Integration of RFID into the Rural Education School System

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Abstract

Barcodes are ubiquitous in today's world, facilitating diverse functions from retail transactions to access control. In rural education systems, barcodes are commonly used to track inventory, meeting state mandates for items purchased with state funds. However, the traditional one-dimensional (1D) barcode system, despite its utility, is labor-intensive and time-consuming, particularly during yearly audits.

This project explores the feasibility of integrating Radio Frequency Identification (RFID) technology to enhance inventory management for Chromebooks and library materials in a local K-12 public school district and involves comparing the efficiency of the traditional 1D barcode method with the RFID system, using RFID tags for 30 Chromebooks and just over 900 library books.

The results demonstrated that RFID technology significantly reduces inventory time, transforming audits of library books that previously took an average of 14 minutes and audits of Chromebook that previously took an average of 27.33 minutes to complete to under a minute completion time. Based on the results of the experiment, school districts will be able to make the determination on whether or not it would be in their best interest to explore RFID labeling in the future or if the current 1D barcode systems provide adequate coverage.

Keywords: Inventory, Radio Frequency Identification, RFID, Barcodes, Rural Education, One-Dimensional (1D) Barcode System

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Introduction

If you look around any given space right now, chances are you can find something with a barcode on it. That barcode may have been used to identify the pack of Skittles you just bought from the store, telling the clerk's register how much to add to the sales total and removing one pack from the overall stock count. It could be granting access to a favorite gym's locked door to get a grind on or even giving a way to track the important package being delivered by UPS. Barcodes provide an almost limitless number of uses, and there is no way of avoiding them in today's world.

In the rural education system, it is not uncommon for barcodes to be used to track inventory for school districts. State mandates are partially responsible for this practice as they may require that purchases made with state funding be inventoried and tracked. Attaching or assigning a barcode to such purchases gives school districts an easy way to pull up data about the product, such as when and where the purchase was made and where it should be located in which building. Information can be logged into something as simple as a Google Sheet on a shared Drive folder, or for the more advanced, an inventory system, such as the web-based Asset Tiger. Once the data has been entered into the chosen database, inventory audits can be conducted by just scanning the barcodes instead of manually capturing the required information each time, speeding up the entire process due to the bulk of data entry being completed upfront at the time of purchase (Deepali et al., 2024). However, even with the utilization of barcodes, a significant amount of time can be spent performing a yearly audit.

A local K-12 public school district with an enrollment of roughly 3,400 students across 14 building sites was selected to investigate the feasibility of integrating Radio Frequency Identification (RFID) barcodes into their current one-dimensional (1D) barcode system. A 1D barcode is a linear barcode that represents data by varying the widths and spacings of parallel lines. These barcodes are typically used to store product information, such as price and inventory levels, and are scanned using a laser scanner. While effective, the 1D barcode system has limitations, particularly in terms of the time and labor required for scanning each individual item (Deepali et al., 2024).

At the current time, the school district uses 1D barcodes to help track the inventory of library materials and technology via two different web-based software solutions. Audits, averaging one and a half to two weeks to complete per library, are performed yearly in five of the building libraries. School district technology, consisting of but not limited to printers, projectors, desktop PCs, and Chromebooks, is often only audited at a rate of one school building per year due to the availability of technology personnel and the extensive number and variety of items needing to be inventoried.

This inability to perform timely inventory audits on school district library materials and technology has created a delay in the notification of missing or misplaced technology. This inventory inaccuracy is not unexpected as the items are fluid, moving between the students in the case of library materials, but technology is often relocated to other classrooms to replace failing equipment as well, ultimately causing a “mismatch of inventory information between the reality and what is on the record of information systems" (Dai & Tseng, 2012).

The school district may not know for years which assets have been stolen or broken due to teacher retirements, new positions, etc., and by the time it is reported, the assets have little or no chance of being recovered. In addition, Goyal et. al (2009) reported that "various studies have shown the inherent fallibility of inventory accuracy…documenting that inaccuracy to be 55%" (p. 2). Goyal et. al (2009) primarily looked at studies involving retail store inventory, but the data is applicable to this project as well due to the similarities in item inventory. Items belonging to the school district are spread out across 14 buildings on a 220-acre campus are just as susceptible to theft or misplacement as those in retail. Introducing RFID technology could significantly mitigate these issues and enhance the school district's inventory management.

RFID uses electromagnetic fields to automatically identify and track tags attached to or placed on objects. These objects can be just about anything, like the bag of Skittles mentioned previously, file folders, vehicles, nursing home bed sheets, luggage at the airport, the tollbooth car pass, or even a ticket to that football game being hosted on Sunday night. Unlike 1D barcodes, RFID tags do not require a line of sight to be read, and multiple tags can be scanned simultaneously. This means that entire rooms of equipment can be audited quickly and efficiently, drastically reducing the time and manpower required for inventory checks. Moreover, RFID tags can store more information than 1D barcodes, providing a more detailed record of each item. By integrating RFID technology, the school district could streamline its inventory processes, reduce losses, and ensure that all technology is accounted for in a timely manner (Tejesh et al., 2018).

Literature Review

The school district currently relies solely on 1D barcodes for all inventory management. These barcodes are typically represented as black vertical lines on a white background, intentionally spaced in a way that can be read by a barcode reader device or a barcode scanning app, as shown in Figure 1 below. Almost every piece of movable technology and library material in the school district has a 1D barcode label applied to it. When it comes to managing inventory, this approach makes sense. Zebra Technologies published a case study from Coca-Cola Bottling Company Consolidated (CCBCC) which concluded that the use of barcode technology not only "achieve[d] greater visibility and control over [CCBCC] inventory," but also resulted in improved inventory accuracy (Deepali et al., 2024). The school district experienced similar results when transitioning to web-based inventory management software. These software programs created a centralized location in which to store the identifying and tracking information of district-owned items in one accessible place for any school district staff member with device and internet access.

Previously, only the school district's library materials had been inventoried, with the software limited to two computers per library. The global pandemic of 2020 accelerated the need for a different solution, as the school district had to provide Chromebooks for every student to take home. They needed to figure out a way to inventory and track all the technology that would be leaving campus. Using the library's management software as a guide, it was determined that 1D barcodes inventoried through web-based software would be the best and fastest way to move forward.

Figure 1:

Sample of School District Barcode

1D barcodes are simple by nature. The information printed on the barcode cannot be changed and requires no power source to be read. While it is recommended that a barcode scanner or app be used to decode the vertical lines, it is technically possible for a barcode to be read without one if a person has the time and knowledge. Assuming a barcode scanner is used, only a direct line of sight within the working proximity range of the scanner would be required to scan and decode the data. The school district has taken advantage of this simplicity. It was decided that the barcodes for the school district would only represent numerical characters ranging from 4-12 digits long. This allows them to be linked to materials in the inventory software for inventory purposes without allowing curious students access to additional information besides the barcode digits. The school district does not like having any possibility of information leakage, even if it only contains a printer's serial number.

Serialized asset labels can be purchased in advance, assigned, applied, and inventoried as items are received. If one of the asset labels is removed, scraped, or otherwise damaged to the point that it can no longer be read, technology staff can simply print a new one from a blank sheet of labels. New labels can be applied to the item without the need to re-inventory it (Jamkhedkar et al, 2021). This system has been a win-win for the school district. However, with the return to in-person schooling, yearly inventory checks have become a daunting, tedious chore. While the barcodes and inventory systems allow school district personnel to track where the inventory is located or who it is checked out to in their respective management systems, every inventoried item has to be scanned individually while utilizing a 1D barcode system. RFID labels involve a more complex initial setup and require more specialized equipment than traditional 1D barcodes, but their ability to batch process, along with other unique benefits, warrant their consideration for use in the school district.

Along with sharing the advantages of 1D barcodes, RFID labels have a layer of added functionality. Using RFID-specific equipment, these adaptable labels can be encoded with numeric digits, printed on-site, scanned by a reader, and if necessary, re-encoded with new information. There are two types of RFID systems currently in use today--active and passive. Active RFID tags require an internal battery as they are always transmitting their information at either a frequency of 433MHz or 915MHz. Passive labels, however, do not need an internal power source and are instead powered by an RFID reader (Chhetri &

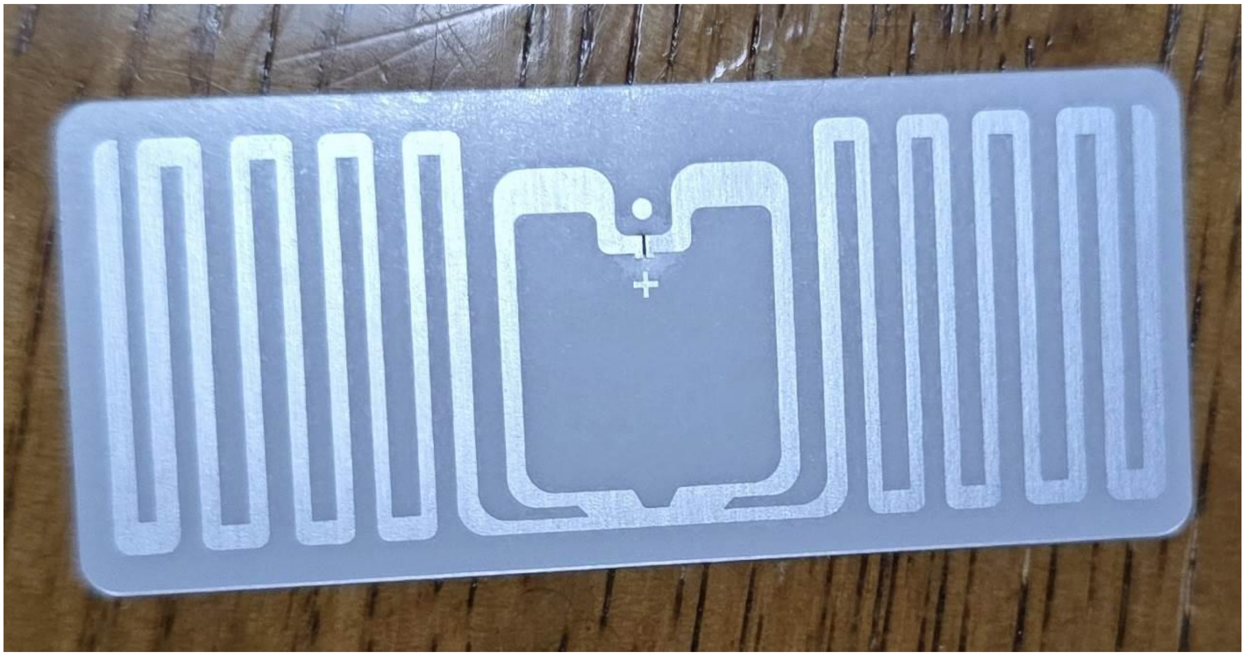
Thakur, 2019).

Passive RFID labels have three main frequencies—low frequency (LF), high frequency (HF), and ultra high frequency (UHF). Low frequency (125KHz to 134 KHz) labels transmit with a long wavelength and have a short reading range of 0 cm to 10 cm. High frequency (13.56 MHz) labels transmit a medium wavelength and can be read from 1 cm out to about 1 meter away. Ultra high frequency (300 MHz to 3 GHz) labels transmit a short, high-energy wavelength 1 meter in length. This long wavelength gives UHF labels an average long reading range of 3-5 meters up to 30 meters, depending on antenna size and reading conditions (Chhetri & Thakur, 2019).

With passive RFID labels, the RFID antenna and a silicon chip can be embedded on a label that allows for the top surface of the labels to be printed with a traditional 1D barcode and to serve a redundancy function in case of equipment malfunction. A sample of the antenna inlay and chip can be seen in Figure 2. It is the RFID antenna that gives the label its distinct advantage.

Figure 2:

RFID Label Showing Inlay



The RFID antenna allows the labels to be read without direct line-of-sight, from a distance, and at a rate of over 800 labels per minute (Su et al, 2009). As a result, instead of pulling every single book off a shelf of 300+ books to scan their individual barcodes, an RFID reader can be aimed in the general direction of the shelf, scanning the entire shelf in a matter of seconds. It is this ability that caught the attention of the Vatican Library. Housing over 2 million books and other artifacts, the library had to close for an entire month out of the year for inventory. In 2004, the library started making the change to an RFID management system, dropping the time required to inventory to less than half a day (Camdereli, 2007).

In previous years, one of the deterrents to making the switch from 1D barcodes to RFID had been the high cost. The use of RFID for a plethora of applications across the world has led to a rapid decrease of more than 50% worldwide in the pricing of RFID components (readers, writers, labels, etc.) since 2004 (Chhetri & Thakur, 2019). As the cost of the RFID components continues to drop, more end users have the ability to purchase such equipment for their unique purposes, increasing the demand for RFID technologies and resulting in higher production of the components. This increased availability and decreased cost of RFID technology has made further integrations into real world applications, such as aiding in inventory tracking, more viable to the general public. It would not be unrealistic to picture every item sold in stores in the near future to have a RFID label placed on or in it to aid in the manufacturer's or distributor's collection of inventory data. The same label that ensured delivery to the store could then also be used to highlight theft, popularity, or even to help with a product recall. In fact, a school in Taiwan has recently started integrating RFID into a "butterfly and ecology unit of a fourth grade natural science course" (Li, Kong, & Chen, 2015).

In the classroom a PDA, RFID reader, and RFID tags were used to "construct a context-aware ubiquitous learning environment" (Li, Kong, & Chen, 2015). Throughout the lesson students used the RFID reader to scan the tags which opened interactive prompts on the PDA. These prompts "allowed students to interact with avatars, participate in the virtual world to conduct experimental investigation and collect and analyze data" (Li, Kong, & Chen, 2015). While not the focus of this project, the integration of RFID technology for classroom use only further stresses that this technology is not going away anytime soon.

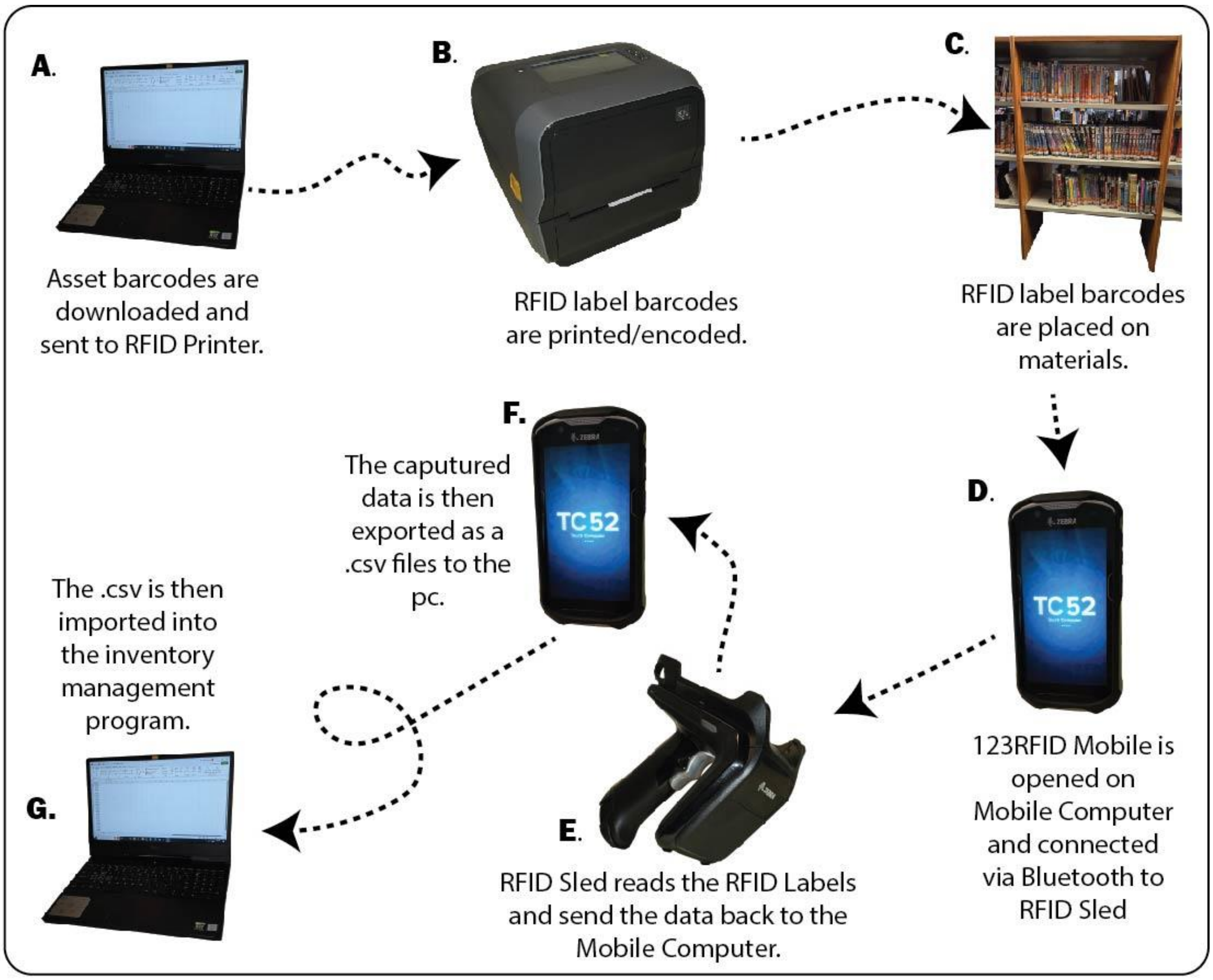
By implementing RFID technology, the school district should be able to achieve similar results to the Vatican, as the RFID label can be encoded with the same 4-12 digit numbers that the current inventory systems recognize with the added benefit of simultaneous scanning. Using the previously assigned barcode numbers allows for easier integration with the RFID technology and maintains the standard of privacy by not using any personal identifying information.

Simultaneous scanning, or batch reading, typically involves utilizing a server outfitted with a middleware software to download, store, interpret, and then output the information that was encoded on the RFID chip (Al-Yahya, 2017). For this experiment, the focus was to keep the cost down while keeping the process simple. One way it was planned to accomplish this is through the use of a hand-held mobile computer that will act as the server, downloading and interpreting the data read by a hand-held RFID sled and outputting the data onto a Google sheet ran on the mobile computer. This setup will allow for the staff to be mobile while taking inventory, eliminating the need for any permanent solutions that would involve running cables, mounting static RFID antennas or controllers, or installing any additional software. A simple setup will also reduce the amount of training required of the personnel who will be using it, further reducing the potential for human error and eliminating the need for extensive technology support.

An added benefit of setting up the project in the way proposed is that the school district will be able to utilize the web-based inventory management programs they already have in place, reducing the project cost to the RFID labels themselves and the hardware required for RFID barcode capture. The proposed setup can be visualized in Figure 3.

Figure 3:

Visualization Map of Proposed RFID Scanning Process.



A. & G. Computer B. RFID Printer C. Assets D. & F. Mobile Computer Acts as Server E. RFID Sled

To reduce the cost of the actual RFID labels, the labels being considered in this experiment are passive, meaning the embedded RFID chip has no internal power source. Instead, the chip receives power through the embedded antenna from an RFID reader emitting radio waves. This allows the chip to transmit the digits back to the reader where the information is processed by software on the reader or via a computer (Jamkhedkar et al, 2021). Al-Yahya (2017) points out that these labels can be the most cost-effective, averaging 0.13-0.65 cents a label, but they may also be the "most sensitive to radio wave interference" and have difficulty reading around metals or through liquids.

Data and Methodology

Anticipating that older and previously used equipment would be less expensive than newer hardware, two used Zebra TC52 mobile computers, two used Zebra RFD40 UHF RFID scanning sleds, and an older but unopened Zebra ZD621R RFID printer were purchased from eBay. A picture of the hardware used can be seen in Figure 4. It is important to note the risk of acquiring Zebra mobile computers stolen from stores like Home Depot and Walmart when buying from eBay. To mitigate the risk, it is recommended to purchase future units from an authorized Zebra partner to ensure legitimacy and authenticity of the products. The RFID labels and thermal ribbon for the printer were purchased from The ZPS Store.

Figure 4:

Picture of the Hardware to be Used in the Project

Ultra High Frequency (UHF) labels, specifically Zebra RFID Label 10036992, were selected for this experiment. These labels were chosen due to their compact size and impressive 14-meter read range, making them versatile and suitable for use on various materials. They were applied to 30 Lenovo 100e Gen 1 Chromebooks from a preselected loaner cart in the intermediate school library and to three library bookshelves at the elementary school containing over 300 books each. Chromebook loaner carts are representative of the general Chromebook inventory and highlight the need for accuracy and timeliness when auditing. These carts, as seen in Figure 5, are fully stocked with 30 devices which are available throughout the school day from the library to students who might have left their devices at home or whose device batteries have died. Despite the school district's technology policy that these devices be checked in and out, some school buildings have struggled to maintain the proper records. Loaner Chromebooks are needed by students frequently throughout the day. It is not uncommon that a library to have the entire cart of 30 out on any given day. Often being needed first thing in the morning, the libraries can be swamped with 15-20 students at one time while also managing their other responsibilities. As can happen in middle of chaos, the full check-out procedure may not happen at the time of disbursement when it is believed that it can be done when the Chromebook is brought back. This inadvertent mismanagement has necessitated weekly audits to track missing Chromebooks, something that could potentially be mitigated by a single swipe of a RFID reader over the loaner cart at the end of every day.

Figure 5:

Picture of Chromebook Loaner Cart

For the library materials part of the experiment, the three bookshelves that were selected each housed a similar number of books as shown in Figure 6. As part of the teaching rotation, all 27 classes in the elementary school visit the school library every week, at which time students return, renew, or check out two new books in their name. The result is that the books have an equally high amount of turnover as Chromebooks, being equally likely to be lost in a backpack, left in an unknown location, or mis-shelved within the library. A long-term solution that is outside the scope of this project is to investigate the use of RFID tags as part of a Real-Time Location Solution. In the short-term, the implementation of RFID technology in the library is expected to streamline the inventory process, enhance tracking accuracy, and reduce the time required for inventory management.

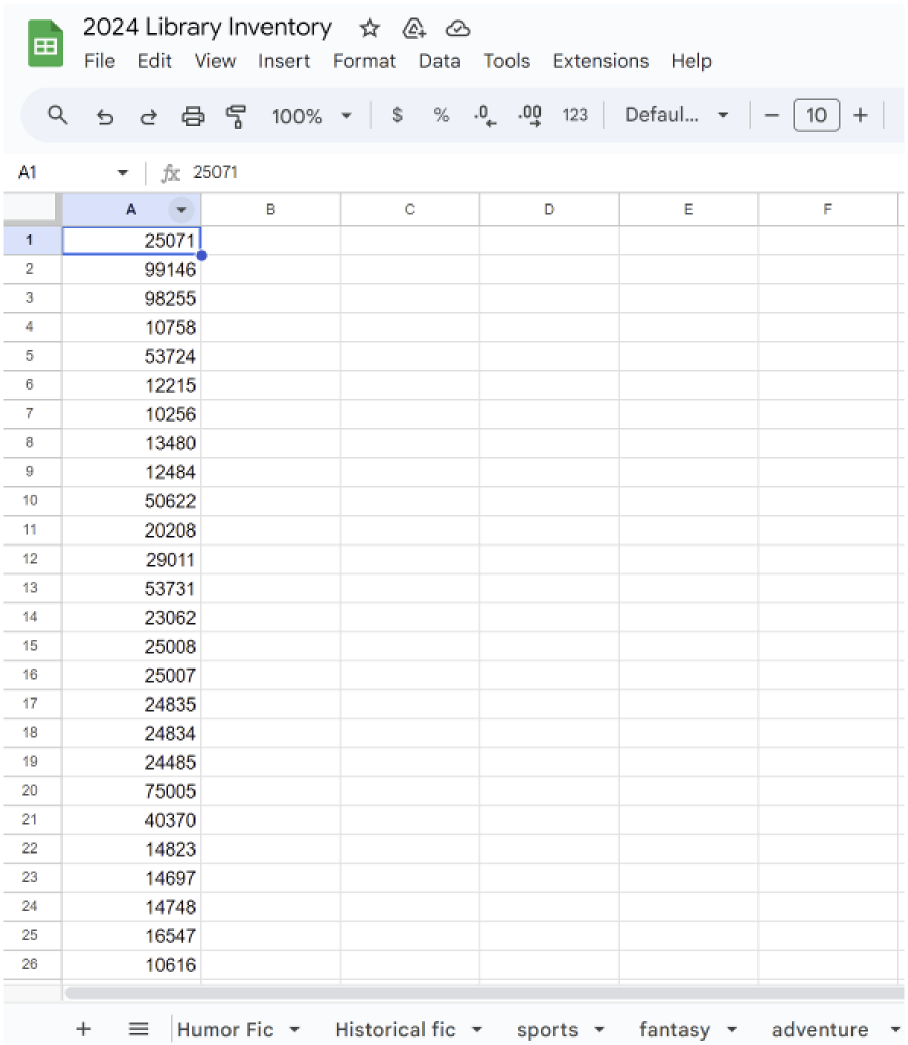
Figure 6:

Picture of Library Shelf

In both use cases described above, inventory is currently managed using what will henceforth be referred to as legacy software and 1D barcodes. As part of the process, barcodes are captured into a Google sheet. A sample of this for the library scan can be seen on Figure 7, and a Chromebook sample can be seen on Figure 8.

Figure 7:

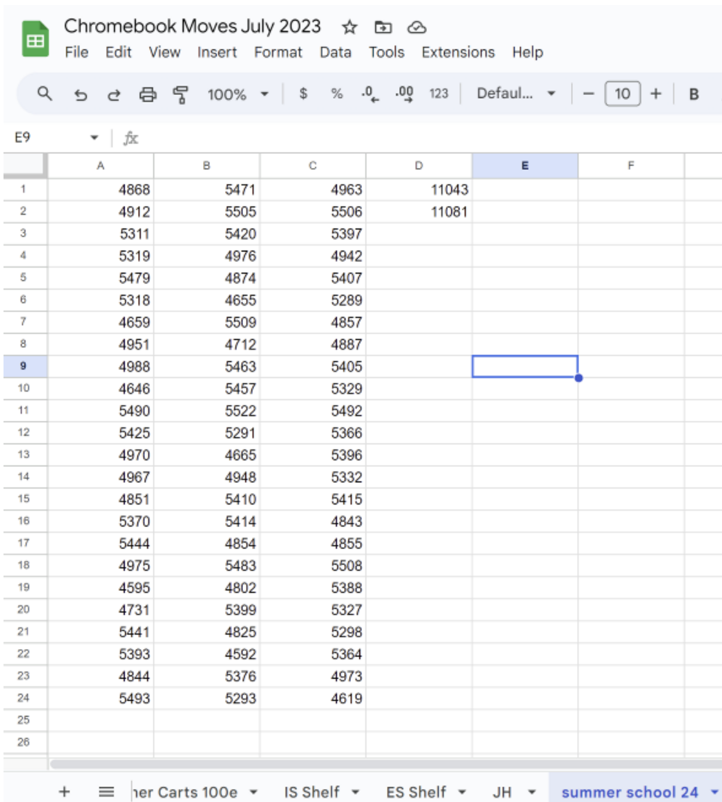
Captured Library Barcodes



	A	B	C	D	E	F
1	25071					
2	99146					
3	98255					
4	10758					
5	53724					
6	12215					
7	10256					
8	13480					
9	12484					
10	50622					
11	20208					
12	29011					
13	53731					
14	23062					
15	25008					
16	25007					
17	24835					
18	24834					
19	24485					
20	75005					
21	40370					
22	14823					
23	14697					
24	14748					
25	16547					
26	10616					

Figure 8:

Captured Technology Barcodes



	A	B	C	D	E	F
1	4868	5471	4963	11043		
2	4912	5505	5506	11081		
3	5311	5420	5397			
4	5319	4976	4942			
5	5479	4874	5407			
6	5318	4655	5289			
7	4659	5509	4857			
8	4951	4712	4887			
9	4988	5463	5405			
10	4646	5457	5329			
11	5490	5522	5492			
12	5425	5291	5366			
13	4970	4665	5396			
14	4967	4948	5332			
15	4851	5410	5415			
16	5370	5414	4843			
17	5444	4854	4855			
18	4975	5483	5508			
19	4595	4802	5388			
20	4731	5399	5327			
21	5441	4825	5298			
22	5393	4592	5364			
23	4844	5376	4973			
24	5493	5293	4619			
25						
26						

Captured barcodes can then be imported into the legacy software to cross-check against current inventory, or in the case of technology, cross-referenced on a separate Google sheet exported from the legacy software, as seen on Figure 9. Integrating RFID labels into this existing inventory system has the potential to significantly reduce the time spent on inventory management, allowing library staff to dedicate more hours to instruction and ensuring more precise and up-to-date technology audits.

Figure 9:

Cross-Referenced Inventory Google Sheet

Asset Tag ID	Description	Brand	Model	Serial No	Site	Location	Category	Toner Cartridge	Drum	Lamp
8964	Smartboard	Smartboard	SBM680	[redacted]	Hillsboro Primary	411	Smartboard			
201510230018	Computer	Built		[redacted]	Hillsboro Primary	411	Computers			
013371108SP	Document Came	Avermedia	POU1	[redacted]	Hillsboro Primary	411	Document Cameras			
7556	Printer	Brother	HL-L5200DW	[redacted]	Hillsboro Primary	411	Printers	TN-820/TN-850	DR-820	
10001055	Computer	Built		[redacted]	Hillsboro Primary	411	Computers			
8965	Projector	NEC	NP410	[redacted]	Hillsboro Primary	411	Projectors			NP14LP
8967	Smartboard	Smartboard	SBM680	[redacted]	Hillsboro Primary	406	Smartboards			
8966	Projector	NEC	NP410	[redacted]	Hillsboro Primary	406	Projectors			NP14LP
20003333	Computer	Built		[redacted]	Hillsboro Primary	406	Computers			
201509080009	Computer	Built		[redacted]	Hillsboro Primary	406	Computers			
5238	Printer	Brother	HL-L5100DN	[redacted]	Hillsboro Primary	406	Printers	TN-820/TN-850	DR-820	
10004175	Computer	Built		[redacted]	Hillsboro Primary	409	Projectors			
016601108SP	Document Came	Avermedia	POU1	[redacted]	Hillsboro Primary	409	Document Cameras			
5009	Printer	Brother	HL-L5100DN	[redacted]	Hillsboro Primary	401	Printers	TN-820/TN-850	DR-820	
10004219	Computer	Built		[redacted]	Hillsboro Primary	405	Computers			
8968	Projector	NEC	NP-M282X	[redacted]	Hillsboro Primary	405	Projectors			NP27LP
8969	Smartboard	Smartboard	SBM680	[redacted]	Hillsboro Primary	405	Smartboards			
10004217	Computer	Built		[redacted]	Hillsboro Primary	407	Computers			
8970	Smartboard	Smartboard	SBM860	[redacted]	Hillsboro Primary	407	Smartboards			
8971	Projector	NEC	NP-M283X	[redacted]	Hillsboro Primary	407	Projectors			NP27LP
10003968	Printer	Brother	HL-5450DN	[redacted]	Hillsboro Primary	404	Printers	TN-720/TN-750	DR-720	
10003967	Computer	Built		[redacted]	Hillsboro Primary	404	Computers			
8972	Smartboard	Smartboard	SBM680	[redacted]	Hillsboro Primary	404	Smartboards			
4737	Projector	NEC	NP-MC453X	[redacted]	Hillsboro Primary	404	Projectors			NP47LP
8973	Smartboard	Smartboard	SBM680	[redacted]	Hillsboro Primary	402	Smartboard			

Primary | Elementary | ES 6-28-22 | Intermediate | Junior High | Tech Storage | Field House | High School | Learning Ce

To demonstrate the potential benefits, an inventory audit will be conducted on the three shelves of books and the Chromebook loaner cart using both the traditional 1D barcode method and the new RFID labels. Existing 1D barcodes will be utilized for the first round of scanning whereas new matching RFID labels will be encoded and applied for the second round of scanning. Audits will be conducted across 6 school days. 1D scanning will take place the first 3 days with the remaining 3 days being for RFID scanning. This is being done to help prevent confirmation bias, scanning fatigue, or any other changes in scanning speed due to it being a repetitive task.

The project will involve a comparison of the two methods. For the 1D barcode method, current procedures for inventory audit will be used to scan and record the inventory data, documenting the time taken to record all the materials. A similar procedure will be put in place for the RFID method where the newly encoded labels will be placed on the back cover of the books and on the top cover of the Chromebooks. Based on the results of a study conducted by Abcouwer & Van Loon (2021), “the tags positioned directly next to the spine were always read, but those near the opening of the book (far from the spine and inventory reader) were not always read”. The thickness of the books did not significantly impact the reading of the labels. An observation based on the research would be that it actually helped the label reading, as the thicker books most likely created a space for a clean RFID read and avoided a possible read tag collision that would result from labels being placed too close to each other.

Based on the results of this project, rural schools will be able to determine whether or not it would be beneficial to explore RFID labeling in the future. If the RFID system does prove to be more efficient, it could justify the initial investment in the new technology. Conversely, if the current 1D barcode system provides adequate coverage in a comparable amount of time, rural schools might choose to continue with the existing setup.

Ultimately, the goal of this experiment is to provide data that will inform future decisions regarding inventory management technology in rural educational settings lacking in financial resources, personnel, and human capital. By highlighting the potential improvements in barcode scanning efficiency and accuracy, insights will be provided that could lead to more effective resource management for the school employees, better transparency for tax payers regarding assets purchased with tax money, and enhanced educational outcomes for students.

Contents and Results

Over the course of the 6 days of scanning, it became apparent that RFID technology is a much faster method for capturing barcode data compared to the traditional 1D barcode scanning. Time spent using the current barcode capture process to scan the same Chromebook loaner cart daily and a different library shelf each day can be seen in Tables 1 and 2, respectively. For consistency and to ensure all readable tags were captured, all RFID read capture times were initially standardized to 30 seconds as shown in Tables 3 and 4. The reason for this standardization was due to the difficulty in documenting the actual capture time needed for RFID scanning using the pre-programmed RFD40 scanners. In contrast to the 1D barcode scanning where the total capture time lasted more than ten minutes, performing the same task with RFID labels yielded a read rate of all or most labels captured in under 30 seconds.

Table 1:

Chromebook Cart 1D Scanned

	Number of Chromebooks Scanned	Time Spent
Day 1	30	31 min
Day 2	30	24 min
Day 3	30	27 min

Table 2:

Library Shelf 1D Scanned

	Number of Books Scanned	Time Spent
Day 1	312	14 min
Day 2	315	15 min
Day 3	307	13 min

Table 3:

Chromebook Cart RFID Scanned

	Number of Chromebooks Scanned	Time Spent
Day 4	30	30 s
Day 5	30	30 s
Day 6	30	30 s

Table 4:

Library Shelf RFID Scanned

	Number of Books Scanned	Time Spent
Day 4	312	30 s
Day 5	315	30 s
Day 6	307	30 s

On average, it took 27.33 minutes to capture the 1D barcodes of the 30 Chromebooks in the loaner cart. This number was obtained by averaging the Total Time Spent Scanning divided by the Total Number of Chromebooks Scanned and multiplying the total by 30 Chromebooks. The math looked like this:

(31 min + 24 min + 27 min) / (30 Chromebooks x 3) = 0.91 min per Chromebook.

0.91 x 30 = 27.33 min total average time to scan 30 Chromebooks

A significant portion of this time was spent pulling the Chromebooks out from their slots on the cart, scanning the barcode, and then placing them back in the cart. This process was not only time-consuming but also labor-intensive, which highlighted the inefficiencies of the 1D barcode process for large quantities of materials. Similarly, the library materials part of this experiment experienced a comparable outcome. The three shelves chosen from the library to scan each had an average of 311.33 books. Using the 1D barcode scanning method for this quantity of books, it took an average of 14 minutes per shelf, or 0.04 minutes per book, to capture all the barcodes. To arrive at these averages, the same formula as above was used, replacing Chromebooks with the total number of books scanned and updating the Total Time Spent Scanning as shown below:

(312 books on shelf One + 315 books on shelf Two + 307 books on shelf Three) / 3 = 311.33 average books per shelf.

(14 min + 15 min + 13 min) / (3 book shelves) = 14 average min per book shelf

14 average min per shelf / 311.33 average books per shelf = 0.04 average min per book

Like the Chromebooks, this process involved individually handling each book to ensure the barcode was visible in order to scan it before moving on to the next one. However, the process is even more labor-intensive as the book shelves have materials placed at varying heights, requiring bending, stooping, and sometimes climbing a step-stool in order to reach the row of books currently being scanned. While it was not explored in this experiment, it can be hypothesized that the repetitive motions would most likely cause a scanning fatigue and soreness if capture of the barcodes was attempted in longer one-day sessions instead of broken up across several weeks, adding to the cumulative time spent on inventory. Instead, when employing RFID technology, the time required for scanning was drastically reduced. The barcode data for an entire shelf was captured in a matter of seconds. However, without an easy way to compare the barcodes scanned to what should be on the shelf, it was difficult to tell if all books were indeed present or if tags from adjacent shelves were being included in the place of tags that did not read correctly.

Toward the end of data collection for the project, after continued talks with the Zebra Technologies technical support team, it was determined that by using a feature of the 123RFID demo application, data capture time of RFID labels could be more accurately measured and data capture accuracy improved. The feature called Tag List Match Mode allows a list of barcodes to be uploaded for specific shelves and each loaner cart. The software then searches only for those barcodes, slightly increasing the overall scan time, but eliminating the need to manually compare the scanned barcodes to the list to see which books or Chromebooks are missing. To improve the accuracy of this project and compare how long it takes to scan all labels versus specific labels, three additional bookshelves and 30 Chromebooks in a second Chromebook cart were tagged with RFID labels, and a second round of scanning took place when time permitted. The results of the additional scans can be seen in Table 5 and Table 6.

Table 5:

Additional Library Shelf RFID Scans

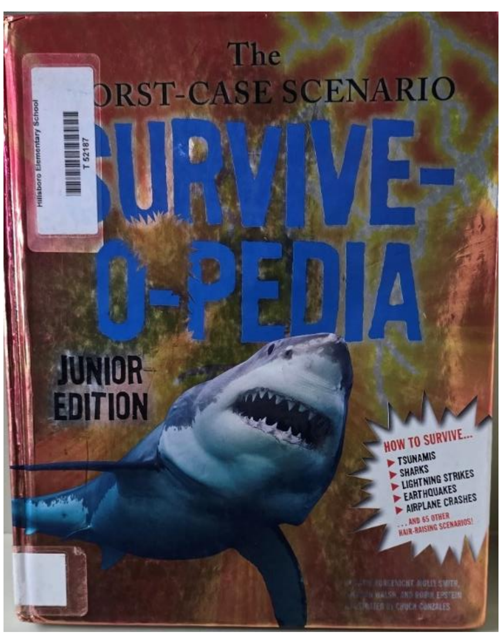
	Number of Books Scanned	Time Spent
Additional Scan 1	1043	6 min
Additional Scan 2	1040	2 min 52 s
Additional Scan 3	202	24 s
Additional Scan 4	1045	33 s
Additional Scan 5	311	39 s

Table 6:
Additional Chromebook Cart RFID Scans

	Number of Chromebooks Scanned	Time Spent
Additional Scan 1	30	4 s
Additional Scan 2	30	5 s
Additional Scan 3	30	4 s
Additional Scan 4	30	6 s

The ability to use the Tag List Match Mode facilitated the ability to scan multiple library book shelves at once, meaning that for this project, RFID scanning over 1,000 books in one scanning session became a possibility as shown in the data previously in Table 5. Additional scans 1, 2, and 4 from Table 5 were taken from books across 6 bookshelves. Using the Tag List Match mode feature also gave the ability to identify and then track missing RFID labels. It is through locating missing RFID labels that it was determined that books with foil book covers, such as *The Worst-Case Scenario Survive-O-Pedia* (shown in Figure 10) or the *Guinness World Records* book series whose library-bound hard cover releases are often fully encased in foil, could not be read via RFID scanning.

Figure 10:
Foil Book Cover



Likewise, it was not unexpected that the library books sitting next to metal bookends often had difficulty being read as seen in Figure 11 and may need to be pulled out slightly from the shelf before an inventory scan is conducted. Other solutions could entail going back after the inventory scans and locating the individual books that were not read by the RFID sled or replacing the book ends with ones constructed of alternative materials, such as wood or plastic.

Figure 11:
Book Behind Metal Bookend

Using the constant read time limit of 30 seconds and extrapolating the average of 0.04 minutes per book to an entire 13,000 book library, it could be possible to complete an entire book audit in 520 minutes, or 8.67 hours. That would only be slightly longer than the average 8-hour workday and with the benefit of less physical maneuvering. The ability to scan multiple RFID labels simultaneously without the need for direct line-of-sight scanning or physical handling of the materials eliminates the need for the bending, stooping, and possibly, climbing associated with the physical aches and pains of scanning fatigue. Still, implementing RFID scanning was not without its issues.

Complications

One of the first complications regarding RFID implementation involved the preparation of the RFID labels themselves. Trial versions of Bartender and Zebra Designer were downloaded to handle the task of encoding and printing the labels after a web search determined them to support industry-standard and compliant labels barcode processing due to ease-of-use and available customer support (Barcodes, 2024). The installation of the programs, including setup, was guided by the software itself. However, neither program was able to produce functional RFID labels for this project.

Zebra Designer came the closest, being able to print the 1D barcode in the center of the label, yet unable to encode the RFID in a manner that could be interpreted within the parameters of the project, coding additional zeroes to the end of five-digit barcodes, but not four-digit barcodes. These extra digits produced barcodes which did not match the asset barcodes on the audit lists and could not be removed without potentially removing a final zero in an actual asset barcode. Bartender experienced a similar encoding issue, as well as a printing problem, printing the 1D barcode flush along the top of the label regardless of what settings were selected. An example of this can be seen in Figure 12.

Figure 12:

RFID Label With Top of Label Printed Flush

In order to address the Bartender encoding issue, a YouTube tutorial by Seagull Scientific, LLC (2019) with step-by-step instructions was followed. The first label printed successfully, but the second label printed out as VOID, as can be seen in Figure 13. Upon further review, the sole difference in the labels was the number of digits making up the barcode. Even-digit barcodes encoded correctly, while an odd number of digits resulted in a voiding out of the label. This brought to attention a valid concern as the current templates for barcodes used by the school district range from 4 digits to 12 digits in length.

Figure 13:

Image of Voided Label

As data specifically detailing RFID encoding can be difficult to find as a consequence of it being a newer technology and often proprietary to each software company, support at both software companies were contacted and could not explain the encoding issue. Several other companies, including the RFID Lab at Auburn University, Bibliotheca, PTS Mobile, RFID4U, RIOT RFID and POSGuys were also contacted for guidance. The responses ranged from it being impossible to encode short barcodes or those with an odd number of digits to it being possible with the purchase and utilization of the responding company's proprietary software. Many of these software programs cost upwards of $10,000 after paying monthly fees for assets, not including the price of the RFID Labels, printer supplies, etc., and were impractical solutions for small quantity of barcodes that a rural school would need versus a retail establishment tracking tens of thousands of assets (Asset Vue, 2024). For example, one of the returned quotes had a monthly subscription cost of $2,965 but waived a $5,000 on-boarding fee, while another company quoted out a monthly cost of $5,381. There were even a few companies who after being told that their services would only be required for one RFID printer at one location responded that they would only support a fleet of devices.

A general internet search using Google Chrome was done for many variations of the search term “RFID encoding”, looking for a cheaper alternative to the pricey, proprietary software. The alternative that was selected was to use Zebra’s ZPL printer language to send printing and encoding data straight to the Zebra printer via a text file. A recent community article on the Zebra Support Community Forum (2024) provides a step-by-step guide on how to install the Zebra printer as a virtual printer and print labels using Notepad. For visualization purposes of the 1D barcode, the ZPL code could be placed into the Labelary viewer beforehand to adjust barcode placement and sizing (Labelary, 2024). A copy of the ZPL code used for this project has been included in Appendix A.

Through the EPC Radio-Frequency Identity Protocols Generation-2 UHF RFID: Specification for RFID Air Interface (GS1, 2013), it was determined that current RFID chips must be written and read at multiples of 16 bits. Since each hexadecimal value is represented by a 4-bit value, this explains why barcodes containing four digits, or multiples thereof, encoded without adding extra zeroes (TSC, 2013). Knowing the format that the encoder expected to write made it necessary to find a solution for the library materials, which largely contained barcodes with an odd number of digits. The answer was a setting located in the DataWedge software that comes native on the Zebra mobile computer. The Remove Leading Zeros function gave it the ability to output the interpreted barcodes without any leading zeroes. By manually adding three zeroes to the beginning of the 5-digit library barcodes to bring the total digits to eight, the correct number of digits output into Google Sheets and into the legacy library management software.

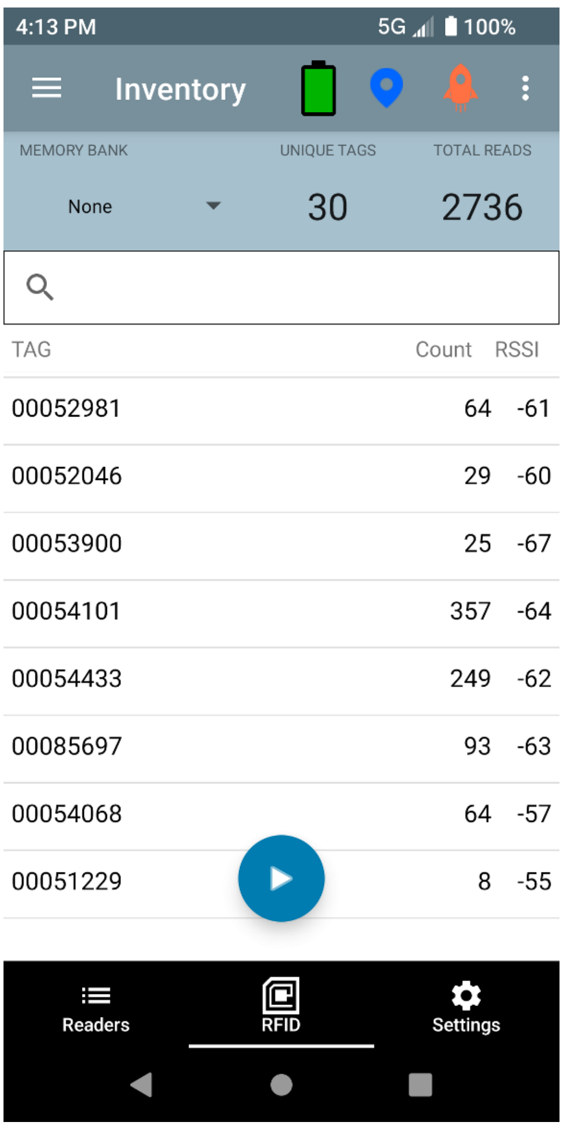
Along with manually adding zeroes, the concept of how to prepare RFID labels in bulk presented itself as labor-intensive. Creating and printing a ZPL code for each barcode would increase the time to implement the RFID process and potentially deter future users. To address this issue, various discussion boards, such as Reddit, Stack Overflow, and the Zebra Developer Portal, were scoured for a method of batch processing ZPL code. The chosen solution came a Medium article by Lahek (2024). It involved inserting the barcodes to be printed into an Excel sheet then running a macro that automatically writes the required ZPL to an existing text file on the desktop, prints the text file, and advances to the next barcode on the sheet using the Visual Basic for Applications (VBA) language. A copy of the modified ZPL portion of VBA code for bulk printing can be found in the Appendix B. While it was not researched as part of this project, a similar code may also be available for Google Sheets via the JavaScript language.

Part of the reason coding in Google Sheets wasn't more researched in this project was a complication involving how Google Sheets captures the RFID scans. The current inventory scanning process outputs barcodes into a Google sheet that can be shared, exported, or imported as needed. However, there is a glitch between the newer TC5x series Zebra mobile computers, the newer Zebra RFD40 RFID sleds, and Google programs at the time this paper is being written that results in the barcodes being transposed somewhere between interpretation and direct output into the Google sheet. For example, 0012345 became 21345, 1234 became 1432, and 123A became 12A3.

Zebra Technologies was contacted about the Google Sheets glitch, and it is currently an ongoing support ticket involving Zebra Software and Zebra Engineering Teams. A few suggestions from the Zebra teams so far have been to change the configuration of the RFID Sled to only decode in plain text, to have it operate in Human Interface Device (HID) Mode which allows for the mobile computer to decode the data as emulated key strokes, to slow down the decoding keystroke speed via sled's internal configuration file to give Google Sheets a chance to input the digits just in case it was too much information too fast for the program to handle, or to adjust the number of times the sled scans a RFID label before transmitting the information. None of the suggestions or configuration files sent have been successful as of yet. To move forward with the project, a work-around was found. Zebra's proprietary, but free, 123RFID Mobile demo application can be downloaded to the Zebra mobile computers via the Google Play Store, as well as to a PC from the Zebra Technologies webpage. While not ideal because of lack of 3rd party application integration into other applications like Google Sheets, the 123RFID Mobile application did yield accurate scans that could be exported into .csv files. Figure 14 shows a screenshot of a RFID label scan of a Chromebook loaner cart utilizing 123RFID Mobile on a Zebra mobile computer.

Figure 14:

123RFID Mobile Chromebook Cart Scan

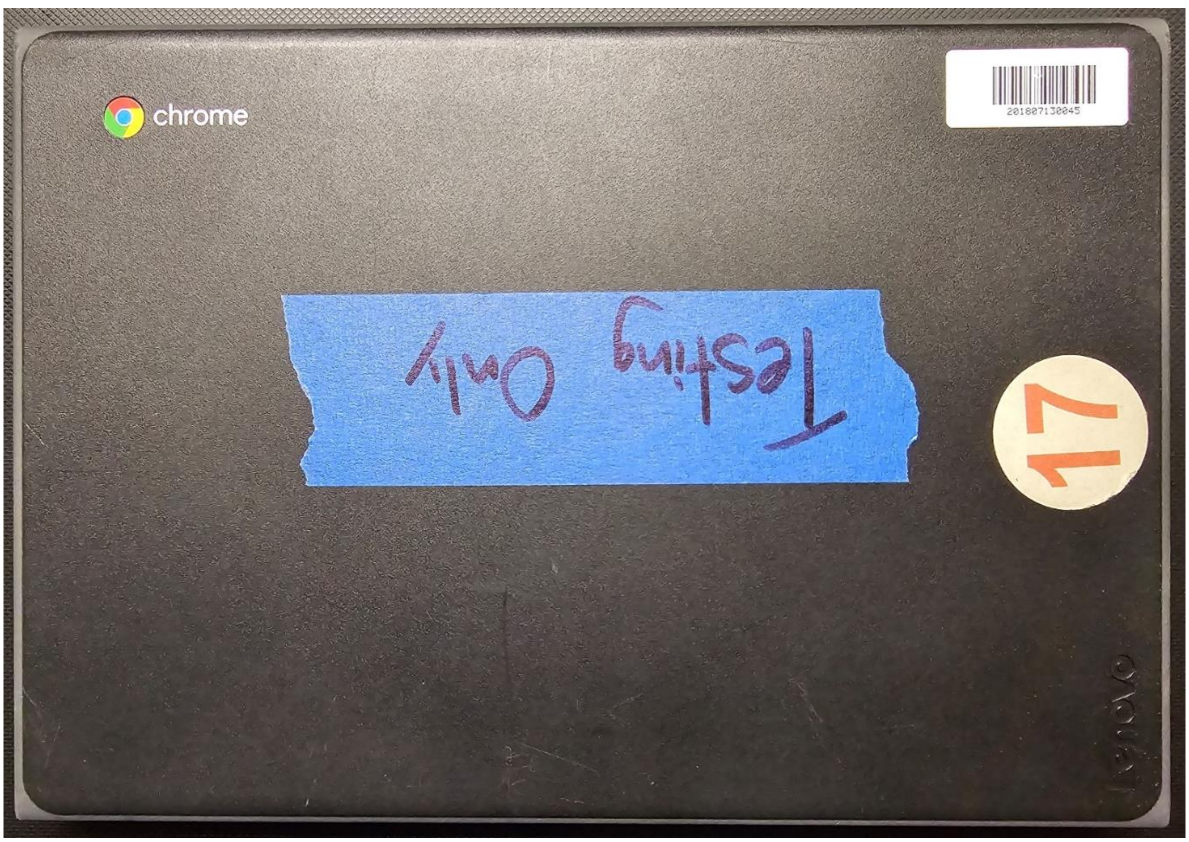


Another complication discovered during this project was RFID labels not scanning within the Chromebook loaner cart. Initially, it seemed like there was an issue with the RFD40 sled itself pertaining to a failure to scan, but after using the same sled to scan books at the elementary school library, it was determined to be an issue related to the location where the Chromebook loaner cart was housed. An investigation at the intermediate school library led to the revelation that a UHF CB radio repeater stationed in an adjoining room could be leaking radio waves into the library that interfered with the RFID scanning process. To conclusively determine if the competing UHF signal was causing the disruption, the Chromebook loaner cart was relocated to another room for scanning purposes. The change in environment did allow the barcodes to be scanned with the RFID sled. This is something that will need to be addressed if the intermediate school library should choose to implement RFID technology, but for now is simply a consideration that should be noted when exploring a conversion to RFID labels in areas near UHF devices.

A second complication with Chromebook RFID tag scanning was discovered when doing the additional scans of a second Chromebook loaner cart at another library. Even though the RFID labels were placed in the same location on the back of the Chromebooks, the RFID sled would not read any of the tags in the second cart. It was hypothesized that the issue resided in the model of the Chromebook in the cart being different from those in the initial Chromebook cart and that different Chromebook manufacturers use of varying amounts of plastic and metal parts accounted for the discrepancy. To troubleshoot, the labels were placed in multiple locations on a Chromebook model from each cart. It was ultimately discovered that placing the RFID label on the front cover opposite of the motherboard charging port, as seen in Figure 15, allowed for the labels to be read across all the HP and Lenovo Chromebook models that the school had available.

Figure 15:

RFID Label on Top of Chromebook



Discussion

While RFID technology has the ability to speed up the inventory process, it is not a flawless technology. Shahrabi's study in 2023 calls out that when the accuracy of the RFID technology was studied in 2004, it had a 60-70% rate of accuracy when implemented in working environments. In 2018, the accuracy rate had risen to above 90% but had not yet reached 100% (Shahrabi, 2023). After running this project in the school district, the accuracy percentage appears to remain about the same, as we can get near-perfect scans using 123RFID Mobile, yet could not replicate the same results in scanning to other software programs, like Google Sheets.

The restriction to encode only an even set of digits without extra digits being added also provided a bit of roadblock. It would be ideal to have the ability to encode only the needed digits, but RFID technology has not progressed to that point at this time. Restrictions on where RFID technology can be used also presented themselves after noting how easy it was to prevent RFID scanning based on proximity to the school district's UHF CB radio repeater. As more technology makes the transition to being wireless, it could be deduced that a higher risk exists for the radio waves to collide. Still, the staggering difference in barcode capture time underscores the potential benefits of utilizing RFID technology.

To put the technology's potential into perspective, at any given time, the school district has more than 60,000 books that the libraries need to have inventoried. Using the data derived from the project, it can be estimated that it takes an average of 0.04 minutes to scan the 1D barcodes on each book. Multiplying that average by 60,000 books would result in all library staff taking a combined five full school days to inventory all the books within the school district.

60,000 x 0.04 = (2,400 min / 60 min) = (40 hr / 8 hr work day) = 5 school days

Of course, this does not account for any other responsibilities the library staff would have to attend to at the same time, i.e. teaching classes, checking out books, working parent pick-up. The additional responsibilities quickly turn the 5 days into a multi-week endeavor. If the physical scanning of every book can be replaced with RFID technology, the time required for inventory could be significantly reduced. When the same formulas were calculated using the new additional RFID scan times, the predicted time spent for inventory became 2.83 hours out of the school day, as the math shows below:

(1043 books scanned + 1040 books scanned + 202 books scanned + 1045 books scanned + 311 books scanned) / 20 book shelves = 182.05 average books per shelf.

(360 s + 172 s + 24 s + 33 s + 39 s time per RFID scan) / (20 book shelve) = 31.4 average seconds per book shelf scanned

31.4 average seconds per shelf / 182.05 books per shelf = 0.17 average seconds per book

60,000 x 0.17 = (10,200 seconds / 60 seconds) = 170 min to scan books / 60 minutes = 2.83 hr of school day.

Estimating the time spent and time saved by transitioning to RFID technology for the general technology items spread across the school district would be harder to gauge accurately. Unlike the libraries and Chromebook loaner carts where the materials are located primarily in one room or location, general technology hardware can be found in every classroom, office, and most closets. However, applying the ratio of 0.91 minutes per Chromebook for 1D barcodes, it could be estimated that if 12,000 technology assets were in the same place that it would take 22.75 school days to inventory them all. Something that could be done in 24 minutes based on the results of Table 6 when implementing the RFID technology, as shown below:

12,000 x 0.91 min = (10,920 min / 60 min) = (182 hr / 8 hr) = 22.75 school days

(13 s total time spent scanning Chromebooks) / (90 Chromebooks scanned) = (0.14 average seconds/ 60 seconds) = .002 minutes per Chromebook.

12,000 x 0.002 min = 24 min

Transitioning to RFID technology also has another immediate advantage when utilizing the set up as described in this project—the locating of a specific RFID label. In the library setting, this means putting a book's barcode number into the 123RFID Mobile app under a locate tag tab and turning the RFD40 RFID Sled into a technological Bloodhound. The locate tag setting allows for a Geiger counter-like experience where the librarian or patron could scan for a specific book on the shelf. In this use-case scenario, it can be assumed that a student has accidentally placed a book on a different shelf, and a quick sweep of the shelves is needed to find the book before the student heads back to class. While in the locate setting, the sled searches for the barcode with beeps and a visual bar. The closer the sled gets to the label, the faster the tone beeps, and the bar on the screen rises.

Another potential advantage with an RFID transition is the possibility of checking books in and out with the new RFID labels instead of using the traditional 1D barcodes. Using the RFD40 in HID mode allows the barcode to be outputted into the library management system directly as if it had been scanned like a 1D barcode. If this is an option the school district would be interested in exploring in the future, then changing the location of the RFID labels from the back cover where they were placed in this project to nearer to the spine of the book. Abcouwer & Van Loon (2021) reported that out of 31,680 attempts at reading 210 books with RFID labels near the spine, only 16 of the attempts did not read all of the books, giving a successful read rate of 99.9%.

As much time as can be reduced having made the transition to RFID labels, another consideration to take into account will be that most school districts would not be able to label their entire inventory at one time due to time, budget, and manpower restrictions. As such, the conversion will most likely need to be planned for in phases. Some possibilities could be to approach labeling inventory by building location or spread out over long student breaks like Thanksgiving/Fall, Christmas/Winter, Spring, or Summer. If the budget allows, pre-programmed RFID labels can be ordered which will help reduce the time required in deploying the labels.

Conclusions

In conclusion, by integrating RFID technology, improved efficiency in both Chromebook and library book management can be anticipated. The ability to read multiple RFID labels on a densely packed bookshelf or inside a cramped Chromebook cart cannot be over-exaggerated enough as a game changer for inventory purposes, as based on the results from this project, implementing the technology significantly reduced the time required to perform inventory audits.

The reduction in the time required is substantial because Goyal et. Al (2009) concluded that there is "approximately a 4% deterioration [of accuracy] per month" when a "physical inventory [is performed only] one time per year" (p. 5). Multiple inventory counts would be needed throughout a year in order to restore or get close to a 100% accuracy rate. However, it would be too labor-intensive to manage a 1D barcode inventory more than once a year at the school district. That is why the project's findings could pave the way for broader adoption of RFID systems, providing valuable insights for future implementations in similar environments and benefits beyond those of 1D barcodes, such as real-time locating of materials. Implementing RFID technology opens up the possibility for more frequent inventory checks. More frequent inventory checks ultimately "provides accurate inventory information to align the recorded and actual inventory data in a timely manner", and a byproduct of more frequent checks may not only increase the inventory accuracy rate but also point out issues that need addressing, such as item theft or unauthorized equipment relocations (Dai & Tseng, 2012).

While not without its shortcomings, like consistent data capture, UHF interference, RFID label removal, and correct data encoding, RFID technology could be considered a viable option for integration into the rural education system. Much like the Taiwanese school integrating RFID labels for lessons, school systems around the world are also pushing the envelope to incorporate as much technology as possible in the classroom. These smart classrooms will include Chromebooks, "laptops or desktops, interactive whiteboard, media projector, digital still camera, printer, scanner," etc. (Li, Kong, & Chen, 2015).

As the volume of items needing to be inventoried will continue to increase over time, RFID technology's scalability becomes a critical advantage. Unlike traditional barcode scanning, RFID can handle an unlimited number of materials in a single scan session, scanning them without the need for direct line-of-sight and from a considerable distance. No longer would items need to be handled to scan the barcode. A simple point-and-shoot of the RFID sled at those densely packed library shelves or sweep around the classroom could gather all the required inventory data. This capability significantly streamlines the inventory process, transforming a task that once took 30 minutes per area into a minute-long activity. An entire building's inventory could be completed in less than a day, freeing up staff to focus on other essential duties.

One suggestion that comes to mind based on the author's experiences in working with RFID supply vendors is to create a cooperative purchasing group amongst the school districts or state library associations. Forming such a group could lead to cheaper product costs overall and form a support system for future

RFID issues or deployments. The resources for troubleshooting are just not available at the current time in writing this paper. Often the sales teams of the manufacturers of RFID products and encoding softwares were unknowledgeable in their products, unable to answer questions due to the constantly evolving nature of the technology. At the time of this writing, the author still has an open ticket with Zebra Technologies support regarding the transmission of barcode data into a Google sheet—almost a year after the ticket had been opened. A cooperative would also help mitigate the frustration of RFID technology acquisition for those who would otherwise seek to purchase, rent, or even inquire about single unit products, only to be ignored or turned away by vendors who are uninterested in working with single unit customers and deal only with businesses or locations that require a large quantity of products. Creating a cooperative purchasing group would give the schools more buying power and better access to the technical support that does currently exist.

Looking ahead, a future project could explore the deployment of RFID antennas throughout a school building to track not only the overall inventory, but also the specific locations of technology and library materials within different rooms. This enhanced level of tracking could provide even greater insights and efficiencies. Considering these advantages, RFID technology clearly demonstrates its superiority in terms of efficiency and ease-of-use compared to traditional barcode scanning. Should the school district decide to proceed with RFID integration, it could revolutionize its inventory processes, allowing for more effective resource allocation and overall operational efficiency. This step forward could set a precedent for other educational institutions, particularly in rural areas, to adopt similar innovations, ultimately enhancing the educational experience for students and staff alike.

Appendix A:

ZPL Code to Print from Notepad

```
^XA


^FX Section for Barcode.

^FO90,50

^BY2 ^BCN,75,Y,N,N,A

^FD20126^FS


^FX Section for RFID.

^RFW,H,,,A

^FD00020126^FS


^XZ
```

Appendix B:

Modified ZPL Portion of VBA Code for Bulk Printing

```vba
            'Start the ZPL command
               FileToWrite.Write "^XA"
            'Insert a blank line
            FileToWrite.WriteBlankLines (1)
      'Barcode part
            FileToWrite.Write "^BY2"
            'Insert a blank line
               FileToWrite.WriteBlankLines (1)
             'Center the barcode
               FileToWrite.Write "^FO70,50^B3N,N,75,Y,N^FD" & ThisWorkbook.Sheets("Data").Range("A" & i).Value & "^FS"
            'Insert a blank line
               FileToWrite.WriteBlankLines (1)
      'RFID part
               FileToWrite.Write "^^RS8^RFW,H,,,A^FD" & ThisWorkbook.Sheets("Data").Range("A" & i).Value & "^FS"
            'Insert a blank line
               FileToWrite.WriteBlankLines (1)
             'Insert a blank line
               FileToWrite.WriteBlankLines (1)
            'End the ZPL command
               FileToWrite.Write "^XZ"
```

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