Final Design Report

Disposable Cassette System for ATM Currency

in conjunction with:

NCR

by Team ELK:
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ME113: Mechanical Engineering Design
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1. Project Information

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2. Background

Ever since their invention of the first mechanical cash register in 1884, National Cash Register (NCR) has generated major advances in currency management technology. They installed over 300,000 of the world’s currently active automatic teller machines (ATMs) and now lead the world ATM market, working in 130 countries. Every year their machines process over twenty billion transactions, and each day, NCR ATMs hold a total of over fifteen billion dollars in cash. The company’s next objective for capitalizing on this rapidly growing market is “to develop a solution that puts the right technology in the right places, defines the most effective approach to maintenance and replenishment and applies the tightest security measures”\(^1\). A strong focus within this objective is to make their product more efficient and less expensive to own. They want to revolutionize their ATM design along these lines so that the company can continue to meet the changing needs of businesses and consumers today.

\(^1\) NCR web site: Improving Self-Service Operational Efficiency
3. Problem Statement

NCR has identified the currency cassette as a source of high cost in the existing ATM system and cash management process. The present design requires the use of large, expensive currency cassettes to hold and protect the bank notes during transport and within the machine. Their H-8015-STD1-01/02-08 Currency Cassette is illustrated in Figure 1 as an example of the current device. The three main disadvantages of this design are its size, cost, and service requirement.

![Figure 1. NCR’s Existing Currency Cassette](image)

**Size**

Designed to accommodate world-wide currencies, these cassettes are unnecessarily bulky when used with small bills like those in the U.S.; consequently, the money often occupies only a small fraction of their volume when the cassette is full. Space-inefficiency is highly undesirable in an industry where a small footprint is a prime selling point. The large size and weight of the cassettes also makes transport difficult and inefficient, which increases service costs. Capital and insurance costs can also be high because each cassette holds 2,500 bills; low traffic ATMs must hold this cash inside of them for long periods of time even though the money could be used more profitably in other locations. With the number of ATMs increasing quickly worldwide and the number of transactions per ATM simultaneously decreasing, this criteria of packet size is becoming increasingly important. The existing currency cassettes are inefficient in size because...
they can waste space, depending on the note size, are heavy and unwieldy, and hold a fixed number of notes.

**Cost**

With a unit cost of approximately U.S. $100, the cassettes are “a very high cost item within the ATM”\(^2\). Each machine can hold up to four cassettes at a time, and replenishment requires double this number because new, full cassettes must be swapped regularly with the empty ones inside the ATM. The present cassettes have a high cost because their design incorporates many complex moving parts, including gears, springs, and adjustable guide rails. Also, they are difficult to assemble because each one must be custom-fit for the currency it will hold. Because they are continually transported from the ATM to the bank and back, they are susceptible to handling damage and wear and must be repaired and replaced over time. The high production, assembly, and maintenance costs for these currency cassettes increase the overall ATM system’s cost to the customer.

**Service**

The inefficiencies in the current system for restocking the ATM also significantly increase ownership costs. The cassette is filled by hand at the bank vault or bullion center, conveyed to the site of the ATM by a security carrier, and installed in the machine. Partially exhausted cassettes are returned to the bank to be refilled. Loading bills into the cassette is a time-consuming, difficult task that must be performed by a worker with high security clearance. The refill process is subject to human error because the cassettes, which are magnet ID coded by denomination for the ATM, must be matched with the correct bank notes by hand; this process is especially difficult when all currency denominations are the same size, as in the U.S. These cassettes are loaded into the ATM from the front or back of the system. The ATM usually cannot be used by customers when it is being refilled with money, which is a powerful disadvantage in the service-oriented ATM industry\(^3\). Cassettes are swapped out and returned to the bank when they are still partially full; the untapped currency inside these cassettes constitutes a fundamental inefficiency in the cash flow system. Transporting these already opened cassettes

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\(^2\) NCR Invention Disclosure Record, Disposable Container for Currency or Valuable Items, Section 7a.

also poses a sizable risk of currency theft by service engineers, security workers, and bank employees. The service process of the current ATM cassette design is time intensive, inefficient, and risky; it sizably increases the cost of ownership for NCR machines.

**Design Goal: Minimize Size, Cost, and Service Requirement of Currency Container**

In developing their next-generation ATM system, NCR plans to focus on reducing the size, cost, and service requirement of the currency cassette. To that end, the company has presented our design team with the problem of creating a new currency container that addresses these issues. The new cassette will require a different loading interface inside the ATM and does not need to work with the existing dispenser. NCR has requested that we produce a wide breadth of potential solutions and then create a prototype of the most promising option.

NCR has defined very open-ended redesign criteria for the currency cassette and the cassette/dispenser interface. Their concerns focus primarily on the cassette and not on its interaction with the machine. After initial investigation of the problem, however, our team believes that the currency cassette and the currency dispensing mechanism are intricately related and must be examined first on the system level. After the general design of the system has been specified, the necessary functionality of the interface can be intelligently divided between the cassette and the ATM. These decisions will determine the final design of the new currency cassette that NCR has requested. Rethinking the entire ATM system first will provide a more complete solution to the problems of inefficiency and cost, yielding a better answer than a redesign of the cassette alone.
4. Design Objectives

ATM System
Based on NCR’s redesign goals, the new ATM system should accomplish the following tasks:

1. Dispense money to the customer efficiently and accurately.
2. Protect the money within the machine from theft. The system should be capable of identifying theft and tampering.
3. Accommodate wide variations in traffic levels by having a large maximum currency capacity and a small minimum cash requirement.
4. Minimize the machine’s footprint and overall size as a prime industry selling point.
5. Have a lower cost of ownership than the existing machine (figures currently unavailable from NCR); maintenance and service time should be minimal.
6. Enable currency replenishment that does not impact the availability of the machine to customers.

Currency Cassette
The new currency cassette must enable the system to perform the above tasks and also meet the following functional goals:

1. Provide a means to store and hold the money for transit.
2. Minimize packaging inefficiency by reducing wasted space in the cassette. The new cassette should achieve a space efficiency that far exceeds the current cassette design.
3. Reduce the cost of the cassette so that it would become a single-use item. NCR has requested that the final design cost less than U.S. $5.00 to produce in large quantities.
4. Conform to environmental laws that mandate that companies take full life-cycle responsibility for their machines. The disposable cassettes must be easily recyclable.
5. Deter theft using features that provide evidence of any illicit attempts to remove cash from the container.
5. Team Objectives

Our team of engineers has the following goals for this project:

1. Generate numerous possible solutions that fulfill the above criteria.
2. Select the most promising solution and develop it into a prototype.
3. Document the design process by providing a proposal, first report, midway presentation, trade show presentation, final report, and team member logbooks to our instructors.
4. Present many possible solution ideas and a single working prototype of our chosen design idea to NCR, our company sponsor, and thereby contribute to their work on developing the next-generation ATM.

We plan to observe the following schedule, represented in Fig. 2 as a Gantt chart, in pursuing this project. Course deadlines for deliverables are identified by white diamonds.

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Figure 2. Project Timeline
6. System Solutions

Before we can design an appropriate new currency cassette, we must formulate a clear conception of the ATM system in which it will function. With the previously stated design criteria in mind, we began this exploration with the concept that NCR initially presented to us.

NCR’s Original Idea

The initial inspiration for designing a disposable currency cassette system stemmed from the idea of a refillable, top-loading dispenser. The classic example of such a device is the soda vending machine. It stores the cans in a vertical stack and then dispenses them by letting the lowest one fall. The stock of cans is replenished by placing new cans on the top of the existing pile. Figure 3 details how this concept could be applied to an ATM in an illustration taken from NCR’s “Invention Disclosure Record of a Disposable Container for Currency or Valuable Items.”

![Vertical Stack, Pick Wheel, Empty]

Figure 3. NCR’s original model for an ATM system with disposable currency cassettes.

The primary difference between the soda machine design and an ATM is that the ATM cannot simply dispense the cassette like a can of soda. Instead, the empty cassettes must be stored within the machine after the notes have been removed. If a simple pop-in-the-top, pull-out-the-bottom approach is used, the ATM layout would have to reserve enough space to store all the empty cassettes. This strategy halves the number of bills that can fit into the ATM’s limited space. We decided that dedicating half of the machine’s volume to storing empty cassettes is undesirable, and we began considering several more space-efficient alternatives to NCR’s original system model. The four plans that we generated are detailed in Appendix A.
7. System Decision

We proposed the following four ATM system designs as different methods of improving the space efficiency of currency cassette management.

A. Top-Loading
B. Rotary
C. Stationary
D. Cassette-less

After obtaining input from our sponsors at NCR, we decided that the Top-Loading system is the most promising option. The Rotary system adds unnecessary complexity and cost and is less space efficient than the other designs. The Stationary design was eliminated because it is too similar to the current ATM system to provide significant improvements over the existing design. Though they liked the minimal role that the cassette plays in Design D, the Cassette-less system was discarded because the refill process is a significant security risk.

Of the four proposed solutions, the Top-Loading design meets our initial system objectives most fully. It protects the money within the machine from theft, can hold varying levels of currency, and has a relatively small footprint. Most importantly, it enables replenishment that does not impact the availability of the machine to customers as the new cassettes are simply pushed in the top of the machine and the empty, collapsed cassettes are removed from a bin at the bottom. This design is also advantageous in that the internal mechanisms are simple to build. Thus our final ATM system choice is the Top-Loading design.

**Chosen ATM System: Top-Loading Design**

With this framework in mind, our team set out to design a currency cassette for such a system.
8. Cassette Solutions

While addressing the system-level needs for this project, we generated many initial ideas about the cassette itself. In order for the cassettes to be tamper-resistant, they should be completely enclosed. The ATM can then burst or open a part of the cassette in order to obtain access to the bills. The cassettes should show a visible sign if they have been tampered with. We have considered the following options to achieve this goal:

- Opening the cassette destroys part of the container, which a security worker or the ATM itself will be able to identify.
- Ink or dye is released if the cassette is opened incorrectly, thus marking the thief or the stolen bills.
- The bills are sealed in an airtight container surrounded by detectable gas, for which the ATM tests upon opening the cassette.

A cassette that needs to be broken in order to gain access to the bills is the simplest of these choices to manufacture. The back of the cassette could be sealed with a plastic lid that clips internally into the cassette and thus cannot be removed without shearing the plastic clips. By recessing the lid, opening the cassette becomes even tougher as one would need to break the recess in order to leverage the lid open. Some simple catch mechanisms are shown in Fig. 4.

![Simple Catch Mechanisms for a Plastic Currency Cassette](image)

Figure 4. Simple Catch Mechanisms for a Plastic Currency Cassette
Another method entails that the machine gain access to the currency by bursting a perforated or weakened section of plastic or paper in the cassette. The weakened section of the container could be pushed or pulled from the container. If the weakened section were pushed in, a cavity within the cassette would need to be left to store the piece. If it were pulled off the cassette, it would need to be collected in a storage bin so that it could be discarded. One design solution could use the bill pushers themselves to burst the weakened section of the cassette covering the first bill. If this removable section was very thin, it could be carried away to the purge bin by the bill rollers. This idea of a burstable cassette is detailed in Fig. 5.

Building on these initial cassette ideas, we generated eight full cassette design schematics that would function well within the chosen Top-Loading ATM system. They are the following:

1. Rigid
2. Slide-By
3. Push-Over
4. Collapser
5. Edge-Breaker
6. Cruncher
7. Shrink-Wrap
8. Paper

The eight designs, which are presented in Appendix B, are intended to cover a wide spectrum of possible solutions. They are conceptual in nature, but we believe that any of them could be successfully implemented as part of a Top-Loading ATM system.
1. Sealed cassette has a sheet of plastic or paper covering first bill.

2. Bill pusher mechanism bursts perforations. Seal piece is removed with picker mechanism and sent to purge bin.

3. Money is accessible for picking.

4. Bill is picked.
9. Cassette Decision

In order to compare the merits of these eight designs and choose between them, we identified seven key criteria for the currency cassette. We rated all of the cassette designs on these seven metrics by assigning them each scores from zero to one in each category. The scores were roughly estimated using our knowledge about the designs. We then assigned each of these criteria a relative importance rating from one to ten based on the overall design objectives given to us by NCR. For instance, we initially thought tamper-resistance was the crucial parameter; however, after further discussions with NCR, it became evident that they require only tamper-evidence because cassette transport is quite secure. Andy Calder of NCR defined the cassette security standard as “tamper-evident,” and we adopted his definition, which follows, as our standard.

“If an unauthorized attempt is made to gain access to the inside of the currency container, then a clear indication of this unauthorized attempt should be visual on the container.”

Because tamper-resistance is not necessary, it was given a weight of three. Tamper–evidence was given a weight of ten because it is crucial. All of the designs presented are tamper-evident by this definition, so they all earn ratings of one on this criterion. The scores were then computed as a weighted sum of the seven individual ratings to arrive at a composite score for each cassette – the higher score being more desirable. The table of results from this process follows as Fig. 6.

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<tr>
<th>Criteria</th>
<th>Weight</th>
<th>1 Rigid</th>
<th>2 Slide-by</th>
<th>3 Push-Over</th>
<th>4 Collapser</th>
<th>5 Edge-Breaker</th>
<th>6 Cruncher</th>
<th>7 Shrink-Wrap</th>
<th>8 Paper</th>
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Figure 6. Cassette Design Rating Results: Paper Cassette Wins
This rating process determined that the Paper Cassette design offers the most promising solution. It earned 42.2 of the available 50 points because of several key features. It is the least expensive to manufacture, most space-efficient, and most environmentally friendly. It is also the most simply designed of the proposed schematics. The two categories in which it fell short of the other designs are “Ease of Loading” and “Tamper-Resistance.” Currency loading can be simplified by the design of a special frame for the process, and tamper-resistance was deemed unnecessary by NCR. Thus our team has chosen to proceed with the Paper Cassette Design.

**Chosen Cassette Concept: Paper Design**

Our team then set about determining how to implement a simple paper cassette for our working prototype of a top-loading ATM system. With our chosen conceptual framework in mind, we began by identifying the two most important aspects of the design that we still needed to investigate: the exact construction of the cassette and the interface between the cassette and the machine. We then generated several ideas for each of these issues.

![Figure 7. Conceptual Paper Cassette](image)

The chosen paper cassette solution was very abstract in nature; consequently, we did not initially define the method by which it could be built. As shown in Fig. 7, we proposed a six-sided paper box with perforations surrounding the front and rear ends, but such a box cannot be constructed out of flat paper without seams joining the different sections.

As we worked on solving this manufacturability problem, we kept the primary objective of tamper-evidence in mind. The construction of the cassette needs to provide protection to the
money both from theft and from damage during use. Because the forces experienced during transit are of a magnitude similar to those felt during tampering, some of the methods we investigated use signals unrelated to force to indicate whether someone has tampered with the cassette. Other designs rely on a visual signal on the cassette that results from the act of tampering. Our five proposed methods of tamper-evident cassette construction are detailed in Appendix C. They are the following:

a. Paper with Adhesive  
b. Cardboard with Adhesive  
c. Thin Stickers  
d. Ultraviolet Paint Pattern  
e. Encoded Information

The second issue we investigated for the design of the paper cassette was the in-use interface between the cassette and the machine. We needed to determine exactly how the machine could gain access to the bills inside our cassette. The initial concept for opening the paper cassette was taken from the burstable container idea illustrated in Fig. 5. When the pusher mechanism actuates, it bursts both the front and rear seals on the cassette. The seals drop into the bin below or pass through the bill rollers to the purge bin where the machine usually sends rejected notes and double picks. Using seals that have a different thickness or opacity from normal bills will insure that the machine’s sensors can properly detect and handle them. In order to implement this solution, however, the machine must hold the top, bottom, and side walls of the cassette stationary in order to react against the force of the pusher. Without such reciprocation, the perforations around the seals will never break. Consequently, we focused on finding methods for holding the sides of the cassette still and generated three viable solutions to this problem, which are illustrated in Appendix D. They are the following:

i. Protruding attachments  
ii. Peg Holes  
iii. Front Frame

10. Cassette Construction and Interface Decision
After generating many possible construction and interface solutions for the paper cassette, we evaluated the viability of each option and selected a final design.

**Construction Decision**

We decided to implement a hybrid paper/cardboard construction in order to optimize the tamper-evidence of the cassette and minimize its cost, as shown in Fig. 8.

![Figure 8. Chosen paper/cardboard cassette construction](image)

We opted for paper seals over the front and rear ends of the cassette so that the perforations would burst easily under the force of the pusher and during a tampering attempt. We also selected paper because broken seals could be sent to the purge bin like bills. We elected to use cardboard for the top, bottom, and sides of our cassette in order to cover the edges of the bills securely and give structural integrity to the container. The two paper ends are attached to the four cardboard sides with strong adhesive to prevent them from being separated and rejoined by a thief. If this structural level of security was deemed insufficient, the proposed thin sticker seals, UV paint pattern, or encoded information tactics could be implemented for an additional cost. This chosen cassette satisfies NCR’s definition of tamper-evidence without incurring significant expense or introducing unnecessary complexity to the design.

**Interface Decision**

After evaluating our three proposed ideas for holding the cassette sides motionless during use, we chose to pursue the front frame solution, as depicted in Fig. 9.

**Chosen Construction: Paper/Cardboard Hybrid**

After evaluating our three proposed ideas for holding the cassette sides motionless during use, we chose to pursue the front frame solution, as depicted in Fig. 9.
Figure 9. Chosen front frame cassette interface

We chose the front plate design because of its simplicity and ease of implementation. Attaching extra pieces to the cassettes, as proposed in other designs, would complicate stacking, and adding holes would reduce the security of the cassette. Any option that required the modification of the simple cardboard cassette sides would also incur increased construction costs, but the front frame design requires no cassette alteration. In addition, this solution allows the walls of the container to fall away after bursting because they are not at all attached to the machine. These advantages made the front frame option the obvious choice for interface design.

**Chosen Interface: Front Plate**

With the hybrid paper/cardboard construction and the front plate interface in mind, our team next set about creating a prototype of our new ATM currency cassette system.
11. Cassette Prototype

In designing the cassette for our prototype system, we focused on creating a secure container for the bills that would also facilitate loading and alignment. We centered our design of the paper and cardboard cassette around the length and width dimensions of U.S. currency. Based on our sponsor’s request, we determined that each packet would hold approximately 500 bills. After progressing through several iterations in which we tested tamper deterrence, structural integrity, and ease of loading, we settled on a final template design for the paper part of the cassette, as shown in Fig. 10.

![Scale Model of Cassette’s Paper Template](image)

**Figure 10. Scale Model of Cassette’s Paper Template**

When combined with four cardboard walls and several adhesive stickers, this paper template forms the front and back paper seals of the new currency cassette we have designed. Both seals are surrounded on all four edges by perforations to aid in bursting. For an illustration of the construction and loading of the chosen container from this paper template, please see Fig. 11.
Figure 11. Construction and loading of final currency cassette design: Continued on following page.
The front and back pages (labeled with the NCR logo) are the size of the notes so that they can pass through the ATM’s machinery to the purge bin. The cardboard sides cover most of the bill edges, leaving the corners open. In reducing this cardboard edging, we decreased the cassette’s theft deterrence because the notes are now visible within the cassette. However, smaller cardboard sides ensured that the pieces of cardboard would not catch or bind on the ATM dispenser mechanism. At the same time, alignment of the notes is much easier with such a design as the ATM can directly orient the bills before, during, and after the bursting of the cassette. This reduction in cardboard siding also leads to an overall decrease in total waste and allows for a smaller collection bin below the dispenser.

As seen in the paper template, the front and back pages are joined via one side of the cassette. Combining these two cassette parts makes the paper portion of the product easier to produce and saves time in cassette filling. Using stickers that have a removable backing, we were able to pre-assemble the cassettes so that the cardboard, paper, and stickers were all one unit. This allowed for faster construction of the cassettes and aided in transport of the unfilled cassettes.

Several of the features we incorporated in our design of the cassette focused on ways to indicate tampering. We created a repeating pattern of colored lines over the perforations of the paper
walls so that any breaking and resealing of the perforations would be revealed as a misalignment of this pattern. We also joined the cardboard and paper via stickers on the outside of the cassette that would tear the paper and mar the cardboard if they were removed. Given a wider range of resources and time, we suggest incorporating stickers that are both thinly sliced and transparent to further discourage tampering by making their removal very visibly obvious. A final feature of the cassette that acted as a tamper indicator were the perforations that we designed into the cassette to aid in bursting. By including these perforations in the cassette design, we placed an upper limit on the level of force the cassette can experience before bursting. Any undue force on the cassette due to tampering would break these perforations and indicate tampering. This structural weakness does not constitute a design flaw because the cassettes are securely transported in strong, locked briefcases, and they experience minimal handling by employees. Any excessive force can be used as a signal of tampering, and the torn paper identifies the act.

Our final cassette design securely encases the notes in a cardboard and paper sheath that has several features to indicate any attempts at tampering. These features along with others previously mentioned, can provide enough protection of the notes to discourage theft. Although our cassette does expose the money at the very edges of the cassette, this is not considered a concern by NCR and the benefits in waste reduction, loading, and alignment outweigh any concerns of having semi-visible notes. The cassette as currently implemented is cheap, easy to produce, recyclable, tamper indicative, and highly space-efficient.
12. Dispenser Prototype

After choosing the final design for the paper cassette, we set about designing a dispenser prototype that would validate the functionality of the cassette design. Our aim was to demonstrate that the cassettes could be effectively managed by the ATM. We wanted to prove that the dispensing mechanism could fulfill the following requirements:

**Cassette Cycling**
- Easy loading from the top of the machine
- Storage of several cassettes in the ATM machine
- Transport of the cassettes from their initial loading position to the picker mechanism
- Easy removal of the used cassette material after bursting

**Cassette Dispensing**
- Bursting of the cassette
- Accessibility of the burst seals to the picker mechanism for removal
- Guiding the money to the bill-picker for dispensing

We decided to perform the cassette cycling as illustrated in Fig. 12. The cassettes are pushed into an opening in the top of the machine, where they are stacked one on top of another. Vertical guides orient and align them, and they fall down under the influence of gravity. The bottom cassette is held in position with two rollers, one at each end, that squeeze against the sides of the cassette and hold it in a fixed position. The cassette is lowered by turning the rollers. When the bottom cassette is advanced all the way past the rollers, it falls, and the rollers catch the next cassette and the cycle repeats.
The bursting of the cassette is performed by a back pusher plate squeezing the money cassette against a front plate. This plate prevents the cardboard sides from moving forward and thus shears the paper seals along their perforations. The pusher mechanism needed to be designed to occupy as little space as possible to keep the device small, so we chose to use a plate that was advanced by two lead screws, one on each of its sides. The pusher is therefore a plate that travels in both the forward and reverse directions. We chose to power our lead screws using two separate hand cranks, but they could also be geared together so that they advanced at exactly the same rate. When the pusher advances against a cassette it forces the cassette against the front shear plate. As the pusher plate continues to advance the paper cassettes shears along the perforations and the cassette material falls down into a catch bin. The bills rest on two rail guides and hit a front stop through the plate. In order to insure it bursts along the perforations, it is imperative that the paper cassette be lined up correctly with respect to the front shearing plate. This necessary alignment was accomplished with several vertical guides. The specifics of these mechanisms will become clearer when the final prototype is detailed.

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**Figure 12. Schematic of the cassette cycling mechanisms**

![Diagram of cassette cycling mechanisms](image-url)
After several paper mock-ups we decided to build a robust ATM dispenser model. The prototype was designed mainly out of acrylic plastic cut on a laser-cam machine. The acrylic served as a framework to hold the mechanism and guides. The pusher-plate, front shear-plate, and front stop were machined out of aluminum for strength and rigidity. The shear plate was specked for a 1/1000th inch clearance between a bill and the plate, as were the gap between the guides and the cassette. The prototype was designed to serve as a mock-up to test the cassette concept. Thus we decided to turn the lead screws and rollers manually, and not to implement a bill-picker. The prototype is diagrammed in front, back, and side view in Figs. 14, 15, and 16 respectively. Technical drawings of the parts appear in Appendix E.
Figure 14. Front view of dispenser prototype
Figure 15. Back view of dispenser prototype
Figure 16. Side detail view of dispenser prototype
13. Prototype Performance

The prototype functioned well and demonstrated that our cassette-dispensing concept is feasible. The cassette cycling scheme worked perfectly every time, dropping down the bottom cassette and catching the next one up. When the pusher advanced to squeeze the cassette, all the perforations usually sheared and the cardboard pieces of the cassette fell down to the bottom of the box. On our demonstration day, we burst 24 cassettes, and the cassette burst perfectly 21 times. See Fig. 17 for an illustration of a successful run, noticing the four fallen cardboard sides. One side remained attached after three of the runs because the cardboard had slipped inside the hole in the front shear plate instead of butting up against it.

![Successful Cassette Bursting and Dispensing](image)

**Figure 17. Successful Cassette Bursting and Dispensing**

We were very pleased with obtaining these successful statistics because our prototype was very simple. A more precise design and construction would enable the mechanism to work every time. The errors can be attributed to slight misalignments of both the guides and the pusher plate. Firstly, the accuracy and tolerance of the guides could be improved to better align the
cassettes. Secondly, since we were manually cranking the pusher plate on two unlinked lead screws, we could not ensure that the plate advanced evenly. The speed that we advanced the plate at was also limited to our hand actions. A motor driving the lead screws together could achieve much faster rates of advancement, which would increase the impulse and decrease the risk of misalignments and slow timing. Thirdly, the cassettes were hand-constructed and hand-perforated. With more consistent cassettes and more even perforation strengths, the reliability of the entire system would improve as well.
14. Conclusion

The performance of our prototypes indicates that our solution is very feasible. Our thorough investigation has determined that a disposable currency cassette can best be implemented in a Top-Loading ATM system. The cassette itself should be a very simple design, constructed with cardboard sides and paper end seals. The machine should burst the cassette using its bill-pusher mechanism, holding the sides of the cassette stationary by using a front plate that frames the money. The prototype cassettes and dispenser that we constructed and successfully tested prove the validity of this concept as a solution to NCR’s specified design criteria. The system we created has significantly reduced the size, cost, and maintenance requirement of the currency cassette. The paper and cardboard cassettes that we designed are extremely space efficient, and they will cost only pennies to make in bulk. The Top-Loading system design, combined with the disposable, collapsible cassettes, minimizes the service required to replenish the machine and allows it to remain continually in operation. To fully determine the performance characteristics of this solution, a high-end prototype should be constructed and integrated with an actual ATM. Further iterations would entail trying different tolerances for the guides and shear plate to achieve maximally consistent alignment. The bill-picker mechanism could also be incorporated, as could automated driving of the lead-screws and rollers. The total system that we have created is more efficient and lower cost than the existing design, and as such, it is an excellent candidate for NCR’s next-generation ATM system.
Appendix A. System Solutions

Design A: Top-Loading System with Collapsing Cassettes

The first proposed system solution builds on NCR’s original idea by introducing the notion of a collapsing cassette. A collapsible cassette is advantageous in two ways. First, it significantly reduces the amount of storage space required for empty cassettes. Disposing of these empty cassettes is also simpler because their smaller size requires less transport space. Second, if the cassette collapses on itself as it dispenses the bills, the system does not require an internal bill pusher mechanism. Instead as the machine pushes on the outside of the cassette, the bills are pushed to the front and the cassette compresses in size.

One method of implementing a collapsible cassette is illustrated in side view in Fig. A1.

One method of implementing a collapsible cassette is illustrated in side view in Fig. A1.

![Figure A1. Collapsing Cassette Schematic](image)

The Top-Loading system for the ATM that would handle such a cassette is diagrammed in Fig. A2. This design is attractive because it is space efficient for a pop-in the-top, pull-out-the-bottom design. However, several complexities are introduced by the above design. Since the cassette collapses, it cannot structurally orient the bills in a neat stack. This function, which is traditionally performed by the cassettes, would need to be fulfilled by the ATM. The cassettes could have thin slits on each side into which a plate could fit and guide the notes. A further complexity with the design is the fact that because the cassettes drop into a bin at the bottom, the bill picker mechanism below the cassettes would need to be able to retract out of the way so the empty cassettes can fall freely.
Figure A2. Design A: Top-Loading System with Collapsing Cassettes

**Chief Advantages**

+ Simple to service
+ Space efficient

**Disadvantages**

- Cassette design could be difficult to manufacture
- Since the cassette collapses, the machine must align the bills using internal guides
- The bill picker mechanism must move out of the way in order for empty cassettes to fall
**Design B: Rotary System**

Instead of expelling empty cassettes, which requires a separate storage space, the ATM could just cycle through the cassettes sequentially. Such an ATM system is diagrammed in Fig. A3. The cassettes would travel around on a track inside the ATM, allowing the bill picker to access one cassette. When a cassette was empty, the ATM would simply rotate through to the next one and the emptied cassette would stay in the rotary cycle.

This strategy would eliminate the need for collapsible cassettes and internal guides for the currency because the cassettes could be rigid. This design would not require extra storage space inside the ATM, so it could potentially hold more currency per unit volume than other designs; however, the excess machinery and clearance spaces for the rotary cassette train might mitigate the space-saving advantage of the rotary cycle. Another chief disadvantage with such a design is the mechanical complexity introduced by the rotary chain. Furthermore, the design requires that all cassettes are emptied and refilled in a sequential process, which would complicate the replenishing process and take the machine out of service for a longer period of time.
Figure A3. Design B: Rotary System

Chief Advantages

+ Simple, rigid cassettes
+ No extra storage space required

Disadvantages

- The rotary chain is complex and expensive to implement
- Rotary mechanism requires extra space
- Sequential emptying and refilling makes service time-consuming

Cassettes inserted or removed; Cycle cassettes and repeat.
Design C: Stationary System

Our third proposed system design explores another method of eliminating the extra storage space for empty cassettes. This idea, which uses slide-in, pull-out cassettes, is illustrated in Fig. A4. The design has a stationary holder for each cassette, and each cassette has its own bill picker mechanism. When a cassette is emptied, it remains in its location and the ATM begins picking money from a different cassette. During service, the technician pulls the empty cassettes out of their holders and slides new cassettes into the vacancies.

This design is advantageous in that the cassettes remain stationary in the ATM. No extra machinery is needed to move the cassettes around, so the ATM can be less complex to produce and maintain. However, this does mean that multiple bill picker arms are required, or alternatively a moving picker arm would need to be employed. Using multiple bill pushers would not be space efficient, and thus the bill pushers would need to be contained in the cassettes. These would probably take the form of a back plate in the cassette that would be pulled forward by the machine.
**Figure A4. Design C: Stationary System**

**Chief Advantages**

+ Highly space efficient
+ Cassettes remain stationary

**Disadvantages**

− Need for multiple bill picker arms increases cost and complexity
− External bill pushers would require too much space, so the cassette would need to incorporate an internal bill pulling mechanism.
Design D: Cassette-less System

In our final system design, the currency cassettes serve to transport the currency, not to hold it within the machine. Such a cassette-less system design is illustrated in Fig. A5. The ATM will store only the bills themselves; the dispensing cassettes will be used to replenish the machine and then discarded. Thus there will be no cassettes stored in the ATM. This tactic greatly improves the storage capabilities of the machine and reduces the complexity of managing the cassettes. However, several complexities arise in offloading the cash into the machine. The person performing the refill process must not have access to the bills. The ATM would need to engage the dispensing cassette and only release it when all the bills had been emptied from it. A further complexity is that mechanisms within the ATM would need to orient and hold the bills. This design idea fully redefines the relationship between the cassette and the ATM.
Figure A5. Design D: Cassette-less System

Chief Advantages

+ Highly space efficient
+ No cassette management within the machine

Disadvantages

– Offloading the bills securely is difficult
– The machine itself will need to orient the bills

Internal Guides

MACHINE FULL

MACHINE IN USE

REFILLING

Dispenser used to insert money into machine
Appendix B. Cassette Solutions

Figure B1. Design 1: Rigid Cassette

**Description:**
The Rigid Cassette consists of six solid walls. There is a perforated seal covering the money behind the front wall, which has an opening. When the pusher rods push through two open holes in the back wall, they move a solid plastic plate forward which advances the bills. The front seal breaks under the pressure and this sheet of thin plastic or paper is picked like a bill. It either falls or is sent to the purge bin. The picker accesses the face of the next bill through a window in the front wall, and the bills are pulled out through a thin slit at the front of the top wall. When the pusher rods have moved all the way through and every note has been dispensed, the cassette remains a fully rigid box. In summary, this design is a rigid sealed box that does not collapse.

**Advantages:**
- Very tamper resistant – the box would need to be destroyed to obtain access to the cash. Even the front perforated seal is hard for a human to break.
- Structurally sound – this rigid cassette holds the money in alignment throughout operation.

**Disadvantages:**
- Space inefficient – the empty cassette occupies same space as a full one, so machine capacity is limited.
Description:
The Slide-by Cassette consists of two C-shaped parts that slide into each other. The first part is the back wall and the two side walls connected by living hinges. The second part is the front plate and the top and bottom walls connected with living hinges. Both parts are grooved along their mating edges so that they can slide together. There is also a ratchet mechanism or front-stop that prevents the two parts from sliding apart; they can only slide towards each other. As in the Rigid Cassette design, when the pusher begins to push, the front seal breaks and the money is accessible. In this case, however, the pusher advances the entire three-sided back piece of the cassette. When the pusher has moved all the way through, the two side walls and top and bottom wall can fold out because of the living hinges. The two parts are detached from one another and collapse into a flat shape.

Advantages:
- Space efficient – collapses entirely.
- Very tamper resistant – the box must be destroyed to gain access to the cash.

Disadvantages:
- Complex manufacturing – mating grooves and living hinges are difficult.
- Difficult loading procedure – filling the cassette requires fitting the parts together.
Figure B3. Design 3: Push-Over Cassette

Description:
The Push-Over Cassette is a plastic box consisting of four solid walls connected by living hinges at the edges. The front and rear walls are perforated seals. When the pusher begins to push, the front and back seals are broken. The front seal is picked like a bill and sent to the purge bin. When the pusher has moved all the way through, the box folds sideways along the living hinges to form a flat shape. This box’s primary feature is that it can fold over when it is empty.

Advantages:
- Space efficient – collapses completely.
- Tamper-resistant – the box starts off completely sealed and needs to be broken to get access to the bills.

Disadvantages:
- Complex machinery – the machine needs a mechanism to fold or push the box over.
Description:
The Collapser Cassette consists of four tapering rectangular sections stacked together, connected by thin sections of plastic. The money is held aligned with internal cords or bands, as shown in the detailed view below. When the pusher actuates, the bottom seal breaks and the first thin connection shears. As the pusher advances, each successive joining sections is sheared. When the pusher has moved all the way through, one is left with the sections stacked together to form a rectangular shape the size of the largest section. In summary, the box progressively collapses as it is pushed.

Advantages:
- Space efficient – the cassette collapses significantly.
- Tamper resistant – the box is completely sealed at the start, and the money is difficult to access.

Disadvantages:
- Money misalignment - because the money does not occupy the entire volume of the box, there needs to be a mechanism for aligning the money in the box. This could be done through the use of cords that are pulled through, or taut bands.
- Complex manufacturing – thin joining sections are difficult to injection mold.
Figure B5. Design 5: Edge-Breaker Cassette

**Description:**

The Edge-Breaker Cassette is a rigid plastic box consisting of four walls joined at the edges with thin staggered sections. The front and back walls consist of perforated seals. The pusher plate is designed so that as it advances, it moves inside the four walls and breaks the thin sections at the edges. When the pusher has pushed all the way through, all that is left is four unattached walls and the thin sections that originally held the edges of the walls together. The defining feature of this cassette is that the pusher breaks away the corners of the box as it progresses.

**Advantages:**

- Space-efficient – it collapses entirely.
- Rigid – the box remains structural as it is being used.
- Tamper-resistant – one must break the plastic to access the cash.

**Disadvantages:**

- Complex to manufacture – the thin, staggered edge joints could be difficult and expensive to make.
Figure B6. Design 6: Cruncher Cassette

Description:
The Cruncher Cassette consists of a thin plastic box that collapses under compression. The front is sealed with a pull-away cover. To start, the front seal is pulled off. As the pusher moves through, the plastic is crunched. After the pusher has moved all the way through, only the front seal and a crunched up flat piece of plastic are left. In short, this box collapses as it is pushed and does not have a rigid front plate.

Advantages:
- Space efficient – it collapses.

Disadvantages:
- Non tamper-resistant – pulling away the front seal could easily open the box.
- Complex machinery – the front end pull-away seal needs a special opening mechanism.
- Money misalignment – it is difficult to keep the notes lined up inside the crunching box.
Description:
The Shrink-Wrap Cassette has a hard front dispenser wall with a shrink-wrap bag holding the cash behind it. External supports must hold and align the money. When the pusher begins to push, the front seal is broken. As the pusher pushes, the thin plastic bag is entirely crunched up. When the pusher has moved all the way through, only the front plate and crunched up shrink-wrap are left behind. In sum, this design holds the money in flexible thin plastic and dispensing occurs through a rigid front plate.

Advantages:
- Space efficient – it collapses entirely.
- Material efficient – requires less plastic than other designs

Disadvantages:
- Structural integrity – the box has no structural properties and the cash must be held by external supports
- Not tamper-resistant – one can access the cash by slitting the shrink wrap and pulling out a bill.
- Not damage-resistant – fragile construction could be damaged if dropped.
**Description:**

The Paper Cassette is a cardboard box consisting of six walls perforated at all edges. External supports hold the money and the side walls from moving. When the pusher begins to push, the front and back walls break away and the box no longer has any structural properties. External supports must thus hold the money. When the pusher has moved all the way through, only six unattached walls remain. In essence, the cardboard box is just a way of holding the cash for transport and breaks as soon as it is used.

**Advantages:**
- Space efficient – it uses minimal space both during and after use.
- Simple to manufacture – inexpensive and easy to construct.

**Disadvantages:**
- Structural integrity – the box has no structural properties, so the cash must be held by external supports
- Non tamper-resistant – the cash can be accessed easily by tearing the box, though it is tamper evident.
Appendix C. Cassette Construction Solutions

Design a: Paper with Adhesive

The first idea we generated for building a tamper-indicative paper cassette consists of two overlapping pieces of paper joined by adhesive, as illustrated in Fig. C1.

![Figure C1. Assembly of cassette from two paper pieces joined by adhesive](image)

This design glues the four overlapping sides together very strongly so that the force necessary to separate these joints easily exceeds the force sustainable by the perforations. Any attempt at tampering would break the perforations around one of the ends, thereby releasing an entire side of the box to swing freely and providing an obvious indication of the tampering. Such an attempt could be disguised, though, if the two separated sections were carefully joined back together. The malleability of paper led us to consider cardboard as a more rigid material.
Design b: Cardboard with Adhesive

The cassette can also be constructed from two overlapping pieces of cardboard joined by strong adhesive, as illustrated in Fig. C2.

![Adhesive](image)

**Figure C2. Assembly of cassette from two cardboard pieces joined by adhesive**

Building the cassette out of thick cardboard gives it solid structure and prevents a thief from slicing open the side, removing a few bills, and reattaching the separated sections. The rigidity of the sides, though, makes it easier to separate two glued pieces without breaking the perforations. Such considerations led us to investigate tamper deterrents that do not rely solely on the strength of the container itself.
**Design c: Thin Stickers**

Covering the cassette’s cardboard seams with an obvious pattern of thin, strong stickers provides an obvious visual indication of tampering, as shown in Fig. C3.

![Thin, colorful stickers covering the cassette’s cardboard joints](image)

**Figure C3. Thin, colorful stickers covering the cassette’s cardboard joints**

Any attempt to penetrate this coating will reveal itself as a break in the pattern because the sticker adheres very strongly to the cardboard and breaks easily under force. Such a system allows anyone later inspecting the cassette to recognize the disruption of the pattern as an attempt at tampering. Although the forces experienced during transit may be enough to break the pattern in a few locations, this pattern would typically be random and thus easily ruled out as a case of tampering. If it were deemed necessary, the entire cassette could even be covered in such a pattern, reducing the likelihood that someone could gain access to the bills without leaving a noticeable signal. A careful thief, however, could possibly arrange the sticker so that it appeared non-disrupted, leading us to consider a less obvious protection pattern.
Design d: Ultraviolet Paint Pattern

Another marker we could use to indicate tampering is a pattern applied to the cassette joints with paint that is only visible in ultraviolet light, as illustrated in Fig. C4.

![Untampered and Tampered Cassette Joints](image)

**Figure C4. Distinctive pattern applied over cassette joints with UV paint**

Because it would not be visible to people in normal light, this pattern would serve as a reliable indicator of tampering attempts. If someone opens the cassette, they disrupt the continuity of the painted lines. They cannot re-align the pattern when they close the cassette because they cannot see the special paint. By examining it under UV light, an employee or even a sensor within the ATM can discover whether anyone has opened the cassette. Such a strategy might work better on paper than on cardboard because paper deforms more under stress, so pattern disruptions would be more obvious. A clever thief would soon figure out this tactic, though, and obtain a portable UV lamp. Because this solution does not provide an obvious visible indication without the special light, we decided to consider other means of tamper-evidence.
Design e: Encoded Information

The last design idea for making the cassette tamper-evident is to use a bar code to mark it with a trait that is unique to that particular package of money, as illustrated in Fig. C5.

![Bar code sticker](image)

**Figure C5. Bar code sticker containing information that identifies the cassette**

When the cassette was filled, information about a certain property of the package, such as the weight of the cassette, the number of notes, or selected bill serial numbers, would be recorded in the form of a barcode sticker which would then be attached to the cassette. This encoded data would serve as the cassette’s signature, and the destination ATM or an employee would compare the information in the barcode with the property of the cassette itself. Any discrepancy between the two would indicate that tampering, such as the removal of bills or the altering of the cassette, had occurred. For instance, if the code indicated that the full currency cassette should weigh 520 grams but the machine weighed it at 480 grams, 40 grams of notes must have been removed since it was filled. If implemented as a barcode or other marking that is difficult for people to understand and change, it should act as a reliable indicator for most tampering. A cunning thief could replace stolen notes with an equivalent weight of other material and thus foil the security tactic. Also, it is difficult to implement because it requires the integration of precision sensing equipment into the ATM to achieve the necessary level of accuracy and tamper-evidence.
Appendix D. Cassette Interface Solutions

Design i: Protruding Attachments

The first solution we developed for the machine/cassette interface involves creating protruding pieces on the sides of the cassette for the machine to attach to, as shown in Fig. D1.

![Figure D1. Protruding attachment points for the machine to latch onto](image)

Such a design could be implemented in many forms and is illustrated here as loops into which the machine can insert bars and as flaps onto which the machine can clamp. The machine could also use some sort of hook to fasten onto the loop attachment points. The protruding attachment pieces could be cut out of the sides themselves and folded up, or they could be glued-on parts. Any such addition would get in the way and compromise the stacking efficiency of the cassettes, both in transit and inside the machine. Such considerations led us to look for other interface solutions.
Design ii: Peg Holes

Another solution for holding the cassette stationary entails cutting holes in the sides into which the machine can insert pegs, as illustrated in Fig. D2.

![Figure D2. Machine inserts pegs into holes cut in cassette sides](image)

The holes could be cut round, rectangular, or any other shape, and they have the advantage of not requiring extra material on the cassette. Unfortunately, though, they do expose more bill surface area to the environment, which could entice theft. The material of the sides would need to be thick and rigid in order to insure that the sides could withstand the bursting force without crushing or buckling. The machine would also need mechanisms to engage all four sides of the cassette, which could get in the way of the cassette path through the top-loading ATM system. This limitation encouraged us to search for an even less invasive solution.
**Design iii: Front Frame**

Our final solution positions a precisely sized frame at the front of the money to prevent the sides from moving under the force of the pusher, as shown in Fig. D3.

![Diagram of the front frame](image)

**Figure D3. Machine’s front frame prohibits the cassette sides from moving forward**

A rigid plate with a hole that is exactly the size of the notes would allow the currency to pass through to the bill picker but would hold the four sides stationary. This design has the advantages of high space efficiency and simplicity of implementation. The cassette sides would need to be thick enough to resist the force of the pusher, and the cassette would need to be aligned precisely to insure the proper feeding of notes. Such a solution does not require any additional complexity in the design of the cassette itself, though, so cassettes for this solution could be manufactured at lower cost than for our other ideas.
Appendix E. Technical Drawings of Dispenser Prototype

Front Shear Plate
Back Pusher Plate

Side Plates of Holder
Back and Front Plates of Holder

Roller Support and Front Stop Plates

Miscellaneous, including Guides, Handles, Pusher Plate Front, Logos, and Box Bottom