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AUTO-ID CENTER

BUSINESS CASE STUDY

Auto-ID Fare Collection at the MBTA

Brandon Bean, Robert Dudley, Hideaki Tomikawa

AUTO-ID CENTER MASSACHUSETTS INSTITUTE OF TECHNOLOGY, 77 MASSACHUSETTS AVENUE, BLDG 3-449, CAMBRIDGE, MA 02139-4307, USA

ABSTRACT

Radio frequency identification, or RFID, technology is a form of automatic identification, or Auto-ID, technology that has already proven to have compelling applications in numerous industries. Item tracking and supply chain management are commonly cited applications, but these are far from the only ones. The goal of this paper is to determine, both qualitatively and quantitatively, whether or not low-cost RFID tags can be a viable fare medium in the mass transit fare collection process for single-use passengers. Contactless smart cards, a more expensive form of RFID technology, are already being used in transit systems internationally, and to a limited extent within the United States; however their use, because of card production costs, has been in the form of stored value cards for multi-use passengers. However, if a business case can be made for low-cost RFID for single-use ticketing, this would allow the industry to move away from dual fare collection systems and toward a fully integrated, homogenous solution for all mass transit passengers. As the adoption of low-cost RFID technology increases among all industries, costs will continue to decline, which will make the technology even more financially attractive and available to additional industries.

This project intends to show decision makers within the mass transit industry an analytical approach and some example data to help them decide if this new technology provides a potential cost-effective solution for single-use passenger ticketing. To accomplish this, the Massachusetts Bay Transit Authority (MBTA) will be used as a case study. The MBTA provides an excellent case study for these purposes because of the current state of the authority's fare collection initiative. The MBTA has begun to move forward with an expanded AFC (Automated Fare Collection) System, which would completely replace its existing, antiquated system with a smart card solution for multi-use passengers and a low-cost magnetic stripe solution for single-use passengers. A detailed analysis of the future AFC system will provide the necessary data to assess the cost effectiveness of an all-RFID solution versus a dual maintenance, smart card/magnetic stripe solution. This project is based on industry research, information provided by the MIT Auto-ID Center, and interviews with industry leaders from the MBTA.

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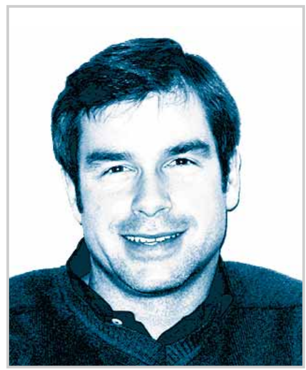
Biography

Brandon Bean

Brandon Bean will receive a Master of Business Administration from the MIT Sloan School of Management in June of 2003. Before attending MIT Sloan, Brandon was the Director of Business Development at Clipscom, a global Internet media services provider. Prior to Clipscom, Brandon was a Manager in Arthur Andersen's Business Consulting practice with four years of experience as an eBusiness strategy, information systems, and organizational change professional. He graduated from the University of Texas at Austin with a BBA in Honors Business and a MPA in Accounting. Brandon is a Certified Public Accountant licensed to practice in the state of Texas.



Bob Dudley

Bob Dudley will receive a Master in Business Administration from the MIT Sloan School of Management in June of 2003 with an emphasis in Financial Management. Prior to attending MIT Sloan, Bob served for seven years in the U.S. Navy, which included two Arabian Gulf deployments. His experience aboard ships included leadership roles in the Engineering, Operations, and IT departments. He also served as a Foreign Relations officer, training international military officers from 40 nations. He also worked at Sprint Corporation in its wireless division performing statistical analysis on individual performance. He is a 1994 graduate of the U.S. Naval Academy with a B.S. in computer science.

Hideaki Tomikawa

Hideaki Tomikawa, MIT Sloan Management of Technology Program Class of 2003 and Researcher of Sony Corporation, has five-years of experience in product development in Robotics and four-years experience in Researching Computer Graphics (CG) and Large Scale Integration (LSI). Hideaki has worked in manufacturing innovation at Sony introducing new manufacturing concepts such as Cell Production. He has also worked as a researcher focusing on the divergence of core LSI technology, the migration of Computer Graphics technology into Sony Products, and emerging technologies for new business development. Hideaki received a B.Eng. in Mechanical Engineering and an M.Eng. in Manufacturing Engineering from Yokohama National University in Japan.

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Contents

1. WHAT IS RFID?

[1] www.rfidjournal.com/FAQs.html

[2] "RFID - Is it Good For You", http://www.bellhawk.com/PDF/Past%20MXT%20PDFs/RFID.pdf, September, 2001.

RFID is a generic term for technologies that use radio waves to automatically identify items. One method of identifying objects using RFID, advocated by MIT's Auto-ID Center, is through a serial number or identification code, called an Electronic Product Code™ or EPC™, which is programmed onto a microchip. The chip is attached to an antenna, which when put together is called an RFID transponder or an RFID tag. The antenna enables the chip to transmit the identification information to a reader[1]. When the chip is interrogated by receipt of a radio signal transmitted by the reader, the tag broadcasts its identification code. This is picked up by the reader, decoded, and sent to a computer for use. The identification number relates to a database entry that contains all the information about the tagged item[2].

RFID tags are one of two main types, active or passive. Active tags contain a battery to power their electronic circuitry. They can be interrogated at relatively long ranges of 25 feet or more. Because of the additional expense of the on-board battery, active tags are relatively expensive. Passive tags, on the other hand, extract enough electricity from the reader's transmitted signal to power their electronic circuits. This causes their range to be much more limited. Current units operating in the 900 MHz or 2.45 GHz frequency ranges work at about a one-meter range in real-world environments.

While the power source is one factor of tag costs, memory size is also a determinant. Some tags contain only enough memory to hold their unique identification code and come from the factory with this pre-programmed into the tag. Other tags have enough memory to hold 1,000 or 2,000 characters of data, which is broadcast when they are interrogated. Active tags typically have large memories, while passive tags may be limited to 96 or even 64 bits of data storage to minimize cost.

The Auto-ID Center is focusing its efforts on developing an economically viable commercial solution for contactless item-level identification. In order to achieve a minimum-cost solution, the Center is focusing on developing a system around passive tags containing only a 64-bit EPC™ of data storage. For the purposes of mass transportation, this type of tag will have the all the required functionality for single-use passengers and will ultimately be the lowest-cost RFID approach. The important question, then, is: does EPC™ technology (or any RFID system) provide unique qualitative benefits and can it be procured and implemented cost-effectively? In this paper, we will refer to "low-cost RFID" as a general term for RFID-based single use tickets; although more specifically we expect EPC™ systems to emerge over time as the most flexible and least expensive of several "low-cost RFID" alternatives.

2. AN OVERVIEW OF THE MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

The first subway in the United States opened in Boston, Massachusetts, on September 1, 1897, running under the Boston Common from Park Street to the Public Gardens. After the success in Boston, subways in New York City shortly followed suit. In the days of few and extremely slow automobiles, the objective of mass transit was to provide a quicker, less expensive means of public transportation. The objective remains the same today, more than 100 years later, although many of the processes have changed significantly and continue to do so.

Today, mass transit in Boston is governed by the Massachusetts Bay Transportation Authority, or the MBTA, which is the fourth largest mass transit system in the United States based on ridership. Approximately 842,700 one-way passenger trips per day are taken on the MBTA's subway, bus, commuter rail, commuter boat, and paratransit services. The ridership numbers below show the number of passengers boarding each of the lines on a typical weekday. The MBTA serves a daily ridership of approximately 1.1 million passengers. Note that the total number of passengers boarding is greater than the total number of passenger trips, since many people transfer between lines to make a complete trip.

Table 1: Source: mbta.com

RAPID TRANSIT, BUS, COMMUTER BOAT, AND THE RIDE (FY01)	DAILY BOARDINGS
GREEN LINE	230,250
RED LINE	241,600
ORANGE LINE	165,600
BLUE LINE	58,200
MATTAPAN TROLLEY	7,750
MBTA BUS	379,750
THE RIDE (PARATRANSIT)	4,800
COMMUTER BOAT	4,150
TOTAL RAPID TRANSIT, BUS AND FERRIES	**1,093,300**

3 www.mbta.com, "Capital Investment Program FY2003 – FY2007," pg.1.

To provide these services, the MBTA maintains 161 bus routes, 3 rapid transit lines, 4 streetcar routes, 4 trackless trolley lines, and 11 commuter rail lines. Currently, its roster of equipment consists of 408 rapid transit vehicles, 181 light rail vehicles, 978 buses, 4 prototype alternative fuel buses, 40 trackless trolleys, 80 commuter rail locomotives, 362 commuter rail coaches, and 426 "RIDE" vehicles. Service is provided to 258 stations. Ridership continues to grow each year and to keep pace the system continues to expand. The next five years will bring 23 new stations into service, including three on the Worcester Line, seven stations on the Greenbush Line and 13 on the new Silver Line [3].

3. FARE COLLECTION AT THE MBTA

For mass transportation, fare collection systems in their simplest form consist of a fare medium and a fare collection device. Authorities typically use a fare medium other than cash to speed the boarding process and to prevent excess cash from being handled throughout the system. The passenger can typically buy either a single-use or a multi-use fare medium. Single-use media, as the name implies, are used only once for a specific trip, while multi-use fare media is typically prepaid and can be valid for any range of times or number of rides. After expiration, the multi-use fare medium is either thrown away or re-validated, depending on the specific fare collection system in place. The other part of the system, the fare collection device, is used to collect and validate the fare medium used.

3.1. The Existing MBTA Fare Collection System

4 www.mbta.com, "Capital Investment Program FY2003 – FY2007," pg.91

The MBTA's existing fare collection system differs by mode and includes station-based, vehicle-based and system control equipment. On the subway/rapid transit system, fare collection equipment includes 475 turnstiles and 90 barrier fare collection locations. Fare collection booths and exit gates at rapid transit stations are also considered to be part of the fare collection system as well as on-board conductors, who perform fare collection on the commuter rail system [4]. The existing fare collection equipment is 25 to 30 years old. Due to its age and the cost of replacement of parts, continued upkeep of the existing system is increasingly expensive for the authority.

The fare collection equipment accepts both tokens and magnetic (mag) stripe cards. In the MBTA system, the tokens are used for single-use rides and mag stripe cards are used for multi-use passengers. The process for collecting the different fare mediums varies by type. The tokens are deposited into a slot in the collection device, which then allows the passenger to pass through for boarding. The mag stripe card is read when the passenger slides the ticket into a magnetic stripe reader, which is typically attached to the entrance gate. If the reader accepts the simple information contained in the magnetic stripe, the person will be allowed to enter. The mag stripe cards used by the MBTA are a thin-weighted paper with a magnetic stripe on the back. The MBTA stores a very limited amount of data on the magnetic stripe. The card contains information printed on the face and back to indicate the time period for which the card is valid.

The MBTA offers a variety of passes and fares to fit the commuting needs of its passengers. For single-use passengers, subway tokens are $1.00 and the basic bus fare is .75 cents. The authority also allows children under 5 to ride free and children from 5-11 pay half fare when accompanied by an adult. For multi-use passengers, monthly passes allow for unlimited travel on all MBTA services. In addition, the passes have built in discounts and benefits such as reduced auto insurance rates and on Sundays, a friend can ride for free [5]. Multi-use subway passengers pay $35 per month, bus passengers pay $25 per month and combination passengers pay $57 per month. These are the typical plans, but additional plans are available in an attempt to meet the needs of as many passengers as possible.

5 http://www.mbta.com/traveling_t/passes_index.asp

3.2. The Future MBTA Fare Collection System

The combination of the existing aging equipment and the developments of new fare collection technologies has been the impetus behind the recent decision by the MBTA to move forward with the current AFC initiative. According to the MBTA, an entirely new fare collection system will be installed beginning in the spring of 2004. From a fare media perspective, the new system will use smart card technology for multi-use passengers and low cost mag stripe cards for single-use passengers. From a fare collection perspective, there will be 288 Full Service Fare Vending Machines (FVM) installed as well as 220 Cashless FVMs. The personnel formerly responsible for the disbursement of tokens will still be located at the terminals, but will become customer service agents. This expanded role would transform the CSA from a cashier/clerk into a transit ambassador for the general public, where they would provide an enhanced level of customer service [6]. The CSA would generally roam outside of the booth, greet customers, handle customer difficulties, and provide for another layer of vigilant security. In addition to the FVMs, 450 traditional turnstiles, 85 high-volume turnstiles with bi-parting leaves, and 1,700 validating fare boxes for collection on the buses will be purchased. Each of those will have the necessary validation equipment such as a mag stripe reader and/or an RFID reader. The estimated cost of the capital equipment for the new system is estimated at $75 million. There will be additional expenditures for technology and telecommunication infrastructure estimated at $37 million.

6 Interview conducted in November 2002 with Mike DeAngelis, MBTA Project Director of AFC.

4. LOW-COST RFID AT THE MBTA FOR SINGLE-USE PASSENGERS

The current fare collection transition at the MBTA offers an excellent opportunity to assess the viability, both economic and operational, of low-cost RFID for single-use passengers. Given that the new system is slated to use mag stripe for single-use passengers, a direct comparison between the two fare media can be made. The quantitative comparison will be made first, followed by a qualitative comparison.

4.1. Quantitative Assessment

The details of the recently approved fare collection modernization project at the MBTA were used to make a quantitative comparison between mag stripe cards and low-cost RFID cards for single-use passengers. In making this comparison, it can be assumed that many of the capital outlays for the modernization are sunk, such as turnstiles, telecommunications infrastructure, FVMs, etc., since the expenditures would be made anyway to upgrade the system. However, from this point, the analysis focuses on the economics associated with replacing single-use magnetic stripe cards with disposable single-use RFID tags.

The goal of the quantitative analysis was to determine the cost savings per card achieved by implementing a low-cost RFID solution instead of a mag stripe solution for single-use passengers. This cost per card, would provide the low-cost RFID equivalent cost per card, or the maximum allowable cost per RFID card, given the complete elimination of mag stripe technology from the fare collection system. The details of the model can be found in appendix items 1,2 and 3 at the conclusion of this report. The approach in creating the model is as follows:

Step 1 – Mag Stripe Reader Elimination
The mag stripe card readers are estimated to cost $2,956 apiece. This is estimated by comparing the cost of a turnstile with a mag stripe reader ($18,400) with the cost of a turnstile without a mag stripe reader ($15,444). This estimate is then multiplied by the total number of turnstiles, 535, and amortized over the life of the equipment, which is estimated at 15 years. Therefore, the total annual subway reader cost savings from shifting to RFID is $105,431. This same process was done for the 1,700 bus validating fare boxes with an annual savings achieved of approximately $335,013. It is important to notice that no additional RFID readers are needed, because the future fare collection system already requires RFID readers for smart card validation. These readers will be able to recognize the low-cost RFID cards as well as the smart cards, which will, as a result, require no additional capital expenditures. Thus the total annual savings due to the elimination of mag stripe readers is approximately $440,444.

Step 2 – Mag Stripe Reader Elimination
Since a dual system will no longer exist, certain maintenance cost savings can be expected. This was calculated by reducing the maintenance FTE's by an assumed percentage based on estimated time spent on mag stripe reader maintenance. It was assumed that maintenance time is split evenly between turnstiles and FVMs. In turn, the turnstile maintenance time is again split evenly between actual turnstile maintenance and mag stripe reader maintenance. The resulting estimate is that 25% of all maintenance time would be spent on mag stripe reader maintenance. The estimate means that the work force of 42-field crew can be reduce by 25% of 10.5 FTEs. According to the MBTA, a fully loaded maintenance employee costs around $84,000 per year. This results in a reduction in costs of $882,000 per year by using low-cost RFID instead of mag stripe. We also estimate that the associated parts and supplies maintenance costs are approximately 20% of labor costs, or $176,400. Again, both of these savings, which total $1,058,400 per year, are a benefit of not maintaining dual systems.

Step 3 – Mag Stripe Reader Elimination
The encoding equipment that would be required under a mag stripe system can also be eliminated. This equipment would be used to associate the initial system identification number with the card. The cost of the equipment is estimated to be $400,000, which can be amortized over its estimated useful life of 15 years. Approximately 1 FTE is used to operate the equipment. Again, this FTE is estimated to have a fully loaded cost of $84,000. The elimination of these two costs results in an additional annual savings of $110,667.

Step 4 – Mag Stripe Card Elimination
An additional savings will be the actual cost of the mag stripe cards themselves. The future plans call for an extremely low-cost paper, black-and-white, mag stripe card. It is estimated that at the volume demanded by the MBTA, these can be procured at a cost of $.025 per card. With a current single-use ridership of 87,100,000 passengers per year, this amounts to an annual savings of $2,177,500.

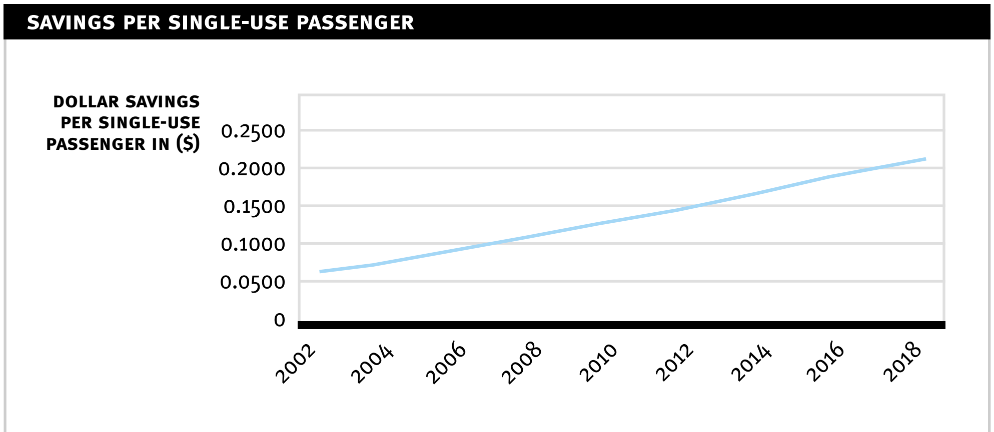
Step 5 – Fare Evasion Savings
Since RFID technology presupposes to have fewer incidents of fare evasion, there will likely be some incremental revenue associated with the new technology. According to the MBTA, it is estimated that there is a loss of approximately 1.5% of revenue due to various forms of fare evasion. The model assumes that only 25% of that loss can be traced to magnetic stripe cards and that that revenue loss can be recouped by switching to RFID, which is a fare medium that is more difficult to counterfeit. This annualized revenue savings is estimated to be $1,053,686.

Step 6 – Calculate Savings per Single-use Passenger
By calculating savings per single-use passenger, the maximum cost allowable per low-cost RFID tag can be determined. This can be calculated by summing all of the annual savings and dividing by the total annual single-use passengers. This calculation yields savings, per card, recognized by switching to RFID technology. Another way to think about this calculation is that it represents the breakeven point for RFID tag costs. For instance, a simple comparison of current RFID tag costs to this figure will determine if immediate RFID adoption makes sense. Immediate adoption will occur only if the RF tag cost is less than or equal to the cost savings of eliminating magnetic stripe technology from the upgrade. Otherwise, a time series analysis can be conducted to show how savings will grow through time. Pro forma costs can be forecasted over time in order to estimate when RFID adoption will make sense.

Findings
The model as described above concludes that the breakeven cost per RFID tag is approximately 7.2 cents. That suggests that if a low-cost RFID fare medium can be procured for no more than 7.2 cents per tag, then it is an economically advantageous solution. However, current low-cost RFID tag cost estimates from the MIT Auto-ID Center suggest that actual tag costs currently are closer to 30 cents. As a result, the financial analysis appears to indicate that a low-cost RFID solution for single-use passengers in mass transit is currently cost prohibitive unless some of the qualitative benefits can be found to outweigh the additional costs of the solution.

However, an interesting point is uncovered when a time series comparing the future card costs of a mag stripe solution versus a low-cost RFID solution is created. To determine the annual future per card savings of a low-cost RFID solution, as opposed to the single year presented in the original model, two adjustments need to be made to the model. First, a gradual migration from single-use to multi-use fare media by passengers over time can be expected as comfort level rises and new pricing programs are introduced that appeal to more specific audiences. For calculation purposes, this reduction was assumed to be smooth over the 15-year time horizon down to 50% of current single-use passenger levels. This will cause the fixed costs of the mag stripe system, such as capital equipment, labor, and maintenance, to have a larger impact due to the decreasing number of single-use passengers. The second adjustment is for inflation. The costs associated with a mag stripe system will be more susceptible to inflation than will the RFID solution. As a result, over time, certain costs in the model, such as labor and maintenance, must be adjusted for the CPI. These two adjustments will cause the RFID equivalent cost to increase from the current 7.2 cents to 21.64 cents by 2017. These adjustments are detailed in appendix item 4 and summarized in the graph on the next page:

Figure 1: Savings per Single-use Passenger Low-cost RFID instead of Mag Sripe

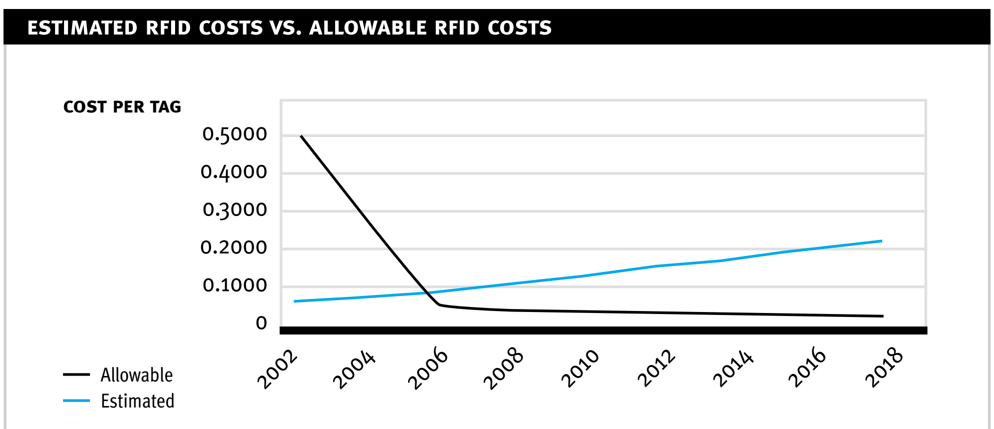


7 Auto-ID Across the Value Chain, Accenture, June 2002.

It is difficult to accurately predict the actual future costs of a low-cost RFID tag, as the biggest driver of price reduction is technology adoption. However, the MIT AUTO-ID Center "…estimates that new manufacturing techniques will drop the cost of passive tags to twenty cents in 2004 with additional scale driving the cost to five cents by 2006… [7]" In addition, intense vendor competition, scale economies, learning curve effects, and technological breakthroughs may accelerate the decline in tag costs over time.

With this assumption of future low-cost RFID tag costs, it is reasonable to assume that RFID tags have a good chance of penetrating the cost-prohibitive threshold in just a few short years. The graph below illustrates the point at which low-cost RFID will become a more economically advantageous solution for single-use passengers:

Figure 2: Time Series Comparison Estimated RFID Costs vs. Allowable RFID Costs



Therefore, it is entirely plausible that RFID adoption within mass transit would make pure economic sense within three years for single-use passengers. Given this conclusion and considering the MBTA's transition to the new AFC system will not be completed until 2005 – more than 2 years from the date of this report, from a financial perspective, making a full commitment to RFID technology for both the multi-use passenger and the single-use passenger during the current modernization is highly recommended. Before making a final determination it is important to assess the solution qualitatively, looking at both the benefits and limitations of a low-cost RFID solution for single-use passengers.

4.2. Qualitative Assessment: The Benefits

With the rapid development of new technologies in chip manufacturing and computing, intelligent ticketing systems, such as those based on RFID technology, are beginning to offer promising superiority over magnetic stripe ticketing systems for both system operators and passengers.

Low-cost RFID for single-use passengers offers the following advantages over magnetic stripe technology:

- **Security** – RFID technology presents a fare medium that is more difficult to counterfeit than magnetic stripe technology. Reducing this and other types of fare abuse, such as rider fare evasion and counterfeiting of media, is extremely important, yet difficult to quantify. It is however, often an important impetus for active consideration of new technology.

- **Reliability** – A key goal is the reliability of the equipment and the fare media. This includes both minimal system malfunctions and a high degree of accuracy in accounting for fares paid. RFID technology tends to be more accurate and reliable than mag stripe technology. It is renowned for its accuracy and low error rates, which equates to higher transit revenues. To further elaborate, RFID equipment will be able to operate in the presence of airborne particles, grease, oil, moisture, wind, noise, vibration, demanding electrical environment and moderate temperature changes [8].

- **Convenience** – Ease of use of the fare system by riders is an important expected benefit of new technology. Contactless cards offer greater convenience to the rider in that they do not have to be swiped like mag stripe cards. The cards/tickets can even remain in the users' purses, pockets or wallets. This is especially important for the elderly or those riders with disabilities. Additionally, contactless cards allow for increased throughput by speeding the boarding of buses.

- **Flexibility** – RFID allows for a range of fare options that can be offered and an ability to modify the fare structure easily and as needed. With a mag stripe solution for single-use fare medium, a constraint may eventually be posed on the multi-use fare medium because of pricing limitations and inflexibility from the single-use fare medium. For example, an eventual move toward distance-based pricing, peak/off-peak pricing, or any future developments of pricing strategy may be restricted by the inability to adjust the pricing scheme of the single-use passengers.

- **Compatibility** – While not a primary concern of the MBTA, as it is the only regional mass transit operator, the single-use technology should be compatible – and allow for future fare integration – with the fare systems of other transit providers in the region. This was a key concern in the NYMTA evaluation of fare system technologies. In some instances, such as the TransLink program in San Francisco and Metrocard program in Los Angeles, this goal has been the driving force behind consideration of new technology options [9]. Making a full-commitment to an open architecture RFID system will not disallow future regional developments, like a proprietary mag stripe system might.

- **System Consistency** – With an estimated 60 million current single-use passengers in the MBTA system, an enterprise-wide RFID solution for all passengers will create greater purchasing leverage, resulting in lower costs. Additionally, it will ensure flexibility regarding future technology developments and migrations to those new technologies.

8 MBTA AFC 2001 Specification, April 2002.

9 Report 10, Transit Cooperative Research Program, August 1995, Chapter 8, Page 154.

4.3. Qualitative Assessment: The Limitations

While there are many economic and non-economic benefits to a low-cost RFID solution, there are some current limitations when compared to other more traditional fare media. The current limitations are as follows:

- **Unproven Solution** – Magnetic technology is proven in both transit and general commercial applications (e.g., credit and debit cards); however, only read-only applications have been tested to any significant extent on buses; stored-value magnetic applications are just beginning to be implemented. Contactless cards, on the other hand, have excellent demonstrated capabilities, but are still relatively new and suffer from immature standards.

- **Lack of Standards** – This point degrades the current viability of low-cost RFID. A major impediment, affecting many hurdles on the path toward RFID implementation, is a lack of coordination among stakeholders in terms of determining universal technological standards [10]. Because there are many technology providers manufacturing incompatible RFID equipment, prices have remained too high and "proprietary technology… inhibits the use of tags and readers across multiple applications" [11]. At this point, researchers, vendors, government agencies, mass transit authority, passengers, etc. need to press the case for a universal, open, low-cost standard in order to propel RFID adoption in mass transit.

  To ensure that companies will not relive the costly scenario of a "Beta vs. VHS" standards war, the MIT AUTO-ID Center is "developing open standards for readers that they expect will promote lower prices by increasing direct competition among vendors." [12] The Auto-ID Center system, based on the Electronic Product Code™ (EPC™) concept, will ultimately provide the lowest-cost technology for transit operators and other RFID users. Although a full range of EPC™ technology is not yet available, operators can reasonably start today with RFID systems based on older access-card standards such as ISO 14443. Planned properly, those systems can be implemented in a modular way to accommodate software upgrades to EPC™ compliance at minimal cost when EPC™ systems have reached the point of being economically advantageous.

- **Uncertain Costs** – Closely related to both of the preceding issues is the uncertain cost-reduction trajectory for Auto-ID systems. Today's contactless products, which often have a proprietary architecture, limit agencies' ability to competitively bid the production of media. More generally, such systems limit both the speed of cost reduction and its predictability. As systems converge toward fewer architectures and eventually towards EPC™ implementation, cost reduction will accelerate and users will be better able to factor cost reduction into their ROI analyses.

[10] Xin Ye, 2002 – Ticket application in mass transportation.

[11] Auto-ID Across the Value Chain, Accenture, June 2002.

[12] Auto-ID Across the Value Chain, Accenture, June 2002.

5. FINAL RECOMMENDATION

RFID, and eventually EPC™, tags represent a tremendous opportunity for all stakeholders involved. Despite the limitations that may initially impede adoption, low-cost RFID has the potential to cost-effectively improve fare collection and transform the industry. Benefits from a system-wide RFID adoption within mass transit will accrue in terms of data collection, demand management, operating efficiencies, and user satisfaction. Most importantly, however, it has been shown that low-cost RFID adoption makes sense financially. While capital outlays for RFID systems will be significant, these investments will yield overall greater revenue generation and lower variable costs in the future.

It is apparent that the benefits, both quantitative and qualitative, far outweigh the costs when viewed over the long-term. In summary, RFID adoption appears to provide expanded opportunities for transit authorities to increase revenues, decrease costs, increase passenger satisfaction and convenience, and improve the existing fare collection process to keep pace in a rapidly growing and evolving industry.

6. APPENDIX

6.1. Assumptions

Table 2

ITEM	AMOUNT	DESCRIPTION
Capital Equipment – Amortization Period in Years	15	Useful Life of Capital Equipment
Time Allocation – FVM Maintenance	50%	Amt of Maint Time Spent on FVM
Time Allocation – Turnstile	50%	Amt of Maint Time Spent on Turnstiles
Turnstile Time Allocation – Turnstile	50%	Amt of TS Maint Time Spent on TS
Turnstile Time Allocation – Mag Reader	50%	Amt of TS Maint Time Spent on MR
Parts/Supplies Percentage of Labor Estimate	20%	Est of Mag Stripe Associated Supplies
Encoding Machine – Amortization Period in Years	15	Useful Life of Encoding Machine
Estimated Revenue Loss Due to Fare Evasion	1%	Est. Rev Loss % Due to All Fare Evasion
Fare Evasion Attributed to Magnetic Stripe	75%	Rev Loss % Due to Mag Fare Evasion
CPI Rate	2.5%	Consumer Price Index growth rate

6.2. MBTA Data

Table 3

ITEM	AMOUNT	DESCRIPTION
Turnstiles – Traditional Tripod	450	Num of Traditional Turnstiles in the System
Turnstiles – Bi-Parting Leaves	85	Num of High-Vol Turnstiles in the System
Validating Fare Boxes	1700	Num of Bus Fare Boxes in the System
Turnstile Cost with Mag Reader	$ 18,400	Turnstile Cost with Mag Reader Included
Turnstile Cost without Mag Reader	$ 15,444	Turnstile Cost with Mag Reader Not Included
Current Maintenance FTEs	52	Num of People Employeed for Maintenance
Shop Maintenance FTEs	10	Number of Maint FTEs not in the Field
Field Maintenance FTEs	42	Number of Maint FTEs in the Field
FTE Salary	$ 60,000	Maintenance FTE Salary
FTE Benefits	$ 24,000	Maintenance FTE Benefits at Load of 40%
FTE Total Compensation	$ 84,000	Maintenance Total Salary and Benefits
Encoding Machine	$ 400,000	Cost of Machine to Encode Mag Cards
Encoding Labor	$ 84,000	Cost of 1 FTE to Encode Mag Cards
Per Card Cost (Black and White)	$ 0.025	Cost of a Single-color Paper Mag Card
Average Single-use Pass/Weekday	275,000	Daily Token Users During the Week
Average Single-use Pass/Weekend Day	150,000	Daily Token Users During the Weekend Day
Weekly Single-use Passengers	1,675,000	Average Weekly Token Users
Annual MBTA Fare Revenue	$ 280,983,000	MBTA Transit Fare Revenue 2001 – 10K

6.3. Model

Table 4

COST SAVINGS ITEM	CALCULATIONS	ANNUAL SAVINGS	DATA SOURCE
MAGNETIC STRIPE READERS			
SUBWAY			
Turnstiles – Traditional Tripod	**450**		MBTA
Turnstiles – Bi-Parting Leaves	**85**		MBTA
Turnstiles – Total	**535**		Calculation
Cost with Mag Reader	**$ 18,400**		MBTA
Cost without Mag Reader	**$ 15,444**		MBTA
Implied Mag Reader Cost	**$ 2,956**		Calculation
Subway Total	$ 1,581,460		Calculation
Amortization Period in Years	15		Assumption
Mag Reader Subway Total – Annually	$ 105,431		Calculation
BUS			
Validating Fare Boxes	**1700**		MBTA
Implied Mag Reader Cost	$ 2,956		Calculation
Bus Total	$ 5,025,200		Calculation
Amortization Period in Years	15		Assumption
Mag Reader Bus Total – Annually	$ 335,013		Calculation
MAGNETIC STRIPE READERS TOTAL		**$ 440,444**	**CALCULATION**
MAG STRIPE READER MAINTENANCE			
LABOR			
Current Maintenance FTEs	**52**		MBTA
Shop Maintenance FTEs	**10**		MBTA
Field Maintenance FTEs	**42**		MBTA
Time Allocation – FVM Maintenance	50%		Assumption
Time Allocation – Turnstile	50%		Assumption
Turnstile Time Allocation – Turnstile	50%		Assumption
Turnstile Time Allocation – Mag Reader	50%		Assumption
Mag Reader FTE Equivalent	10.50		Calculation
FTE Salary	**$ 60,000**		MBTA
FTE Benefits	**$ 24,000**		MBTA
FTE Total Compensation	**$ 84,000**		MBTA
Mag Reader Maintenance Labor Total	$ 882,000		Calculation
PARTS/SUPPLIES			
Percentage of Labor Estimate	20%		Assumption
Mag Reader Parts/Supplies Total	$ 176,400		Calculation
MAG STRIPE READER MAINTENANCE TOTAL		**$ 1,058,400**	**CALCULATION**

Continuation of Table 4

COST SAVINGS ITEM	CALCULATIONS	ANNUAL SAVINGS	DATA SOURCE
MAGNETIC STRIPE CARD ENCODING			
Encoding Machine	**$ 400,000**		MBTA
Amortization Period in Years	**$ 15**		Assumption
Encoding Machine Total – Annually	**$ 26,667**		Calculation
Encoding Labor	$ 84,000		MBTA
MAGNETIC STRIPE CARD ENCODING TOTAL		**$ 110,667**	**CALCULATION**
MAGNETIC STRIPE CARDS			
Per Card Cost (Black and White)	**$ 0.025**		MBTA
Average Single-use Passengers per Weekday	**175,000**		MBTA
Average Single-use Passengers per Weekend Day	**110,000**		MBTA
Weekly Single-use passengers	**1,095,000**		MBTA
Annual Single-use Passengers	56,940,000		Calculation
MAGNETIC STRIPE CARDS TOTAL		**$ 1,423,500**	**CALCULATION**
FARE EVASION			
Annual MBTA Fare Revenue	**$ 280,983,000**		MBTA
Estimated Revenue Loss Due to Fare Evasion	1.5%		Assumption
Fare Evasion Attributed to Magnetic Stripe	25%		Assumption
FARE EVASION TOTAL		**$ 1,053,686**	**CALCULATION**
TOTAL ANNUAL COSTS		**$ 4,086,686**	**CALCULATION**
ANNUAL SINGLE-USE PASSENGERS		**59,940,000**	**CALCULATION**
TOTAL ANNUAL SAVINGS PER CARD		**$ .072**	**CALCULATION**

6.4. Time Series

Table 5:

Items in bold are adjusted for inflation
The 'Annual Single-use Passengers' is adjusted for the migration from single-use to multi-use

YEAR	2002	2003	2004	2005	2006	2007
Mag Reader Subway Total – Annually	$ 105,431	$ 105,431	$ 105,431	$ 105,431	$ 105,431	$ 105,431
Mag Reader Bus Total – Annually	$ 335,013	$ 335,013	$ 335,013	$ 335,013	$ 335,013	$ 335,013
Mag Reader Maintenance Labor Total	$ 882,000	$ 882,000	$ 882,000	$ 882,000	$ 882,000	$ 882,000
Mag Reader Parts/Supplies Total	$ 176,400	$ 176,400	$ 176,400	$ 176,400	$ 176,400	$ 176,400
Encoding Machine Total – Annually	$ 26,667	$ 26,667	$ 26,667	$ 26,667	$ 26,667	$ 26,667
Encoding Labor	$ 84,000	$ 84,000	$ 84,000	$ 84,000	$ 84,000	$ 84,000
Magnetic Stripe Cards Total	$ 1,423,500	$ 1,423,500	$ 1,423,500	$ 1,423,500	$ 1,423,500	$ 1,423,500
Fare Evasion Total	$ 1,053,686	$ 1,053,686	$ 1,053,686	$ 1,053,686	$ 1,053,686	$ 1,053,686
Total	**$ 4,086,697**	**$ 4,086,697**	**$ 4,086,697**	**$ 4,086,697**	**$ 4,086,697**	**$ 4,086,697**
Annual Single-use Passengers	**56,940,000**	**54,093,000**	**51,388,350**	**48,818,933**	**46,377,986**	**44,059,087**
Total Annual Savings Per Card with RFID	**$ 0.0718**	**$ 0.0755**	**$ 0.0795**	**$ 0.0837**	**$ 0.0881**	**$ 0.0928**

Table 6:

Items in bold are adjusted for inflation
The 'Annual Single-use Passengers' is adjusted for the migration from single-use to multi-use

YEAR	2008	2009	2010	2011	2012	2013
Mag Reader Subway Total – Annually	$ 105,431	$ 105,431	$ 105,431	$ 105,431	$ 105,431	$ 105,431
Mag Reader Bus Total – Annually	$ 335,013	$ 335,013	$ 335,013	$ 335,013	$ 335,013	$ 335,013
Mag Reader Maintenance Labor Total	$ 1,022,850	$ 1,048,421	$ 1,074,631	$ 1,101,497	$ 1,129,035	$ 1,157,260
Mag Reader Parts/Supplies Total	$ 204,570	$ 209,684	$ 214,926	$ 220,299	$ 225,807	$ 231,452
Encoding Machine Total – Annually	$ 26,667	$ 26,667	$ 26,667	$ 26,667	$ 26,667	$ 26,667
Encoding Labor	$ 97,414	$ 99,850	$ 102,346	$ 104,904	$ 107,527	$ 110,215
Magnetic Stripe Cards Total	$ 1,650,824	$ 1,692,094	$ 1,734,397	$ 1,777,756	$ 1,822,200	$ 1,867,755
Fare Evasion Total	$ 1,221,953	$ 1,252,502	$ 1,283,814	$ 1,315,910	$ 1,348,807	$ 1,382,528
Total	**$ 4,664,721**	**$ 4,769,661**	**$ 4,877,225**	**$ 4,987,478**	**$ 5,100,487**	**$ 5,216,321**
Annual Single-use Passengers	**41,856,132**	**39,763,326**	**37,775,159**	**35,886,401**	**34,092,081**	**32,387,477**
Total Annual Savings Per Card with RFID	**$ 0.1114**	**$ 0.1200**	**$ 0.1291**	**$ 0.1390**	**$ 0.1496**	**$ 0.1611**

Table 7:

Items in bold are adjusted for inflation
The item in white is adjusted for the migration from single-use to multi-use

YEAR	2014	2015	2016	2017
Mag Reader Subway Total – Annually	$ 105,431	$ 105,431	$ 105,431	$ 105,431
Mag Reader Bus Total – Annually	$ 335,013	$ 335,013	$ 335,013	$ 335,013
Mag Reader Maintenance Labor Total	$ 1,186,192	$ 1,215,847	$ 1,246,243	$ 1,277,399
Mag Reader Parts/Supplies Total	$ 237,238	$ 243,169	$ 249,249	$ 255,480
Encoding Machine Total – Annually	$ 26,667	$ 26,667	$ 26,667	$ 26,667
Encoding Labor	$ 112,971	$ 115,795	$ 118,690	$ 121,657
Magnetic Stripe Cards Total	$ 1,914,449	$ 1,962,310	$ 2,011,368	$ 2,061,652
Fare Evasion Total	$ 1,417,091	$ 1,452,518	$ 1,488,831	$ 1,526,052
Total	**$ 5,335,052**	**$ 5,456,750**	**$ 5,581,491**	**$ 5,709,351**
Annual Single-use Passengers	**30,768,103**	**29,229,698**	**27,768,213**	**26,379,803**
Total Annual Savings Per Card with RFID	**$ 0.1734**	**$ 0.1867**	**$ 0.2010**	**$ 0.2164**

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