, 1999, p. 112). In-house solutions can be made for substantially less but that of course depends on having an employee with the knowledge and skill to construct such a system (Carey, 2014, p.91) For now it will be hard to prove the viability of RFID within a museum collection without at least a minimal budget to get your hands on some equipment.

Conclusion

RFID technology is still in its early stages of widespread implementation. The current research shows that the capability to improve collections management is there, it just needs to be utilized. Libraries have paved the way for museums, proving that complete RFID implementation can be beneficial for not only object tracking and inventory. When it comes to museums, we must remember that the technology behind RFID is of more importance than the current costs and limitations, as costs will eventually come down and limitations removed. That is the way of technological advancement. At the moment, costs are too high for the average museum to adopt, but planning for RFID implementation will allow for a quick a smooth transition once costs drop to achievable levels. An initial pilot project within a museum would be a more cost effective way to provide museums with evidence of RFID viability. In order to break the ice, if you will, on RFID in collections management, I am proposing a project plan that will outline the steps needed to test a museum collection for RFID viability, specifically the Perot Museum of Nature and Science in Dallas, Texas. In addition to providing steps for RFID implementation, this project plan can hopefully provide useful data for the Perot, as well as other museums considering RFID.

Chapter 3: Project Proposal

Introduction

The organization and record keeping of a museum's collection is an endless job, and it is often the regular inventories that are put to the side in favor of more immediate and demanding projects. A lack of regular inventories decreases object location accuracy and leads to confusion when those objects are needed from storage. Through implementation of RFID technology, regular inventories can be carried out routinely, and with more accuracy compared to other methods.

RFID technology has advanced to a point where implementation in museums makes sense, from both cost and practicability standpoints. The recent (2012) adoption of uniform RFID standards by the US National Information Standards Organization has also improved interoperability between institutions and manufacturers, providing a safeguard against any potential obsolescence of RFID tech. These developments have jumpstarted the adoption of RFID in museums around the world, and current research and literature proves these RFID implementations a success. Although a handful of RFID success stories is a positive for the museum community, each museum is different, and contains differing collections. Because of this, one museum's application of RFID may not work for another. This could be due to several factors including but not limited to type of collection, scale of implementation, and budget. I believe it is necessary to provide museums with a plan for RFID implementation, that instructs them on how to set up a pilot program from which they can determine the usefulness, accuracy, and other issues of an RFID system within their collection. I will be using the Perot Museum of Nature and Science in Dallas, Texas as my example museum.

The data from this initial pilot program can then be extrapolated to give the Perot a good view of what the costs and issues with an RFID implementation (full scale or partial) would be. Any project involving an entire collection can seem daunting, and this project plan seeks to alleviate some of those initial concerns.

Goal 1 – Testing Functionality

To prove the usefulness of an RFID system within a collection, a sample of objects representative of the larger collection must be tagged with RFID tags from which data must be gathered and studied by museum staff. For the Perot, this selection will include objects from the Ornithology, paleontology, and mammalogy collections.

Objective 1.1 – Tagging

For this pilot program, I have selected several parts of the collection to be tagged. These objects represent the larger collection in form and/or function as much as possible. By focusing on objects that represent the larger collection, the Perot can trust that the data that is recorded during the testing period will scale properly. Tags should then be applied over a three to four-week period.

I have decided that a three-month testing period should suffice for testing the viability of RFID technology within the Perot's collection. Three to four weeks set aside for physically tagging objects, and the rest of the time spent performing inventories, location checks, and system performance. A testing period of three months offers a short turnaround time from project start to finish, yet is long enough to allow for the data collection to be spaced out, freeing time for collections staff to carry out normal duties.

Objective 1.2 – Testing and Gathering Data

The second part of the RFID testing period will focus on testing the functionality of the RFID system within the Perot's collection environment. One of the most immediate benefits of RFID tagging is the quicker inventory times compared to previous methods. Inventories of the newly tagged objects should be carried out as many times as possible without becoming a disruption for the remaining two months in order to simulate months and/or years of inventories. The longevity and durability of the RFID technology is not what is being tested here, but rather the accuracy and precision of the system. Increased use of any RFID system might alert staff to potential issues they wouldn't normally run across until months or years down the line. By increasing use of the RFID system, I am attempting to reveal these issues before having fully committed to an RFID implementation. Are any RFID tagged objects ever skipped over by the reader? Is tag collision a problem in storage locations with many tags in close proximity? Is the signal from tag to reader disrupted by the storage environment or objects themselves? These are all very real problems that can be experienced, and they represent problems that are mitigated through careful use of the reader in relation to the tags themselves, and tweaking to the system.

Each inventory of the tagged collections should be timed and carried out from start to finish, taking no more than part of a single day, with problems and accuracy noted.

Goal 2 – Making the Decision

The next goal for this project will be to determine the viability of an RFID system within the Perot's specific collection through analysis of the data gathered in Goal 1.

Objective 2.1 – Interpretation

The findings should match the current research that says RFID tagging increases inventory speed, efficiency, and accuracy. The testing period should also provide an increased level of object location accuracy. These findings should then be compared to previous methods of inventorying and collections care.

Objective 2.2 - Comparisons

When making the comparison between the Perot's previous inventorying and location tracking methods and the RFID system, staff should keep in mind the limited scope of the test. While the increased efficiency and accuracy of the RFID system will be apparent within the test collection, the data should be extrapolated across the whole collection to then provide the clearest picture of how an RFID system will benefit the Perot. Once staff have a clear picture of the capabilities of an RFID system, they will be best situated to make the hardest decision of the process, cost.

The cost of an RFID system needs to be considered within the context of the data that will be gathered during the test period. RFID tags and equipment represent a one-time purchase yet a long-term savings. Shorter and more accurate inventories allow for more time to be allocated towards other projects which increases productivity. Time is also not wasted tracking down lost items. It is also important to remember that in non-profit settings, museums are for the publics benefit. Increased knowledge and accuracy of any museum collection will benefit the public immensely through increased programming and access to the collections. Many of the costs and benefits of an RFID system are quantifiable but it is important to acknowledge the intangibles as well.

Conclusion

Using a small sample size, the Perot should be able to use this project plan to estimate the costs and benefits of implementing an RFID system across their entire collection. RFID systems are not an all or nothing situation and it should be stated that any improvement, partial or complete, to a collections management system, is a step in the right direction. Many museums like the Perot, with large collections, still do not have 100% of their collection in digital form. Yet the benefits of transitioning off card catalogues to electronic collections management systems are clear. The same can be said with RFID. This project will hopefully encourage other museums to invest in RFID as well.

Chapter 4: Action Plan

A successful implementation of RFID technology within the Perot's collection requires a detailed action plan. This action plan will cover each step of the implementation in detail as well as provide a rough timeline for the project. This action plan will also assign aspects of the project between the collections staff, and any volunteers or interns. A more accurate timeline will be located on the Gantt Chart provided.

Objective 1 – Preparation

1.1 - Assess the collection (week 1)

- Meeting 1
    - In this initial meeting, it is assumed that the Perot Museum and the Collections department are in favor of carrying out an RFID pilot program within the confines of their collection. Therefore, this preliminary meeting which is run by the collections manager will focus on brainstorming and assessing which portion of the collection is best suited for testing RFID. Nothing needs to be finalized yet.

1.2 - Decide which objects to tag (week 1)

- Meeting 2
    - The portion of the collection that will be tagged with RFID labels should be decided upon during this meeting. After a decision has been made, discussion should switch to purchasing equipment. At minimum, an RFID reader and labels need to be purchased. Supplemental items such as antennas (used in location tracking) go just beyond the scope of this project. Several different options for readers and tags exist from standalone readers to smart phone add-ons. The standalone readers range from around $1200- $4000 while the smartphone add-ons cost between $500-$1000. Because this project is assuming the expenses fit into the regular budget, and that the RFID system will eventually be tied into the current collections software, a standalone reader will be purchased as it offers greater functionality without relying on a smartphone app to function. After this meeting the collections manager and the assistant collections manager should reach a consensus on which RFID tags and peripherals to purchase. A good retailer for RFID materials is https://www.atlasrfidstore.com/ and my prices and selection are based on that.
    - Within the Perot's collection several types of objects are suitable to RFID testing. I have chosen to tag a portion of the mammal study skin collection, a portion of the mineral collection, a portion of the fossil collection, and a portion of the ornithology collection. This range of objects will cover a wide selection of tag location types, storage locations and storage materials (metal drawers in metal cabinet, metal shelves on open shelving, wooden drawers in wooden cabinet).

This range of objects will also see RFID labels affixed to varying surfaces (paper tags, cardboard trays, and directly on the objects). These surfaces represent a majority of the collection, allowing the Perot to successfully estimate cost, time, efficiency, and practicality in the event of a full implementation.
- In total 400-500 objects will be tagged for this project.

1.3 - Order RFID supplies (week 2)

- One Alien Technology ALR-H450 RFID reader, 200 Alien Short RFID White Wet Inlay tags and 300 Alien SIT RFID Wet Inlay tags will be ordered. Wet Inlay simply means that the tags come with an adhesive which makes affixing labels easier. The set of 300 tags have a short-read range of about 6 inches and should prove useful in the study skin cabinets containing many close-quartered specimens. The cabinets are made of metal, so the tags shouldn't read through from drawer to drawer, but just in case they do, the limited read range of the Alien Short should minimize this issue, if reading a whole cabinet at once can really be called an issue. The set of 200 tags have a far larger read range of around 10 feet and will be useful for the ornithology collection which has specimens stored on high deep shelving and on wire racks lining the perimeter of the room.
- The ALR-H450 reader features several features that will be useful to a museum setting.
  - Circular antenna means that tags can be read without having to match up the orientations of the reader and tag, meaning collections of open objects will be easy to read. The full keyboard allows for a quick data entry. Wi-Fi and Bluetooth capabilities allowing for wireless syncing. It also comes with a barcode scanner for any institutions that use barcodes, this reader can replace an old barcode scanner AND read RFID. Great for bridging the gap between technologies while the transition to RFID is fully implemented. (www.atlasrfidstore.com/alien-alr-handheld-rfid-reader)
- Total cost of these products via atlasrfidstore.com is $1,879.

1.4 (Optional) - Integrate RFID capability into collections management system (weeks 2-4)

- I am designating this step as optional because collections software at many museums is renewed on a yearly subscription basis and upgrading the software to integrate RFID tech may not be so simple as sending an update. Software companies may also be reluctant to send technicians out to customize software for one specific museum. The good news, is that in its base form RFID is simply linking a tag's ID with a corresponding entry in the collections database, exactly like a barcode. Because most software already has barcode capabilities it is theoretically (from a non-technical standpoint) easy to integrate RFID into any current system.
- Thankfully, the technology itself does not need to be linked with the museums specific collections software to operate. It uses open source Android so it can work with most open source database software.
- Integration into collections management software is essential to the full utilization of RFID technology, however I do not want this project to be hampered and drawn out by having to deal with software integration and trouble shooting. The point of this project is to show the viability of the RFID tech, not to begin the steps of full adoption.

1.5 - Finalize a schedule for collections department and any stakeholders (weeks 3-4)

- After ordering the materials needed for the RFID pilot, the time can be spent sending a finalized schedule of the implementation to any relevant employees. This can also be the time to inform any regular volunteers of their participation in the program. The Perot has several volunteers that come in on a regular basis once or twice a week. And they will prove invaluable in assisting with the initial tagging.
- The collections manager will create and send out this finalized schedule to the collections department and any volunteers. This schedule should also give an overview of the project to those not directly involved.

Objective 2 - Implementation

2.1 - Begin the tagging (weeks 5-7)

- The next three weeks should be spent tagging the predetermined objects from the collection. The lead on this portion of the project will be the assistant collections manager. The collections manager will then have more time for regular duties and will be able to assist as needed. Regular oversight of the volunteers will fall to the assistant collections manager.

2.2 - Testing (weeks 8-15)

- Regular inventories
    - Inventories of the new RFID system should be performed a minimum of twice a week for the entire 8-week testing period. The ornithology collection is stored at a different location than the rest of the collection and will most likely only be inventoried the minimum amount of times per week by the assistant collections manager. The mammal study skin collection, mineral collection, and fossil collection can be inventoried more frequently because they are stored in the same building as the collections department offices. A daily inventory is certainly feasible with only several hundred items to read with the RFID reader.
    - Inventories should be carried out by either the assistant collections manager or a volunteer under supervision (at least initially). The time that the inventory was performed should be recorded as well as the length of time it took for the inventory to be completed. This will allow the Perot to estimate future inventories in the event of full RFID implementation. Increased inventory speeds will also allow the Perot to regularly perform full inventories of RFID-tagged objects, leading to greater intellectual control of the collection and increased access to the public and researchers.
- Tag read distance
    - During these regular inventories, attention should be paid to the read distances of the RFID reader. Are the read distances greater or lesser than the manufacturer advertised? Does the reader need to be precisely scanned over the tagged objects? Does the read distance suit the application it has been used for? These all should be recorded during the initial inventories and then monitored for any changes over the 8-week period.
- Tag read accuracy

  - During the testing period, different methods of reading should be tried in order to see the full extent of the RFID systems read accuracy. The tags communicate over time frames of milliseconds but it is still important to see whether a slow thorough wave of the reader over the objects will read more accurately than a quick pass over the objects. Different methods of reading will help to discover the margin for error.
- Trouble Shooting
  - Lastly, the collections staff and their volunteers should look out for any potential problems involving regular use of the RFID system. Are the traditional methods of object storage at the Perot conducive to an RFID system? Are objects too close, obscured, cluttered, or otherwise inaccessible to the reader? Specific tags were ordered so that problems like these could be avoided but hands-on experience with an RFID system in the Perot's collection is necessary before ruling anything out. All trouble spots should be noted.
  - Users of the RFID system should make a note of any quirks in the system or learning curves so that future users wont struggle to get their inventories up and running. The goal is to make inventories as effortless as possible so knowing the ins and outs of how the system functions "in the field" is important.
- (Optional) Integration with current collections management system
  - If integration of RFID tech into the current collections database was opted for from the beginning it will be useful to test how well the RFID system communicates with the collections software and the museums network.
  - Test syncing speeds via Wi-Fi and via the provided syncing dock.

2.3 - Gathering data (weeks 8-15)

- During the 8-week testing period, data from the use of the RFID system should be recorded and stored. Data on tag read accuracy, read distance, inventory times, users working with the system, and general use should be collected. The Assistant Collections Manager should gather the data and keep the Collections Manager up to date on any developments.
- Collating the data
  - Data should be organized as it is received, allowing for trends to be predicted during and immediately following the testing period.

2.4 - Monthly Updates (weeks 5, 9, 13, 17)

- Once a month the collections manager should write the department and stakeholders with an update on how the project is coming. This is new technology to the museum field so photographs of staff members and volunteers affixing tags, using the RFID Reader, and performing inventories should be included to give visual context to the scale of the project. Pictures will be useful in proving that RFID tech integrates seamlessly with the collection and is not an obstruction to current storage methods.
- Week 17's update should also include findings of the project and any conclusions that were reached regarding further RFID implementation within the collection.

Objective 3 – Data Analysis, Conclusions, Extrapolation

3.1 - Analysis of data (week 16)

- The last week of the project should be spent analyzing the data gathered from the testing period. "System use" data such as read accuracy, read range, and other technical aspects should be analyzed. This data should then be compared to previous inventory and record keeping methods.
- While previous steps in the action plan were meant to be accomplished alongside regular duties, analysis should be a focused task of the Collections Manager and Assistant Collections Manager during week 16.

Conclusion

Collections stewardship is a time-consuming, never ending task. With an RFID system in place, this task can be improved upon through increased efficiency, accuracy, and speed. Increases in these areas lead to more regular inventories which in turn lead to greater control over a collection. Implementation of an RFID system within a museum collection can only increase the level of stewardship shown towards a collection. The purpose of this project plan is merely to show the viability of RFID within a collection, but hopefully after four months of planning and testing, an RFID system will also prove itself a necessity going forward.

Please see Appendix C for the action plan Gantt chart.

Chapter 5: Criteria for Success and Evaluation

To measure the success of this Radio Frequency pilot, the collections department at the Perot will simply need to examine the data gathered during phase 2.2 in the action plan. Rates of tag read accuracy, frequency of tag collision, and average inventory completion times, among others, will be used to determine the viability of the RFID pilot and its further implementation. The scope of this project is to prove the viability of an RFID system within the Perot's collection, and my aim is merely to show that if in place, an RFID system will work and prove a benefit to the collections staff. It is easy to praise and write about the benefits of an RFID system, but facts speak loudest. Therefore, a pilot program followed by objective statistical analysis of gathered data is the most appropriate method of evaluation for this project.

In a successful RFID pilot at the Perot, the RFID system will be simple to operate and more importantly, come with a low learning curve for staff members, volunteers, and interns. Additionally, analysis of the data gathered will show decreased inventory times with minimal technical issues, and this data will allow the Perot to calculate (and realize) the immediate and long-term benefits of an RFID implementation within the confines of their collection. The staff will also have become comfortable with their RFID system, and will feel assured about any further challenges a collection-wide RFID implementation might bring.

An unsuccessful implementation would have experienced a very high learning curve with some volunteers and staff members struggling to operate the RFID system successfully. Technical issues, such as frequent tag collision and an inability to correctly read the RFID tags would be a constant problem. Whether due to user error or environmental concerns of the collections areas, these issues would in turn, slow down inventory times and efficiency, making the transition to RFID non-viable from an efficiency standpoint. It is hard to imagine every potential problem in a system with so many different parts and factors, but any unanswered questions or concerns will be revealed during the pilot project through regular use of the RFID system. After the success of the project has been evaluated, the next step is either to expand or cease RFID implementation.

If the pilot project has proven a success and the Perot wishes to expand to further portions of the collection the next step would be to determine whether to invest in an RFID printer. An RFID printer is simply a printer that can print barcodes, labels, logos, or anything else on the RFID tag, while simultaneously encoding the RFID tags with unique ID's. Rolls of blank RFID tags can be purchased in bulk to be encoded (with an accession number) by the printer. This is not only faster, but more accurate than having an employee hand encode each tag via the reader. RFID printers cost several thousand dollars so it is important to weigh the manpower hours potentially spent hand encoding tags against the cost of the printer (Armstrong 1). RFID implementation to the entire collection at the Perot would justify an expense like an RFID printer, while a partial expansion may not.

My journey into RFID technology began in the spring of 2015, several months before I had decided on a topic for my capstone. RFID seemed like the perfectly simple way to maintain and increase intellectual control over a collection. It is clearly more complicated than that, but with some careful planning that stays within the limits of the technology, an RFID system can be put in place to give collections staff control over their objects like never before. It would also give museums an unprecedented opportunity to make their collections databases up-to-date to a degree currently not practical for larger institutions, allowing for faster responses to research inquiries. Large nationwide inquiries such as those that were required by the Native American Graves Protection and Repatriation Act (1990) could be completed more quickly and efficiently.

Affecting social and cultural change is not within the scope of this project, but it is nice to see how changes in collections management practices could possibly serve as a catalyst for greater social change via museums.

Appendix A: Annotated Bibliography and References

Ayre, L. (2012, July) RFID in Libraries: A Step Toward Interoperability. *Library Technology Reports, 48*(5), 1-38.

This report covers RFID implementation in libraries from the beginnings in 1999 to today. It also explains how RFID works for identification, security, and object handling. Most important to my research is the chapter on RFID standards. RFID standards allow libraries to feel secure in their switch to RFID based collections management systems. They also ensure the long-term viability of the RFID tags and systems, guaranteeing that a library's investment will not become obsolete due to routine advances in RFID tech.

Bolic, M., Athalye, A., & Li, T. H. (2010). *Performance of passive UHF RFID systems in practice*. John Wiley & Sons Ltd: Chichester, West Sussex, UK.

This book, first published in 2010, is a comprehensive guide to the technology behind Ultra High Frequency RFID systems. It has chapters on RFID tag design, UHF RFID antennas, chip design, tag collision troubleshooting, improving read ranges, security, privacy, and other technical aspects. Most important to my research will be the chapters on tag collision, security, and the chapters on chip and antenna design. This book is not a case study on implementation of RFID tags, rather, it is a look at the technology and design behind passive UHF RFID tags. The authors also include their own parameters for an "ideal RFID system" which will be useful to me in planning RFID systems for museums. Their parameters are not specific to any industry but instead focus on the technical aspects. "High level of security, accurate tag reading, easy integration into existing software" are all some of the requirements of the book's ideal RFID system.

Buck, R. A., & Gilmore, J. A. (Eds.). (2010). *MRM5: Museum registration methods*. AAM Press, American Association of Museums.

As an all-encompassing museum registration textbook, this book has information on the care and storage of objects in a museum's collection. This book was written to be a reference for museum professionals and registrars across the country. Of particular interest to me was chapter 5E on marking objects. The chapter goes into detail on the different methods of marking museum objects, including a short section on the use of RFID. It is important to my research to prove why RFID would be useful in a collections setting and to do this I need to know the benefits and drawbacks of other methods of marking.

Çayırezmez, N. A., Aygün, H. M., & Boz, L. (2013, October). Suggestion of RFID technology for tracking museum objects in Turkey. In *Digital Heritage International Congress (Digital Heritage), 2013* (Vol. 2, pp. 315-318). IEEE.

This article looks at Turkish museums and the possible implementation of RFID technology to protect its cultural artifacts and heritage. It examines the conditions of Turkish museums run by the Ministry of Culture and Tourism. Of particular interest to my research are the comparisons against other technologies such as barcodes. The article also briefly mentions movement tracking via RFID. The article argues that while RFID technology can be beneficial to museums in Turkey and abroad, collaboration between researchers, museums, and private companies will be necessary before it is ever implemented in a state run museum.

Carey, J. (2014). The Future in Three Stages: Managing a Health Sciences Collection through Multiple Moves in an Urban Setting. *Collection Management*, *39*(2-3), 77-95.

This article from 2014 describes the challenges faced when moving a library collection, specifically the health sciences library from Hunter College in New York City. Of interest to my research was the mention of an RFID trial concept implemented by a librarian in 2011 using a custom-built RFID reader and accompanying software. The trial proved a success and RFID implementation began on the rest of the collection. This serves as the inspiration for my pilot project within the Perot's collection.

Ciofi, L., Zappia, I., Balleri, R., & Gherardelli, M. (2016). RFID applied to the cataloguing of a collection of historical plaster moulds. *Journal of Cultural Heritage*.

This case study details the process of adding RFID technology to the historic plaster moulds at an Italian porcelain factory. A prototype RFID system was put in place and tested on a set of 200 moulds. This article is helpful towards my research because it is not only recent (January 2016) but it has proven itself to be a success. The moulds themselves are quite fragile and to be identified they needed to be handled. RFID tags were applied to the moulds in order to be able to more efficiently identify moulds without having to bring them down from the warehouse shelves, which is time consuming and potentially damaging to the moulds. This case study is also an excellent example of how RFID and other technology can work in tandem. The RFID tags are integrated into the factories digital database which updates automatically. The case study also came across several issues such as wireless dead spots and came up with solutions for them.

Curran, K., & Porter, M. (2007). A primer on radio frequency identification for libraries. *Library Hi Tech*, *25*(4), 595-611.

This article gives an overview of RFID technology and its applications within libraries. As I state in other annotations, libraries and museums share many similar qualities when it comes to inventory management and thus, any successful application of RFID in libraries should be looked at when studying the possibility of transitioning RFID into museums. Unlike my other sources on RFID use in libraries, Curran and Porter go into detail using a specific library for reference. This article uses the University of Ulster in Norther Ireland as a case study of sorts, and they use this to create a prototype RFID system that would fit with the library's needs.

Huang, C. H. (2009). An overview of RFID technology, application, and security/privacy threats and solutions. *Masters in Computer Engineering, Scholarly paper, Spring*.

This paper by Chia-hung Huang gives an overview of RFID technology, applications, and security/privacy threats. Most useful for my research is the section on security/privacy and limiting these threats. Adoption of any new technology in a widespread manner will require museums to feel that their assets are secured and safe while on display, on loan, or in storage. It is important to stress to museums that not just anyone can read an RFID tag if they have a reader and there are secure methods of restricting access to the right people in the same manner as a modern collections database is secured.

Nicks, J. (1999). Planning for Collections. In G. D. Lord & B. Lord (Eds.), *The Manual of Museum Planning* (pp. 109-139). Walnut Creek, California: Alta Mira Press.

The Manual of Museum Planning serves as a guide to museum professionals wishing to make smart decisions about the long-term futures of their institutions. As they say in the preface, "…careful planning is also required for the design and implementations of structures and exhibitions.". For my research, chapter 7 on collections management proves useful as it lays out the importance of collections to museums. The book also uses several charts, graphs, and tables to show how operating costs are split up within a museum budget. Collections departments are often overlooked when it comes to getting a larger share of the yearly budget, and the data provided by the John Nicks helps build an argument towards implementing RFID tech in collections.

Pais, S., & Symonds, J. (2011). Data storage on a RFID tag for a distributed system. *International Journal of UbiComp, 2*(2), 29.

In this May 2011 article in the Journal of UbiComp, proper data storage formats and limits are discussed for RFID tags. The authors, Sarita Pais, and Judith Symonds did a preliminary study on which types of data storage would be most appropriate for RFID tags, resulting in promising results that prove their proof of concept. Their proposed method of RFID data storage is called data-on-tag and is essentially storing data other than a simple id number on a tag. As they state in their conclusions, adoption of these methods is promising, but not guaranteed because the concept is reliant on the advancing tech and storage capabilities of RFID tags. This article is important to my research because extended data storage on an RFID tag would help them compete against simple labels and more traditional forms of museum cataloging, in which most if not all of an object's relevant information can be placed.

Popović, N. (2011). UHF RFID Antenna: Printed Dipole Antenna with a CPS Matching Circuit and Inductively Coupled Feed. *International Journal of Radio Frequency Identification & Wireless Sensor Networks*, *1*(1), 28-33.

This paper by Nenad Popović presents “simulated and measured results of Ultra High Frequency (UHF) antenna realized with a dipole matched to a Coplanar Stripline (CPS) and inductively coupled with a small rectangular loop.” (Popović 1) In this brief review, Popović discusses the benefits of his findings, including lowering costs of RFID antenna manufacturing, and improving efficiency through reduced impedance between antenna and reader. This RFID antenna is also able to cover the entire UHF RFID band, matching the different standards of use for the USA, Europe, and Asia. The paper also mentions manufacturers of RFID chips which I have been able to look up and research for the types of RFID chips they offer.

Roberts, C. M. (2006). Radio frequency identification (RFID). *Computers & Security*, *25*(1), 18-26.

This article is a general review of RFID and the technology. It includes information relevant to my research such as RFID standards, data, operation, frequency ranges, and security. Most useful to this capstone was the information RFID frequencies and tag classes.

Ward, M., Van Kranenburg, R., & Backhouse, G. (2006). RFID: Frequency, standards, adoption, and innovation. *JISC Technology and Standards Watch*,*5*.

This journal article, like many other articles in my research, gives an overview of RFID technologies currently available, standards, and adoption rates in various industries. Most important to my research is the section devoted to RFID implementation in libraries. The authors state that "libraries are likely to initiate most of the [RFID] activity over the next five years or so…". In terms of asset management, museums and libraries share many similarities, and these successes in library implementation of RFID can be applied with the same effect to many types of museum collections.

Yu, S. C. (2007). RFID implementation and benefits in libraries. *The Electronic Library*, *25*(1), 54-64.

This article focuses solely on the benefits of implementing RFID tags into libraries. In addition to focusing on the many applications of RFID in libraries, this article also focuses on many of the drawbacks for RFID implementation, namely cost, privacy, security, and access rate. Libraries and museums both can have astoundingly large collections, and the cost of implementing RFID to whole collections can be insurmountable, but partial implementation for specific collections has the potential to be cost efficient to libraries. This can be applied to museums as well, specifically for collections that rotate in and out of display, or on loan to other museums.

Zhu, X., Mukhopadhyay, S. K., & Kurata, H. (2012). A review of RFID technology and its managerial applications in different industries. *Journal of Engineering and Technology Management, 29*(1), 152-167.

In this review, RFID technology is looked at through its many uses in different industries such as retail, restaurants, travel, and tourism, and most importantly to my research, libraries. Any research done on libraries and RFID implementation will be useful to my research because they overlap with museums in many ways, and the successes of RFID implementation in libraries need little tweaking in order to be moved over to a museum collection. This article also goes into detail about the tech behind RFID as well as the costs associated with RFID implementation.

References

Armstrong, Shain. (2013, April) *When Should I Invest in an RFID Printer?* Retrieved from http://blog.atlasrfidstore.com/rfid-printer-when-should-i-invest.

Appendix B: Project Stakeholders

The Organization - Perot Museum of Nature and Science

A merger between three Dallas museums: the Dallas Museum of Natural History, The Science Place, and the Dallas Children's Museum, created the Museum of Nature & Science at Fair Park in 2006. A new location was to be built in Victory Park and because of a $50 million donation the Perot family, the museum would be named the Perot Museum of Nature and Science. The new $185 million building opened its doors to the public on December 1, 2012 and per its 2015 annual report it has had over 3,874,868 visitors in the first three years of its existence. The building does more than capture the attentions of visitors though, as in 2015 alone the building collected over 250,000 gallons of rainwater to recycle through its cistern system and has a "4 green globes" rating by the Green Building Initiative, something shared by only 12 other buildings in the US as of 2013. In 2016 the museum also earned the maximum 3 Michelin Green Guide stars, a rating only four other Dallas attractions share.

The Fair Park facility remains home to the Research and Collections department and the Education Outreach Team while the new museum is home to 11 permanent exhibit halls covering everything from gems, minerals, engineering, energy use, physics, and of course dinosaurs. Key exhibit halls include the Discovering Life Hall, Texas Instruments Engineering and Innovation Hall, Being Human Hall, Lydia Hill Gems and Minerals Hall, T. Boone Pickens Life Then and Now Hall, and the Tom Hunt Energy Hall.

The Perot Museum has attracted some notable donors including: Dallas Cowboys owner Jerry Jones, T. Boone Pickens, Tom Hunt, Texas Instruments, Lockheed Martin, and the museum's namesake, the Perot family. It had an endowment of $19.5 million in FY2015 and total revenues and support of $28.5 million, bringing its net assets to just under $200 million. Its functional expenses for FY2015 were roughly $34 million dollars with 35% of that going towards programming.

In addition to traditional exhibit halls the Perot also offers strives to inspire science education in the minds of school children. In their own words, "Future scientists, mathematicians, and engineers will find inspiration and education through interactive exhibits multimedia presentations and vivid contextual displays." To inspire this learning the museum provides workshops, lectures, field trips, labs, after school programs and summer programs for children. During the FY2015 the Perot hosted 6,500 school field trips, and served guests from all 50 states and 25 different countries. The museum also acts as a resource for educators and teachers seeking professional development.

Organizational Stakeholders

- Collections Manager
    - The collections manager will be responsible for the initial assessment of the collection and the ordering of RFID supplies. The collections manager will be the main contact between the collections department and the rest of the museum, giving monthly updates on the progress and findings of the pilot program. The Collections Manager is also responsible for creating the implementation and testing schedule, including coordinating with volunteers on their availability.
- Assistant Collections Manager
    - Working alongside the collections manager during the assessment and tagging periods. The ACM will head the testing portion of the pilot project. The ACM will also supervise any volunteers helping out with the testing period. The ACM answers directly to the Collections Manager and will assist in the data analysis during the final week of the project.
- Volunteers
    - Volunteers will assist in the tagging, testing, and gathering data sections of the pilot project under the supervision of the ACM. They will coordinate their schedules and availability with the Collections Manager.

Other Stakeholders

- Atlas RFID
    - Atlas RFID, an online retailer for RFID materials and supplies with serve as the vendor for this pilot project. They will have no actual knowledge or involvement with the pilot project itself.

Appendix C: Action Plan Gantt Chart

RFID Implementation Timeline: Perot Museum of Nature and Science

January 4 - May 5, 2017				**January**				**February**				**March**				**April**				**May**
Tasks	**Start**	**End**	**Team Member**	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1
Meeting 1 - Assess the Collection	1/4/2017	1/4/2017	CM, ACM	■																
Meeting 2 - Which Objects to Tag?	1/6/2017	1/6/2017	CM, ACM	■																
Ordering Supplies	1/9/2017	1/13/2017	CM		■															
(Optional) Integrate RFID into CMS	1/9/2017	2/3/2017	CM, ACM, Tech Support		■	■	■													
Finalize Completion Schedule	1/16/2017	2/3/2017	CM			■	■													
Tagging the Collection	2/6/2017	2/24/2017	ACM, Volunteers, CM					■	■	■										
Monthly updates (1,2,3,Final)	2/3/2017	5/5/2017	CM					■				■				■				■
Testing	2/27/2017	4/21/2017	ACM, Volunteers								■	■	■	■	■	■	■	■		
Gathering Data	2/27/2017	4/21/2017	ACM, Volunteers								■	■	■	■	■	■	■	■		
Analysis of Data	4/24/2017	4/28/2017	ACM, CM																■	
Conclusions sent with final update	5/5/2017	5/5/2017	CM																	■

CM	Collections Manager
ACM	Assistant Collections Manager