A Novel Approach to Cash Visibility with RFID

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***Abstract*—Cash movements happen daily between banks, retailers, and the Federal Reserve Bank. These transactions necessitate the use of armored couriers to safely transport large amounts of currency and other valuables. This industry, however, functions without the aid of current technology, relying on paper receipts and faxed manifests. This research proposes the adoption of RFID into cash handling to provide real-time tracking and visibility while decreasing costs and increasing system capacity.**

Keywords— armored couriers, armored truck companies, RFID, API, cash management, banks, retailers, ATMs

I. Introduction

Contrary to popular belief, the use of cash is at an all-time high in the United States. According to Trading Economics, there is approximately $2.28 trillion in circulation today.[1]. These large amounts of cash require significant protection to ensure its safety from wrongdoers.

Over the last decade, the industry has started several initiatives to bring technology to the cash movement ecosystem. The industry worked with the standards organization, GS-1, to establish a common nomenclature and add barcoding as the first traceability method. In addition, the Federal Reserve Bank is promoting an API integration between banks and itself to speed up the processes of transferring cash to and from the Federal Reserve Bank. That API effort has spurred interest in establishing an API between all cash-handling organizations to exchange information about cash movements.

Given all this effort, the industry is still slow to adopt technology. This is partially due to the razor-thin margins of the industry and the fierce competition that exists as each player vies for customer share. This research will compare the current and future states to illustrate the benefits of adopting RFID.

II. Literature Review

A. *Cash Movement Research*

This topic has very little literature in academic journals. This is because the entities in this industry are protective of their processes and because of the sensitivity of the products these couriers carry. Cash handling is accomplished through a process like evidence tracking, where liability for a bag of cash is transferred from one individual to another in a formal way. These custody transfers occur even within organizations as cash is processed.

Valentine[2] describes the trend for banks to outsource cash processing services to armored couriers. In addition, Valentine discusses using on-premises smart safes at retailers that immediately credit the retailer's bank account with deposited cash.

A number of researchers [3]–[8] have researched armored courier transportation route efficiency, seeking routes that optimize routing while considering the safety of the truck and crew.

In the area of Automatic Teller Machines (ATM), several researchers [9]–[17] have explored several paths to predict the cash availability in ATMs and optimize the servicing of these machines. ATM servicing is one of the critical jobs of armored couriers.

B. *Radio Frequency Identification (RFID)*

Research into RFID is prevalent, with many complete journals dedicated to the topic. GS-1 [18] manages the EPC™ Radio-Frequency Identity Protocols Generation-2 UHF (ultra-high frequency) RFID specification for the Air Interface at 860-960MHz. This standard has companion protocols in IEEE and trade alliances like AIM and RAIN.

Several researchers [19]–[21] describe the essential characteristics of RFID, including memory locations, link budgeting, reader-tag cycles, and the anti-jamming techniques used in RFID.

III. Methodology

A. *Process Mapping*

This research began with a thorough processing mapping exercise within a large armored courier branch. The researchers were given unprecedented access to observe operational behaviors and document each process in detail, and this period of observation also included numerous interviews with employees and management. A complete process map of several key processes was developed. These included operational behaviors of vault operations, cash-in-transit (CIT), and cash management systems (CMS). CMS processes cash deposits and maintains the storage of bulk cash. CIT is the operation that controls the trucks and crews as they interact with customers (banks, retailers) and service ATMs. The vault is responsible for the transition of cash between CMS and CIT, including preparing and sorting bags for routes and the collection of bags brought in by CIT.

The researchers spent five days within the armored courier in firsthand observation of the branch operations. The observed branch operated 24 hours a day, and the researchers adjusted their work schedules to observe all activities.

In addition, several additional trips were made to the branch to clarify and validate the findings. Finally, a complete process map and associated description were produced.

B. *Simulation Development*

After completing the process map, a simulation model was developed using AnyLogic™ Simulation Software. This software captured the process mapping behaviors and established timing for CIT and vault operations. Only sorting operations of CMS were considered in the model. The actual processing and consolidation of cash were not included, nor were the coin operational processes. An example of the parameters used in the model is in Table 1.

The simulation was then tuned to match the observed behaviors of the branch. In addition, the armored courier supplied average fully loaded employee hourly costs, 22 weeks of hourly employee work hours, branch productivity reports for a month of operations, and other related documents. These documents were used to adjust the model further to operate as closely as possible to the branch behaviors.

A 95% confidence interval (CI) was chosen using the data provided. Equation (1) was used to calculate CI,

$$CI = \sqrt{\frac{2\left(Z_{\alpha}+Z_{1-\beta}\right)^{2}\sigma^{2}}{n}} \quad (1)$$

where Z_{α} is the probability of committing a Type I error (probability of rejecting the null hypothesis when the null hypothesis is true), and $Z_{1-\beta}$ is the power test based on the probability of committing a Type II error (probability of not rejecting the null hypothesis when the null hypothesis is false). Simulation data standard deviations are compared/validated utilizing this technique.

C. Operational Budget Development

The employee work hours from the simulation model were then valued based on the average hourly wages of the affected employees, focusing on the movement and sorting of bags. This financial model established the cost baseline from which the future state would be compared.

D. Analysis of Technology

While at the armored courier facility, several RFID tests were conducted, and the courier supplied a scale map of the facility. Each area was evaluated for the proper installation of RFID infrastructure. These included chokepoints at the secure zones (mantraps) where cash was transferred between CIT and the vault, armored trucks, and real-time location systems (RTLS) for the truck bay and the CMS processing area. Several laboratory tests were performed to validate expectations of behavior.

In addition, a commercially available robotic package sorting system was evaluated and simulated to sort by RFID. Finally, a bill of materials was created, and a budget for equipment, installation, and maintenance was developed for all systems.

Table 1 - Parameters

Parameter	**Value**	**Units**
inspect truck at entrance	uniform(3,5)	minutes
truck move from entrance to parking and park	triangular(20,30,60)	seconds
unload one bag from truck to trolley/ load bag from trolley to truck	2	seconds
messenger move from branch entrance to the mantrap along the lane or backwards and close/open the entry door	triangular(20,30,60)	seconds
open vault door	5	seconds
submit, scan, and bag messenger belongings	uniform(1,2)	minutes
one bag inspect and scan by vault teller	uniform(4,10)	seconds
one bag preliminary sort by vault teller	uniform(15,30)	seconds
one bag sort by sorting teller	uniform(15,30)	seconds
paperwork and release	uniform(2,3)	minutes
one bag overnight re-sort	uniform(15,30)	seconds
issue keys, manuals, phone/PDA(s), radios, a manifest, and a detailed route sheet for that day to the messenger	uniform(1,2)	minutes
load bag from branch to trolley	5	seconds
move trolley from branch to truck	triangular(20,30,60)	seconds
verify and accept bag to the electronic manifest on the phone/PDA	5	seconds
one bag sort by early morning crew member	uniform(15,30)	seconds
assign outbound change order bag to route or competitor	uniform(15,30)	seconds
take bag to relevant rolling cabinet	triangular(4,5,6)	seconds
register bag on inventory records	5	seconds

E. *Simulation Altered for RFID*

Based on the operational timings from the original simulation, several model factors were changed to incorporate RFID into the solution. The altered simulation was executed for 100 days (4500 truck routes, 120,000+ bags processed), and the resulting data were analyzed.

F. *Comparison of Current and Future State Simulations*

The future state model (with RFID) was compared for employee utilization and armored truck route timing with the baseline data from the original simulation. The comparison focused on person minutes for each task, and then each person's daily utilization was evaluated and compared. The truck routes were also compared but focused on route interactions with retailers, banks, ATMs, and competitors.

G. *Operational Budget Comparison and Evaluation of Return on Investment and Payback Period*

Applying the employee hourly costs to the simulation model output gave the researchers a series of operational cost savings. When applied to the overall cost of the required infrastructure, a Return on Investment and Payback Period calculation was accomplished.

IV. Discussion

A. *Process Mapping*

The process mapping exercise yielded several swim-lane style maps of behaviors that included the outbound transfer of cash bags, the inbound transfer of cash bags, sorting behaviors, CMS processing, outbound transfer, coin processing, and other smaller processes. Figure 1 and Figure 2 illustrate the inbound and outbound cash processing functions relevant to this paper. These maps indicate the processes required to accomplish a task by activities by each department.

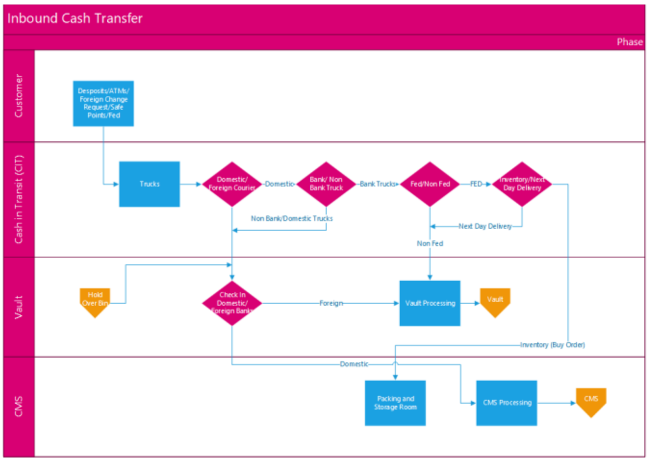

FIGURE 1 - PROCESS MAP - INBOUND TRANSFER

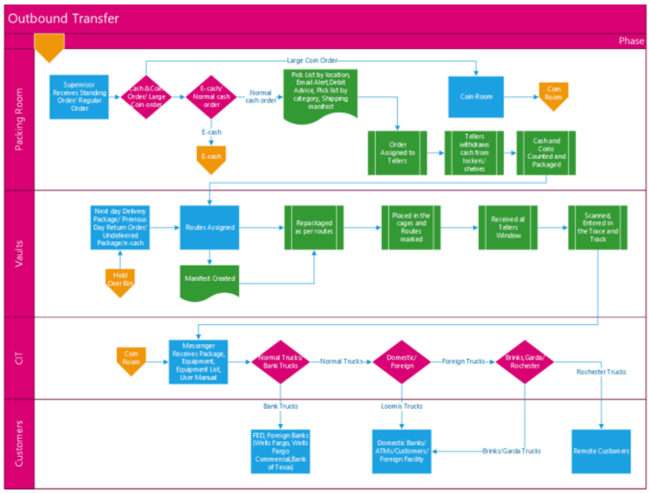

Figure 2 - Process Map - Outbound Transfer

The process mapping exercise was augmented with numerous documents illustrating the cadence and cost of activities.

B. *Simulation*

Once approved by the armored courier, a simulation was developed in AnyLogic Simulation Software that imitated the observed behaviors of the branch. As with the process mapping, each behavior flow was programmed into the software, and the resulting files were compared to the actual branch behaviors. As indicated in Table 1, the researchers had several variables from which to manipulate the output behaviors of the model.

The branch behaviors were not consistent throughout the daily processes, and each person performed in a slightly different cadence and behavior. Because of this, the variables were adjusted to provide a degree of variability based on the time of day and worker performance. Generally, these variables were set to uniform or triangular distributions that matched the variability of the observations. An example of simulation programming is in Figure 3.

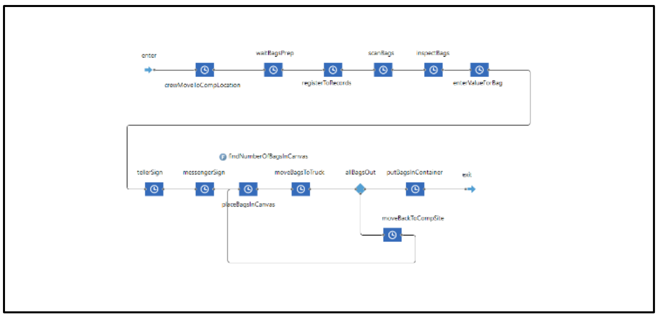

Figure 3 - Simulation Example - Competitor Interaction

Once the simulation was tuned, the simulation was executed many times (typically for 7, 30, and 100 days), the outputs were evaluated, and more minor adjustments were made to the model. Finally, the model was validated against provided and observed information.

The first area of validation was the transfer of custody timing in the mantrap between the vault teller and the CIT messenger (the person that interacts with customers during the route). The comparison started with standard statistical values of mean, and first and third quartiles. Table 2 compares observed data (Obs1day) with several period runs of the simulation model.

TABLE 2 - TRANSFER OF CUSTODY TIME PER BAG (MINUTES PER TRUCKLOAD EXCHANGE)

Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Obs1day	43	9.6225	3.3833	3.3833	6.4917	9.1000	12.0750	18.3833	18.3833
CM1day	44	9.7978	3.6079	3.6079	8.0836	9.7570	11.6683	16.3681	16.3681
CM7day	308	9.2408	3.6079	3.6079	6.7428	8.8423	11.2855	17.8486	18.4616
CM30day	1320	9.3614	2.7867	2.7867	7.0880	8.9967	11.4276	17.8646	19.1386
CM100day	4400	9.4597	2.7867	2.7867	7.1487	9.1478	11.6022	18.0965	19.3050
Δ Obs1day		98%	82%	82%	110%	101%	96%	98%	105%

Table 2 (blue highlights) indicates that the mean of the observed data and the mean of a 100-day (CM100day) model execution are within 2%. The first and third quartiles are within 10%.

The researchers then ran a single-day regression analysis of the data that was less conclusive than expected. See Figure 4 for the regression comparison.

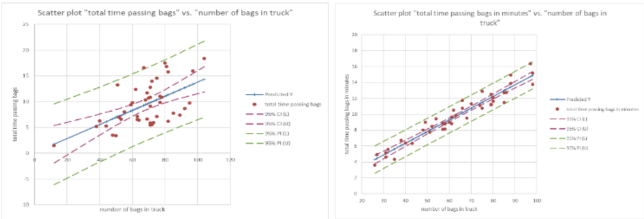

Figure 4 - Regression Comparison of 1 Day Observed and Model Data

The standard deviation was compared to 1-day observed data and 1-, 7-, 30-, and 100-day simulation executions, and found that the simulation model operated with about 25% less variability, as shown in Table 3.

Table 3 - Standard Deviation of Observed and Model Data

Observed 1 day	Model 1 day	Model 7 day	Model 30 day	Model 100 day
4.002	3.059	3.060	3.105	3.086

Next, the researchers looked at the 95% CI utilizing (1) where,

$$CI = \sqrt{\frac{2(1.96+1.6449)^2 4.002^2}{43}} = 9.6225 \pm 2.783\ minutes \qquad (2)$$

Applying the CI to the values in Table 2 clearly shows the values well within the confidence interval.

The next area of validation focused on the number of bags per truck. Having been provided a monthly average of bags per truck by the armored courier and counting bags per truck during observation, the mean bags per truck is 63. Table 4 shows the comparison of the observed bags per truck and the model bags per truck with the supplied average of 63 (shaded column).

Table 4 - Bags Per Truck Comparison

Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum	Average 63
Obs1day	43	69.4419	38.0000	38.0000	61.0000	71.0000	77.5000	97.0000	104.0000	110%
CM1day	44	63.3864	26.0000	26.0000	50.5000	62.5000	79.0000	98.0000	98.0000	101%
CM7day	308	59.5487	22.0000	22.0000	43.0000	58.0000	74.2500	109.0000	109.0000	95%
CM30day	1320	60.2379	22.0000	22.0000	46.0000	58.0000	74.0000	110.0000	110.0000	96%
CM100day	4401	60.9275	21.0000	21.0000	46.0000	59.0000	75.0000	112.0000	112.0000	97%

Utilizing the 95% CI for the number of bags per truck, the

$$CI = \sqrt{\frac{2(1.96+1.6449)^2 14.9814^2}{43}} = 69.4419 \pm 11.647 \qquad (3)$$

bags per truck. The simulation mean for bags per truck is well within the CI limits of observed and ATC-provided data.

Teller utilization is another metric for evaluation. Figure 5 illustrates the handling of inbound bags at this armored courier branch. Bags arrive from CIT and are passed through to the vault team. The bags are segregated by those departing for delivery the next day and those bags that will be processed internally by the branch. Other groups then sort bags until they are ready for delivery or processing.

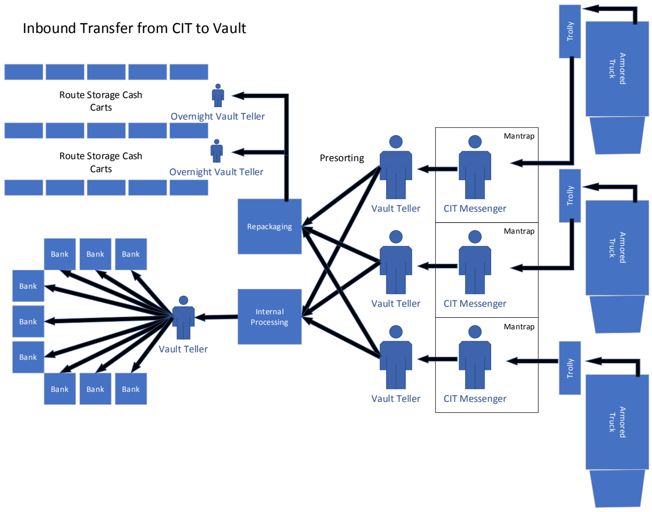

Figure 5 - Inbound Bag Processing

Bags are sorted by the vault tellers, overnight tellers, and CMS tellers to ensure that bags are prepared for the subsequent handling step. In most cases, each inbound bag is sorted by four tellers. At least three tellers handle outbound bags.

According to work hour documentation provided, tellers work, on average, 38.5 hours per week and have an average of 2.363 hours per week. Applying the 95% CI, the regular work hours are

$$CI = \sqrt{\frac{2(1.96+1.6449)^2 3.636^2}{452}} = 38.483 \pm 0.8719 \qquad (4)$$

and overtime hours are

$$CI = \sqrt{\frac{2(1.96+1.6449)^2 4.476^2}{452}} = 2.363 \pm 1.073 \qquad (5)$$

The simulation separates teller sorting behaviors from other teller behaviors. Table 5 shows the hourly teller utilization performing sorting behaviors. There is not a direct comparison drawn between teller utilization work hours and only sorting behaviors. These values will be utilized in the future state to show a work time comparison.

Table 5 - Teller Utilization for Sorting Behaviors Simulation

Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
VAULT 1	31	4.4170	0.0000	3.9283	4.3138	4.5142	4.7167	5.1994	5.4344
VAULT 2	31	4.5269	0.0000	4.1450	4.3933	4.7044	4.8213	5.1906	5.1906
VAULT 3	31	4.4421	0.0000	3.9983	4.3531	4.5306	4.8179	5.2208	5.2208
SORTING 1	31	9.9479	1.7739	9.0719	9.6963	10.1914	10.6832	11.7303	11.7303
OUTSORTING 1	31	7.1775	0.0000	6.4700	7.1947	7.4144	7.6897	8.1039	8.1039
CABINET 1	31	4.2083	0.0000	3.7389	4.1042	4.3550	4.6155	4.8683	4.8683
SECURITY 1	31	4.2086	0.0000	3.7464	4.1106	4.3600	4.6104	4.8606	4.8606
OVERNIGHT 1	31	8.4185	3.0000	7.7822	8.4141	8.6131	8.9563	9.6854	9.6854
OVERNIGHT 2	31	8.4185	3.0028	7.7821	8.4174	8.6189	8.9518	9.6879	9.6879
EARLYAM 1	31	1.9769	0.0000	1.8769	1.9575	2.0447	2.0954	2.2158	2.3586
EARLYAM 2	31	1.9767	0.0000	1.8822	1.9581	2.0431	2.0953	2.2178	2.3519
EARLYAM 3	31	1.9768	0.0000	1.8789	1.9554	2.0389	2.0963	2.2192	2.3564
EARLYAM 4	31	1.9761	0.0000	1.8792	1.9569	2.0383	2.0968	2.2139	2.3556
EARLYAM 5	31	1.9769	0.0000	1.8786	1.9544	2.0408	2.0986	2.2203	2.3558

Next, driver/messenger utilization was examined. Again, using work hours data from the armored courier, the following are the 95% confidence intervals for regular time and overtime.

Regular Hours

$$CI = \sqrt{\frac{2(1.96+1.6449)^2 2.9970^2}{2175}} = 39.016 \pm 0.2376 \quad (6)$$

Overtime

$$CI = \sqrt{\frac{2(1.96+1.6449)^2 7.8605^2}{2175}} = 7.8605 \pm 0.8593 \quad (7)$$

From the simulation standpoint, several configurations of the model were run. The researchers purposely chose a route configuration for a busy route that provided 12 hours of overtime. The purpose is to have a comparison route in the future state. See Table 6 for a simulation run for this very busy route.

Table 6 - Driver/Messenger Work Hours

Variable	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Average	14	52.0991	47.8247	51.0111	51.4709	52.6319	52.9278	53.7428	53.7428
Overtime	14	12.0991	7.8247	11.0111	11.4709	12.6319	12.9278	13.7428	13.7428

The last means of comparison is by the route stop duration. The armored courier provided no observed data collection or quantitative data. However, the simulation model complied with anecdotal information provided during interviews. Based on known route duration, number of stops, and typical types of stops, the simulation model was executed and provided the information in Table 7.

Table 7 - Route Stop Timing

Current State	Count	Mean	Minimum	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Retailer	2680	8.9484	1.6333	1.6333	6.5000	8.9333	11.4208	15.6333	15.6333
ATM	531	8.2562	0.3667	7.0000	7.6417	8.4333	9.1917	11.5000	11.9833
Bank	288	13.7612	4.7833	10.9333	13.1292	14.0833	14.8833	17.1000	17.1000
Competitor	117	10.1101	6.4833	7.1167	9.3667	10.1333	10.9167	12.9833	14.3333

After evaluating the time, the next step was extending these times to an operating budget.

C. *Operational Budget*

The armored courier provided a fully loaded (including wages and benefits) average hourly rate for each type of employee considered. The outcome is the operational budget in Table 8, illustrating an annual operational spend of about $8.5 million.

Table 8 - Financial Baseline

Role	Task	Time on Task (Min)	Cost	#	Daily Cost	Annual Cost
Vault Teller Armed	Outbound Transfer to CIT	11.4483	$5.15	45	$231.83	$84,617.49
CIT Messenger Armed	Outbound Transfer to CIT	11.4483	$4.96	45	$223.24	$81,483.51
CIT Driver Armed	Outbound Transfer to CIT	11.4483	$4.96	45	$223.24	$81,483.51
Vault Teller Unarmed	Bag Sorting & Assignment	430.6522	$165.08	1	$165.08	$60,255.41
Vault Teller Unarmed	Cabinet Sorting	252.4992	$96.79	1	$96.79	$35,328.85
CIT Messenger Armed	Cabinet Sorting	252.5133	$109.42	1	$109.42	$39,939.19
Vault Teller Armed	Vault Sorting	803.1656	$307.88	1	$307.88	$112,376.25
Vault Teller Unarmed	Internal Processed Bag Sort	596.8759	228.80	1	$228.80	$83,512.89
Vault Teller Unarmed	Overnight Sorting Ext Bags	1,010.2231	$387.25	1	$387.25	$141,347.05
CMS Teller	Early Morning Sorting	592.9989	$227.32	1	$227.32	$82,970.43
Vault Teller Armed	Inbound Transfer to Vault	12.9690	$5.84	45	$262.62	$95,857.43
CIT Messenger Armed	Inbound Transfer to Vault	12.9690	$5.62	45	$252.90	$92,307.15
CIT Messenger Armed	Waiting Time for Mantrap	2.9506	$1.28	45	$57.54	$21,000.80
CIT Messenger Armed	Route Operation	465.0333756	$201.51	45	$9,068.15	$3,309,875.05
CIT Driver Armed	Route Operation	465.0333756	$201.51	45	$9,068.15	$3,309,875.05
CIT Messenger Armed	Route Operation (OT)	42.29558034	$27.49	45	$1,237.15	$451,558.19
CIT Driver Armed	Route Operation (OT)	42.29558034	$27.49	45	$1,237.15	$451,558.19
				Total	$**23,384.51**	$**8,535,346.46**

Given the values above, the researchers turned their attention to applying API integration and RFID implementation to the model to compare the current state to a future state with a technology solution.

D. Implementation of an API and RFID into the Simulation Model

Cash bags may be created in a bank, armored courier, or retailer. When a retailer has a deposit, they place the cash and deposit slip in a tamper-evident plastic bag which an armored courier will pick up according to a contracted schedule. Conversely, when a retailer needs cash, they will put in a request through their bank (called a change order), and the cash will be delivered at the next contracted stop. In the current state, the retailer has no visibility of the progress of deposits or the status of change requests until a courier arrives at their location.

The API integration aims to give all entities foreknowledge of cash bag creation and provide real-time traceability of cash throughout the process. This sharing of information provides data-driven decision-making to all parties. For instance, couriers need not stop at retailers without deposits, and retailers get Amazon-like notifications of pending deliveries of change orders. Figure 6 illustrates an API integration for a deposit transaction.

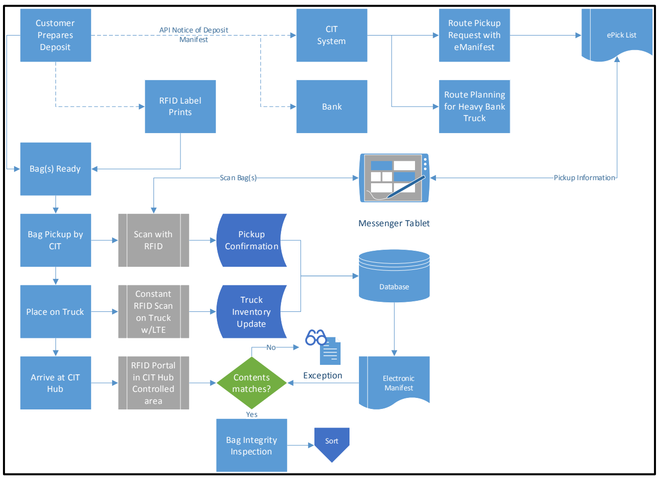

Figure 6 - API Data Flow Diagram

Passive RFID is the enabling technology for traceability and visibility. RFID facilitates faster change of custody transactions speeding up many transactions in the cash bag handling process. It can also provide a real-time location system (RTLS) for vehicle contents and large open areas like cash processing centers. Figures 7 – 9 illustrate RFID installations in a mantrap, on a vehicle, and RTLS in a branch.

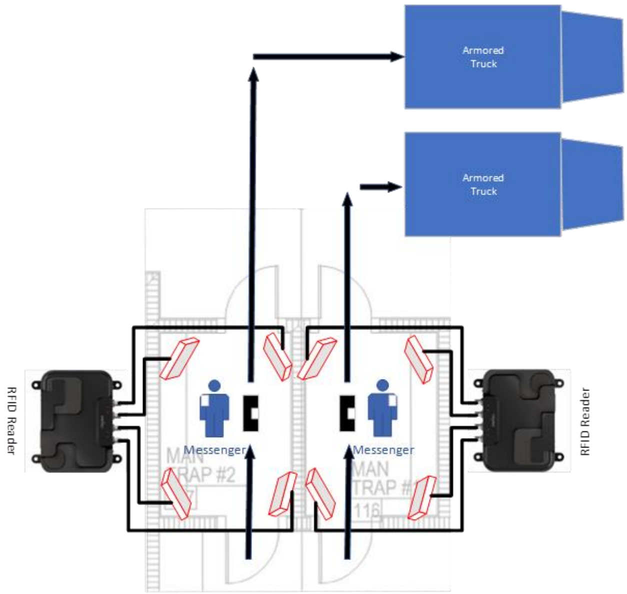

Figure 7 - RFID in a Mantrap

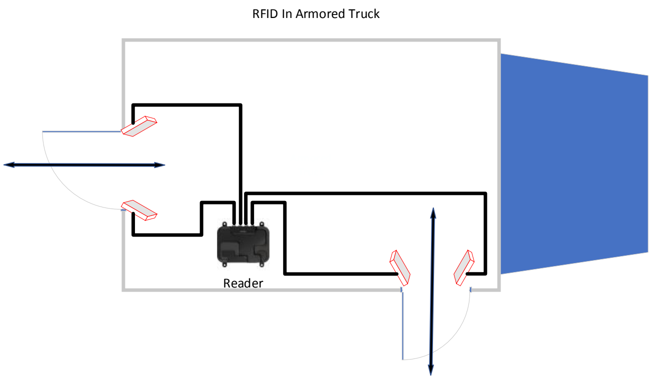

Figure 8 - RFID in an Armored Vehicle

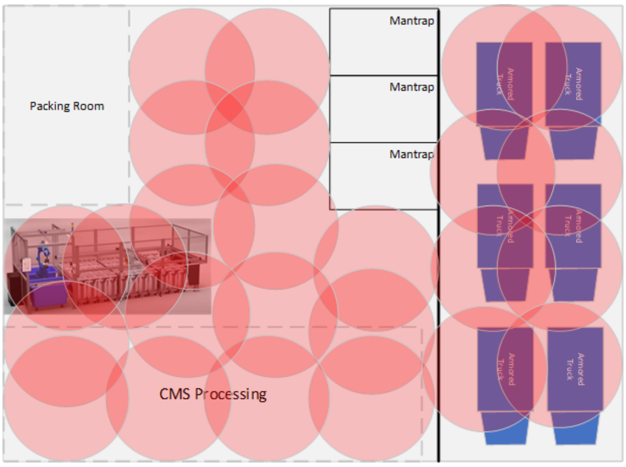

Figure 9 - RTLS RFID in a Branch

Every cash bag will be tagged with RFID labels at the moment of creation, and the RFID will be used until the bag is consumed (opened for use at a retailer or processed by a deposit teller). As shown above, cash bags will pass through portals (Figures 7 and 8) and be locatable by real-time location systems (RTLS), as shown in Figure 9. By placing the infrastructure throughout the path of cash bags, the traceability of the bags will be complete.

Table 9 – Parameter Changes in Model

Current Processing Times Configuration	**Current Model Parameters**			
Parameter	value at retailer	value at bank	value at competitor	units
courier waits for bags and manager to be ready	uniform(0,10)	triangular(3,5,7)	triangular(3,5,7)	minutes
find bags in truck	triangular(20,30,60)	triangular(20,30,60)	triangular(20,30,60)	seconds
enter info of bag on phone or PDA	5	5	7	seconds
Future Processing Times Configuration	**Future Model Parameters**			
courier waits for bags and manager to be ready	uniform(0,2)	triangular(1,2,3)	triangular(1,2,3)	minutes
find bags in truck	triangular(3,4,5)	triangular(20,30,60)	triangular(20,30,60)	seconds
enter info of bag on phone or PDA	1	1	7	seconds

Current Branch Processing Times Configuration	**Current Model Parameters**	
submit, scan, and bag messenger belongings	uniform(1,2)	units
one bag inspect and scan by vault teller	triangular(2,16,8)	minutes
one bag preliminary sort by vault teller	triangular(2,16,9)	seconds
one bag sort by sorting teller	uniform(15,30)	seconds
paperwork and release	uniform(1,3)	seconds
one bag overnight re-sort	uniform(15,30)	seconds
issue keys, manuals, phone/PDA(s), radios, a manifest, and a detailed route sheet for that day to the messenger	uniform(1,2)	seconds
load bag from branch to trolley	5	seconds
move trolley from branch to truck	triangular(20,30,60)	seconds
verify and accept bag to the electronic manifest on the phone/PDA	5	seconds
one bag sort by early morning crew member	uniform(15,30)	seconds
assign outbound change request bag to route or competitor	uniform(20,40)	seconds
take bag to relevant rolling cabinet	triangular(15,30,45)	seconds
register bag on inventory records	5	seconds
Future Branch Processing Times Configuration	**Future Model Parameters**	
Parameter	value	units
scan group of bags by RFID	triangular(5,10,15)	seconds
transfer of custody between messenger and vault teller	triangular(1,3,5)	seconds
move one bag from trolley to bin	2	seconds
move bin trolley and place it in robotic sorter	uniform(1,3)	seconds
sort one bag by robotic sorter	triangular(6,7,8)	seconds
sort one bag by worker	triangular(1,2,3)	seconds

Table 9 shows the model changes when applying RFID to the simulation. The timings change at the retailer, bank, and competitor locations, and the model becomes simpler at the branch location. One of the critical simplifiers is the addition of robotic sorting. Because each bag has an RFID tag, it can be sorted in an automated way. This eliminates several tellers and increases sorting accuracy while improving capacity. Figure 10 illustrates the movement of outbound cash bags from the packing room (where change orders are processed) to the preparation for armored truck routes.

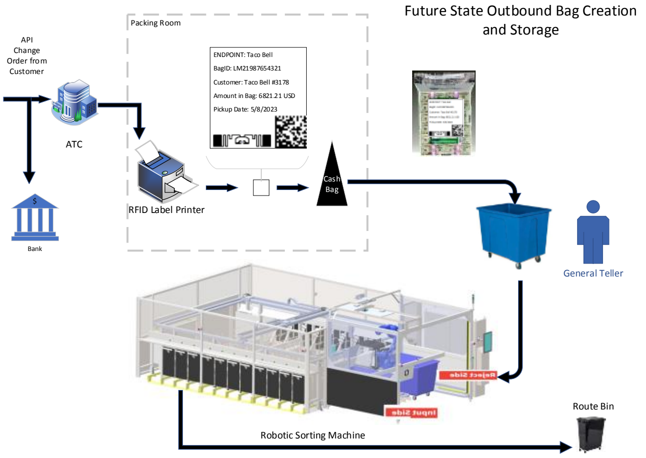

Figure 10 - Outbound Change Order with Robotic Sorting

The model exhibits significant reductions in time as well as increased capacity. Looking at the transfer of bags from the tellers to messengers (see Table 10) shows a 77% reduction in the processing time and all but eliminates waiting time for messengers that arrive at the busiest time of the day.

Table 10 - Mantrap Model Comparison

Current State	#	Mean	Min	Lower Whisker	Q1	Median	Q3	Upper Whisker	Max
total waiting time for mantrap in minutes	4400	2.95	0.00	0.00	0.00	0.00	4.81	11.99	31.01
total time in mantrap in minutes	4400	12.97	5.37	5.37	10.54	12.67	15.17	22.04	23.34
Future State									
total waiting time for mantrap in minutes	4400	0.04	0.00	0.00	0.00	0.00	0.00	0.00	1.32
total time in mantrap in minutes	4400	3.00	1.03	1.03	2.40	3.00	3.59	4.96	4.96
Percent reduction waiting for mantrap			**99%**						
Percent reduction in mantrap			**77%**						

Teller hours are also significantly reduced, as shown in Table 11. In the future state, there will be only general tellers that manage all of the tasks. The time spent transferring and sorting bags by tellers reduces from 68 hours daily to only fourteen.

Table 11 - Teller Utilization

Current Teller Utilization	# (Days)	Mean	Min	Lower whisker	Q1	Median	Q3	Upper whisker	Maximum
Cabinet 1 Sort	100	4.30	3.71	3.71	4.13	4.38	4.49	4.83	4.8289
Sec CabSort	100	4.30	3.66	3.66	4.11	4.36	4.49	4.85	4.8525
Early Sort 1	100	2.08	1.78	1.82	2.00	2.07	2.15	2.21	2.2931
Early Sort 2	100	2.08	1.78	1.81	2.00	2.07	2.15	2.29	2.2939
Early Sort 3	100	2.08	1.79	1.81	2.00	2.07	2.15	2.30	2.2961
Early Sort 4	100	2.08	1.78	1.82	2.01	2.07	2.14	2.29	2.2928
Early Sort 5	100	2.08	1.79	1.79	2.00	2.07	2.15	2.29	2.2936
Outbnd Sort 1	100	7.38	6.36	6.36	7.07	7.50	7.67	8.27	8.2692
Inbound Sort 1	100	10.37	9.00	9.00	10.02	10.43	10.75	11.73	11.7336
Vlt Inbnd Sort 1	100	4.69	3.89	3.89	4.46	4.68	4.90	5.46	5.4572
Vlt Inbd Sort 2	100	4.73	3.93	3.93	4.51	4.70	4.89	5.41	5.5247
Vlt Sort Inbnd 3	100	4.64	3.57	4.04	4.41	4.63	4.88	5.24	5.7794
Overnight 1	101	8.77	3.00	7.67	8.50	8.80	9.19	10.21	10.2653
Overnight 2	101	8.77	3.00	7.66	8.51	8.80	9.18	9.88	10.2650
Current Teller	68.3295								
Future Teller Utilization	**Count**	**Mean**	**Min**	**Lower whisker**	**Q1**	**Median**	**Q3**	**Upper whisker**	**Maximum**
General 1	101	2.83	0.11	2.50	2.69	2.76	2.87	3.09	7.1267
General 2	101	2.84	0.12	2.46	2.69	2.77	2.87	3.06	7.0136
General 3	101	2.81	0.07	2.46	2.67	2.75	2.85	3.05	7.1058
General 4	101	2.79	0.09	2.50	2.65	2.74	2.82	3.05	7.1606
General 5	101	2.80	0.10	2.46	2.67	2.74	2.81	2.96	7.0631
Future Teller	14.0676								

The reduction in time for route behaviors and route duration is even more significant. Table 12 shows the change in stop timing for each armored truck stop. Retailers represent 73% of the stops and have a 58% reduction in stop time. It is important to note that ATM servicing does not change with RFID. However, the traceability of the cash bag and transfers and sorting are significantly improved.

Table 12 - Comparison of Stop Duration

Current State	#	Mean	Min	Lower whisker	Q1	Median	Q3	Upper whisker	Max
Retailer	2680	8.95	1.63	1.63	6.50	8.93	11.4208	15.6333	15.6333
ATM	531	8.26	0.37	7.00	7.64	8.43	9.1917	11.5000	11.9833
Bank	288	13.76	4.78	10.93	13.13	14.08	14.8833	17.1000	17.1000
Competitor	117	10.11	6.48	7.12	9.37	10.13	10.9167	12.9833	14.3333
Future State	**#**	**Mean**	**Min**	**Lower whisker**	**Q1**	**Median**	**Q3**	**Upper whisker**	**Max**
Retailer	2578	3.7713	1.58	1.58	3.27	3.83	4.4000	5.6333	5.6333
ATM	531	8.4220	0.37	7.00	7.62	8.45	9.3250	11.8833	11.9833
Bank	288	8.8499	4.47	6.98	8.42	8.98	9.4667	10.6000	10.6000
Competitor	110	6.6061	3.82	4.77	6.05	6.55	6.9083	7.9500	9.6833
Retailer	58%								
ATM	0%								
Bank	36%								
Competitor	35%								

Table 13 gives the overall reduction in the entire route processing time. RFID not only provides live traceability, but it also reduces total route time by 43%. Routes that were taking, on average, eleven hours are now taking six. This change shows the increase in overall system capacity for armored couriers.

Table 13 - Comparison of Route Duration

Current State	#	Mean	Min	Lower whisker	Q1	Median	Q3	Upper whisker	Max
Route Duration	100	9.43	6.14	6.14	7.07	10.03	10.78	12.42	12.42
Overtime	100	1.77	0.00	0.00	0.00	2.03	2.78	4.42	4.42
Current Total	11.2078								
Future State	**#**	**Mean**	**Min**	**Lower whisker**	**Q1**	**Median**	**Q3**	**Upper whisker**	**Max**
Route Duration	100	6.40	4.84	4.84	5.34	6.73	7.11	7.72	7.72
Reduction	43%								

Given the time saving associated with the addition of IoT, Table 14 summarizes the overall change in time and cost compared to the financial baseline developed earlier. The overall operating costs are reduced to approximately $5.7M annually, a change of nearly $3M annually.

Table 14 - Future State Financial Picture

Role	Task	Time on Task (Min)	Cost	#	Daily Cost	Annual Cost
Vault Teller Armed	Outbound Transfer to CIT	7.5418	$3.39	45	$152.72	$55,743.58
CIT Messenger Armed	Outbound Transfer to CIT	7.5418	$3.27	45	$147.07	$53,679.00
CIT Driver Armed	Outbound Transfer to CIT	7.5418	$3.27	45	$147.07	$53,679.00
Teller 1	Mixed/Shared	2.8309	$1.27	1	$1.27	$464.98
Teller 2	Mixed/Shared	2.8360	$1.28	1	$1.28	$465.82
Teller 3	Mixed/Shared	2.8121	$1.27	1	$1.27	$461.88
Teller 4	Mixed/Shared	2.7934	$1.26	1	$1.26	$458.82
Teller 5	Mixed/Shared	2.7951	$1.26	1	$1.26	$459.10
Vault Teller Armed	Inbound Transfer to Vault	4.0375	$1.82	45	$81.76	$29,842.05
CIT Messenger Armed	Inbound Transfer to Vault	4.0375	$1.75	45	$78.73	$28,736.79
CIT Messenger Armed	Waiting Time for Mantrap	0.0430	$0.02	45	$0.84	$305.92
CIT Messenger Armed	Route Operation	384.2340	$166.50	45	$7,492.56	$2,734,785.50
CIT Driver Armed	Route Operation	384.2340	$166.50	45	$7,492.56	$2,734,785.50
CIT Messenger Armed	Route Operation (OT)	0	$-	45	$-	$ -
CIT Driver Armed	Route Operation (OT)	0	$-	45	$-	$ -
				Total	**$15,599.64**	**$5,693,867.92**

V. Return on Investment

The cost of implementing an RFID solution is based on industry retail prices for equipment, installation, software development, tag purchases, robotics leasing, etc. These costs are broken down into one-time capital expenditures and recurring annual operational expenses.

The one-time capital expenditures include equipment costs, installation, and software development. The operational costs include RFID tags, a lease for a robotic sorting machine, and annual hardware and software maintenance agreements that start in year two of the contract.

Table 15 shows these values, the first-year expenditures, annual savings, and the payback period.

Table 15 - Return on Investment (ROI) and Payback Period

ROI Calculator	
Location	**45 truck Branch**
Initial Costs	
Cost of Equipment	$271,210.00
Software Development	$2,500,000.00
Branch Equipment Installation (5%)	$4,981.25
Truck Equipment Installation (7%)	$12,010.95
Total Capex	**$2,788,202.20**
Operational Costs	
Tags	$102,430.80
Robotics Lease	$120,000.00
Annual Software Maintenance 2nd Year+	$450,000.00
Annual Hardware Maintenance 2nd Year+	$54,242.00
1st year OPEX	**$222,430.80**
Future year OPEX (year 2 & beyond)	**$726,672.80**
Total First-Year Expenditure	**$3,010,633.00**
Future State Savings	**$2,922,895.92**
Period of Return on Investment in years	**1.03**
Period of Return on Investment in months	**12**
Annual Operational savings after ROI	**$2,196,223.12**

VI. Conclusions & Recommendations

With a payback period of one year and annual savings afterward of approximately $2.2 million, there is a significant reason for armored couriers to consider investigating this solution further. Clearly, the model shows potential for reduced costs and increasing capacity while providing real-time traceability and visibility of cash.

Several factors not yet considered in this model include fuel savings, benefits in deposit processing, the actual value of customer satisfaction and increased visibility, compliance requirements, reduced loss, and decreased insurance costs. Other researchers should build on this to fully understand the full extent of this research.

The authors recommend that armored couriers begin small trials of the technology and explore the opportunities and cost savings such a system may provide. In addition, RFID system integrators should join with couriers in this exploration to develop complete solutions.

Given the potential for savings, increased capacity, and visibility, the authors believe that proof has been provided for others to continue the exploration of this topic.

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