– Intentionally Left Blank –
VOLUME VIII – SYSTEM EQUIPMENT

CHAPTER 4 – FARE COLLECTION INTEGRATION DESIGN CRITERIA

REVISION 1

Program Management Consultant

Submitted
Project Manager, Soji Tinubu

Date 4/16/2009

Miami-Dade Transit
Engineering Review Board Members

Approval
Chief of Design & Engineering, Isabel Padrón

Date 4/16/09

Chief of Construction, Ron Steiner

Date 4/14/09

Chief of Safety, Eric Muntan

Date 4/16/09

Manager of Systems Engineering, Daniel Mondesir

Date 4/16/09

Director Approval

Approval
Deputy Director, Albert A. Hernandez

Date 4/20/09

Approval
MDT Director, Harpal Kapoor

Date 06/01/09
## DOCUMENT REVISION RECORD

<table>
<thead>
<tr>
<th>ISSUE NO.</th>
<th>DATE</th>
<th>REVISION DESCRIPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4-26-07</td>
<td>Interim Release</td>
</tr>
<tr>
<td>1</td>
<td>10-30-08</td>
<td>Revisions to incorporate MIC-EH design specifications that have been adopted by MDT.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ISSUE NO.</th>
<th>SECTIONS CHANGED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No changes were made to this chapter for this revision.</td>
</tr>
</tbody>
</table>
– Intentionally Left Blank –
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.01</td>
<td>Purpose, Scope, and Intended Audience</td>
<td>1</td>
</tr>
<tr>
<td>4.02</td>
<td>Applicable Codes, Standards, and Regulations</td>
<td>3</td>
</tr>
<tr>
<td>4.03</td>
<td>General AFC Equipment Requirements</td>
<td>4</td>
</tr>
<tr>
<td>4.03.1</td>
<td>Equipment Placement</td>
<td>5</td>
</tr>
<tr>
<td>4.03.2</td>
<td>Environmental</td>
<td>6</td>
</tr>
<tr>
<td>4.03.3</td>
<td>Electrical and Communications</td>
<td>9</td>
</tr>
<tr>
<td>4.03.4</td>
<td>Station Attendants Booth</td>
<td>12</td>
</tr>
<tr>
<td>4.03.5</td>
<td>Usability and Maintainability</td>
<td>12</td>
</tr>
<tr>
<td>4.03.6</td>
<td>Security</td>
<td>13</td>
</tr>
<tr>
<td>4.03.7</td>
<td>Accessibility</td>
<td>13</td>
</tr>
<tr>
<td>4.03.8</td>
<td>Installation</td>
<td>14</td>
</tr>
<tr>
<td>4.04</td>
<td>Fare Gates</td>
<td>16</td>
</tr>
<tr>
<td>4.04.1</td>
<td>Fare Gate Functions and Design</td>
<td>17</td>
</tr>
<tr>
<td>4.04.2</td>
<td>Quantity, Location, and Space Requirements</td>
<td>21</td>
</tr>
<tr>
<td>4.05</td>
<td>Ticket Vending Machines (TVM)</td>
<td>23</td>
</tr>
<tr>
<td>4.05.1</td>
<td>TVM Functions and Design</td>
<td>23</td>
</tr>
<tr>
<td>4.05.2</td>
<td>Quantity, Location, and Space Requirements</td>
<td>24</td>
</tr>
<tr>
<td>4.06</td>
<td>Ticket Office Machines (TOM)</td>
<td>27</td>
</tr>
<tr>
<td>4.07</td>
<td>Fare Collection Equipment Calculations</td>
<td>28</td>
</tr>
<tr>
<td>Appendix A</td>
<td></td>
<td>36</td>
</tr>
</tbody>
</table>
4.01 PURPOSE, SCOPE, AND INTENDED AUDIENCE

The purpose of this document is to serve as a guideline reference on the design requirements for the automated fare collection (AFC) equipment on MDT Metrorail stations. This document is developed based on the AFC equipment requirements stated in the RFP No. 05-722 and the MDT Compendium of Design Criteria for Fare collection equipment (July 1979).

The AFC equipment to be installed on MDT Metrorail stations will include: (i) fare gates; (ii) ticket vending machines (TVM); and (iii) ticket office machines (for use in stations with the attendant’s both only). All AFC equipment installed on MDT stations will be connected to the MDT communications network and will be monitored and controlled in real-time from the MDT Central Computer and/or the station controller (where available). In addition, all AFC equipment will be capable of operating in an autonomous mode for an extended period of time (up to several weeks, depending on the ridership volume) in the event of a communication network failure.

Fare gates will be installed at each Metrorail station entrance to control access to and from the station Paid area. Fare gates will accept valid fare media including magnetic stripe tickets and contactless smart cards. The fare media will be available for purchase through self-service TVM’s located at station entrances and from station attendant’s booths (where available). The AFC equipment will be configurable to support various fare policies and operational modes as briefly outlined in this document.

This document is primarily intended for MDT station architects and engineers (hereafter referred to “the Designer”) to assist in the design of new Metrorail stations. Unless otherwise directed by MDT, the Designer’s drawings and
specifications shall indicate that the automatic fare collection equipment will be provided and installed by others but the Designer shall provide adequate electrical service, all supporting elements such as conduits, wiring, space, weather protection, lighting and all interface requirements with communication subsystems regardless of the entity designated to provide the automatic fare collection equipment.

The initial installations of AFC equipment for the new rail line extensions shall be designed to support fare collection transactions by either entering passengers or exiting passengers along with future requirements which include growth in patronage. Procedures for estimating the required equipment are included in Section 4.07.
4.02 APPLICABLE CODES, STANDARDS, AND REGULATIONS

The current adopted version of the codes, standards and regulations shall apply, and unless otherwise directed, all addenda, interim supplements, revisions and ordinances by the respective code body shall also apply. Where conflicts exist between these, the more stringent requirement shall take precedence, unless otherwise directed by MDT.

- National Electrical Code (NEC);
- National Electric Safety Code (NESC);
- Local Electrical Codes of the communities through which the transit system will operate;
- Standard for Fixed Guideway Transit and Passenger Rail Systems (NFPA-130);
- Standards of the American National Standards Institute (ANSI);
- Standards of the National Electrical Manufacturers Association (NEMA);
- Standards of the Institute of Electrical and Electronic Engineers (IEEE);
- Standards of the Underwriters Laboratories (UL);
- Standards of the American Society for Testing and Materials (ASTM);
- Standards of the International Standard Organization (ISO);
- Americans with Disabilities Act (ADA);
- Electronic Industries Alliance (EIA);
- Miami-Dade County Building Code
– Intentionally Left Blank –
4.03 GENERAL AFC EQUIPMENT REQUIREMENTS

The general AFC equipment requirements apply to all types of AFC equipment that will be used in the open station environment (equipment may be exposed to the elements).

4.03.1 EQUIPMENT PLACEMENT

The AFC equipment shall be placed on the stations in a manner that:

A. Facilitates and controls customer movement and queues so that a self service fare collection process takes place smoothly, efficiently, and with the greatest customer convenience.

B. Simplifies the fare collection process sufficiently that any customer may be expected to understand it without the need for assistance.

C. Allows flexibility in station layout to accommodate probable changes in the fare collection system and growth in ridership.

D. Provides barriers and fare collection equipment that are resistant to vandalism, fraud and cheating, yet do not present an abhorrent image of security or show evident distrust of the customer.

E. Enables adequate surveillance of the fare collection process from the station attendant’s booths and CCTV cameras.

F. Provides security for handling money and media in the stations and protects from fraud and revenue theft.
G. Provides adequate space for customers queuing during peak periods.

H. Facilitates equipment maintenance with minimal disruption of passenger flow.

4.03.2 ENVIRONMENTAL

A. The AFC equipment shall be designed for normal operation under the local weather conditions that may include direct sunlight, wind-blown rain, hurricane-force winds (Category 3), salt-laden fog, and lightning as well as environmental conditions listed in Table 1.
<table>
<thead>
<tr>
<th>Environmental condition</th>
<th>Ambient temperature 20°F to 122°F</th>
<th>Ambient temperature 20°F to 140°F</th>
<th>Ambient temperature 20°F to 140°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity</td>
<td>5 to 99 %</td>
<td>5 to 99 %</td>
<td>20 to 99 %</td>
</tr>
<tr>
<td>Water</td>
<td>per International Protection Code IP32</td>
<td>per International Protection Code IP34</td>
<td>per International Protection Code IP32</td>
</tr>
<tr>
<td>Dust</td>
<td>per International Protection Code IP32</td>
<td>per International Protection Code IP34</td>
<td>per International Protection Code IP32</td>
</tr>
<tr>
<td>Vibration</td>
<td>0.25 g rms 5-25 Hz</td>
<td>0.25 g rms 5-25 Hz</td>
<td>0.25 g rms 5-25 Hz</td>
</tr>
<tr>
<td>Intermittent shock</td>
<td>1g 8-12 ms</td>
<td>1g 10 ms</td>
<td>1g 10 ms</td>
</tr>
</tbody>
</table>

Table 1 – Environmental Conditions

B. The AFC equipment shall be designed for normal operation in the environment with airborne particles (abrasive and non-abrasive including electrically conductive dust and salt-laden fog) as well as grease and other contaminants accumulated on coins and bills.

C. The AFC equipment shall be sufficiently protected against ingress of water resulting from wind-blown rain, water dripping from customers clothing, water seepage through the concrete from water sprinklers, station cleaning machines, and wet coins or other fare media.
D. The AFC equipment shall be designed for normal operation under a thermal shock of 1°F per minute change in temperature over any 15°F increment between 25°F and 110°F.

E. The AFC equipment shall not cause a sound pressure level, above the ambient, of more than 60 dbA at 3.0 feet in any direction, except for specified alarm conditions.

F. The AFC equipment shall be designed to operate with a solar radiation loading of not less than 275 BTU/hr-ft².

G. Graphical displays used on the AFC equipment shall be designed to be readable under direct sunlight and shall have capability for automatic brightness and contrast adjustment based on the surrounding lighting conditions.

H. The AFC equipment shall be resistant to ultraviolet radiation during normal service and maintenance operations.

I. The AFC equipment cabinet surfaces, which are exposed to the customers and MDT employees, shall be clad in stainless steel. Other revenue service proven materials shall be considered, subject to MDT approval. Materials used in displays, buttons, bezels, trim, and labels of the AFC equipment shall be appropriate for the intended use, durable and weather resistant.

J. All doors, panels, enclosures, and conduit entries of the AFC equipment shall be weatherproof. A replacement grommet shall be installed in such
manner that it cannot be dislodged without removing the conduit. The entry shall be made waterproof with a strain relief bushing with a grommet seal. All electrical equipment enclosures shall have condensate drain holes at the low points. All power conductors shall be in conduits.

4.03.3 ELECTRICAL AND COMMUNICATIONS

A. The AFC equipment shall operate from a single-phase power source of 120 VAC ±10 percent, 3-wire, 60 Hz ±10 percent and draw a maximum of 1500 Watts per unit (including all ancillary devices). Each AFC equipment unit shall be powered from an individual 20A circuit linked to a power distribution panel located at each station entrance.

B. The AFC equipment (with the exception of fare gates) shall not be wired directly from the AC line. Each unit of the AFC equipment (with the exception of fare gates) shall have an AC cord and plug to be connected to a power outlet.

C. The power supply and subassemblies of the AFC equipment shall be designed to ignore micro-cuts up to 15 milliseconds (ms) in duration with a recurrence of 100 ms on the primary power line. The AFC equipment shall be designed to return to operational status after power failure or voltage spikes or drops which exceed the design envelope.

D. The Designer shall protect the AFC equipment against transient voltage surges and lightning strikes (per NEC and NEMA standards) and shall provide UPS-conditioned clean power from an emergency power supply. The minimum operating time to allow proper shutdown of equipment
shall be based upon manufactures recommendation, but no less than 15 minutes composed of a minimum 10 minute delay and 5 minute shutdown. Additionally, the UPS system should have sufficient capacity to allow for a minimum 3 recurring events within the battery recharge time, assuming a 80% depletion rate per event.

E. The AFC equipment shall be designed for normal operation in the environment characterized by close proximity to railroad right-of-way electrified with 750 VDC traction power.

F. The AFC equipment shall be immune from electromagnetic interference and electrostatic discharge and shall comply with the EN 61000-6-2 (2001) standard for susceptibility and 61000-6-3 (2001) standard for emission.

G. Each unit of the AFC equipment (except Ticket Office Machines - TOM) shall have a copper or copper alloy, corrosion resistant, high-conductivity grounding stud to ground all conductive materials such as frames, covers, trays, and doors in accordance with the National Electric Safety Code.

H. Exposed, non-current carrying parts of the AFC equipment, raceway systems, and metallic cable armor shall be grounded (per NEC Section 250). Grounding connections to the equipment shall be made with bolted connectors after the contact surfaces have been cleaned. Nonmetallic raceway shall have a green color insulated grounding wire. Ground wires shall not be smaller than the circuit wires, and the ground
resistance from any metallic part to ground shall not be greater than 500 milliohms.

I. Electronic circuits of the AFC equipment shall be grounded through a network of insulated wires and/or printed circuit traces and be grounded at only one point in the cabinet. Leakage current between the equipment common grounding point and the earth shall be less than 0.5 milliamps with the equipment power "on".

J. Each unit of the AFC equipment (except Ticket Office Machines - TOM) shall have an easily accessible circuit breaker within the unit to open the supply circuit. In the “off” position, the only power to the unit shall be at a 120 volt, 15A convenience receptacle (to be provided) which shall be controlled by a ground fault interrupter (GFI) circuit breaker.

K. All convenience receptacles at the AFCs should be serviced from one, separate 20A circuit. GFI protection to be at the receptacle or circuit breaker next to the receptacle rather than at the circuit breaker panel.

L. Each unit of the AFC equipment shall be connected to the data communication network via Ethernet and shall utilize CAT 6 cable (not to exceed 90 meters). The Ethernet jack shall be installed at an easily accessible location in each unit and the Ethernet connection shall be surge protected.

M. All primary wiring shall be enclosed within metal conduits and raceways.
N. Communications and power cables shall be in separate raceways or conduits as appropriate.

4.03.4 STATION ATTENDANTS BOOTH

A. A raceway shall be provided between the Station Attendant's booth and all fare gates. The raceway dimensions will vary depending upon the number of gates served, including the 50 percent additional requirements to allow for future increase in ridership.

B. Conduits shall be provided from the Station Attendant's booth to the TVM's to allow for changes in fare structure impacting transaction time and future increases in ridership. Wherever possible, the Designer shall precisely locate the conduit to match the TVM equipment locations.

4.03.5 USABILITY AND MAINTAINABILITY

A. Major components of the AFC equipment shall be packaged in replaceable modules. Most frequently maintained modules shall be the most accessible.

B. For the same type of the AFC equipment, modules performing identical functions shall be interchangeable.

C. Modules of the AFC equipment requiring removal for off-site maintenance shall weigh no more than 50 pounds. Modules weighing more than 20 pounds and requiring on-site maintenance within the unit structure shall be provided with hinges or roll-out slides.
4.03.6 SECURITY

A. The AFC equipment shall be designed to provide maximum protection for equipment and revenue contained therein. All equipment shall be designed to be vandal resistant to the extent possible, and shall not suffer damage as a result of reasonably foreseeable conditions.

B. The AFC equipment shall feature high security locks approved by the MDT. All locks used shall be unique, and not employ keys that may be duplicated by anyone other than the lock manufacturer or an MDT approved original equipment manufacturer (OEM).

C. In order to access the interior of the AFC equipment, access codes shall be required. Entry codes shall be entered with delayed alarm triggered if the proper code is not used. In equipment, which contains revenue, the use of an access code and exterior access control system (PIN code, smart card or other security mechanism) shall be required.

D. The AFC equipment, which contains revenue, shall feature multi-point vault-type locking systems on all access doors. In other AFC equipment, access doors shall be designed with multi-point locking systems to eliminate pry points.

4.03.7 ACCESSIBILITY

A. The AFC equipment shall be fully compliant with the ADA requirements (for fare gates, this applies to ADA gate aisles only).
B. The AFC equipment shall be designed to be accessible to and usable by people with disabilities, including people who have limited manual dexterity and people who are blind.

4.03.8 INSTALLATION

A. The AFC equipment mounting shall be done in a secure, hurricane-resistant, and vandal-resistant manner. AFC equipment cabinets shall be mounted by at least four stainless steel anchor bolts which shall be embedded in the concrete platform according to the bolt manufacturer’s specifications.

B. Electrical and communications wiring and cabling shall enter from underneath the AFC equipment, through the base.

C. The AFC equipment shall be installed over any necessary junction boxes so that no wiring or cabling is exposed outside the cabinet or base. There shall be no exposed conduits.

D. The AFC equipment cabinets shall have an integral base with suitable means for leveling the machines upon installation to accommodate any floor slopes or irregularities. Access to the anchor bolts shall be through the hinged service front door or other access panels, subject to MDT approval, in a manner that shall prevent unauthorized access. The equipment shall be fully supported by their anchors.

E. The interface between the base of the AFC equipment unit and platform shall be filled with an exterior grout and/or covered with a metal panel, in
the case of a gap of more than 0.25". The panel shall be fabricated of the same material with the same finish as the unit.
4.04 FARE GATES

Fare gate arrays shall be designed at Metrorail station entrances to control customer’s access to and from the station’s Paid area. Fare gate arrays shall be designed to conform to the following requirements.

4.04.1 FARE GATE FUNCTIONS AND DESIGN

A. Each fare gate within a fare gate array shall be individually capable of operating in the following functional modes that can be activated both automatically, based on a specific time, and manually from the MDT Central Computer:

1) Closed Mode – The panels will normally be in the closed position. When a customer presents a valid fare media, the panels will open to permit the customer to pass through the gate. If an invalid fare media is presented, the panels will not open.

2) Open Mode – The panels will normally be in the open position to permit the customer to pass through the gate quickly. When a valid fare media is presented, the panels will remain in the open position. If a customer without a valid fare media attempts to pass through the gate, the panels will close.

3) Free Exit Mode – The panels will normally be in the closed position. When a customer approaches the fare gate, the panel will open automatically.

4) Controlled Exit Mode – The fare gate will deduct payment on entry and can either be set to open mode or closed mode on exit. The
customer will have to use a valid fare media to operate the fare gate and exit the system.

5) Emergency Access Mode – The fare gate will go into the open position to permit free access in both directions.

B. For each operating mode, fare gates shall be capable of being set for entry only, exit only, or for bidirectional mode. The typical mode shall be either entry or exit use, but the distribution/split shall be based upon business rules and actual station operations. However, the Designer shall investigate entry and exiting requirements at each station and when passenger flows indicate AFC equipment above the minimum equipment requirements, the Designer shall evaluate the need to design the fare array using entry and exit modes to control passenger flows. The fare gates shall provide an indication to the passengers on both sides of the fare array when the fare gates are in entry or exit mode.

C. The fare gate shall accept and process valid smart cards and magnetic tickets only. The use of smart cards and magnetic tickets (either valid or invalid) shall cause a distinct audible tone to sound and the appropriate message to be displayed on the top of the console.

D. The fare gate shall transmit the transaction data to the MDT Central Computer as well as store the data within the unit until a purge command is received. In the event of communications failure, each fare gate shall be able to continue operations autonomously. In the event this data storage capacity (up to 150,000 entry transactions, alarms, events
and status messages) is exceeded, the fare gate shall be automatically placed out of service.

E. The fare gate shall be designed to be remotely monitored and controlled from the MDT Central Computer or a station computer.

F. Upon loss of normal station power, the power supplied to the AFC shall switch to UPS, and shall process the last transaction and initiate an orderly shutdown. When power is completely lost the fare gates shall go into emergency access mode and exit through the fare gate shall be possible without restriction. Data stored at the fare gate shall be stored in non-volatile memory, and shall not be lost even with total loss of power to the fare gate.

G. Upon restoration of power, the fare gate shall return to its previous operating state within two minutes. A message shall be transferred to the MDT Central Computer to identify the time that power was restored.

H. Fare gates shall be of a panel type and shall permit a passage of one customer at a time in one direction. There shall be three types of fare gates that make up an array:

1) The Regular fare gate shall consist of a cabinet (console) and panels that control access through the fare gate aisle.

2) The Accessible fare gate shall be similar to the Regular fare gate but feature wider panels to allow convenient passage of customers with disabilities including customers in wheelchairs. The Accessible fare gate shall only function in the closed mode.
3) The End fare gate shall have the same cabinet and panels as the Regular fare gate and shall serve as the end to the fare gate array.

I. The Designer shall be responsible for allocating space for future placement of additional fare gates. The design of placeholders shall be a part of the contract documentation submitted to MDT for approval as described in the Designer’s scope of work.

J. All fare gates shall be configured to process smart cards. Some fare gates shall be configured to process magnetic fare cards. All fare gates shall be capable of being upgraded to include magnetic card processing and shall include wiring and mounting assemblies to permit an easy installation of magnetic card readers.

K. All fare gates shall have displays capable of showing a minimum of two rows of 20 0.37-inch (or bigger) alphanumeric characters.

L. Fare gate cabinets and panels shall withstand a concentrated load of 200 pounds applied to any one area of one square inch or a uniformly distributed load over an entire surface of 50 pounds per square foot without causing damage or permanent deformation.

M. All fare gates shall incorporate an interface for connection to the station fire control system to provide for unattended emergency gate release.
4.04.2 QUANTITY, LOCATION, AND SPACE REQUIREMENTS

A. Fare gates arrays shall be installed at each station entrance based on the projected ridership for that station entrance. Fare gate arrays shall be installed at locations and in a manner that permits addition of regular or end fare gates in response to growth in ridership. The space allocated for installation of regular or end fare gate arrays shall be at least 50 percent more than required for projected ridership. Unless otherwise directed by MDT, the minimum number of regular or end fare gates in the array installed at each station entrance shall be no less than three gates. In addition each fare gate array shall include one Accessible fare gate for a total of four gates per fare gate array.

B. Emergency egress rates for fare gates shall comply with the requirements stipulated in the NFPA 130 standard and/or as modified by the Architectural Criteria.

C. One Accessible fare gate shall be installed in at each entrance to permit customers with disabilities and others who cannot use the standard gate to enter or exit the station. It may also serve as a service gate, a backup to a regular gate, and an emergency gate, when required.

D. The aisle width shall be a minimum of 20 inches clear width for the Regular fare gate and End console and 36 inches clear width for the Accessible fare gate. The Designer shall design for a console space of 12 inches. The aisle width for the Service gates shall be a minimum of 36 inches clear width.

E. The overall height of the fare gate shall not exceed 40 inches.
F. All fare gate cabinets shall have identical exterior dimensions and identical appearance except for the provision of cutouts, displays and other features required on some configurations and not on others. Frames, panels and doors of fare gate cabinets shall be interchangeable with like elements.

G. End fare gates shall be capable of being installed adjacent to a wall and provide for maintenance access. Servicing or maintenance of a fare gate shall not require the closing of any adjacent fare gate.

H. Sufficient space shall be provided in front of each fare gate for queuing. An unimpeded space of at least 20 feet in length and full width of the fare gate shall be provided in front of each fare gate in both the Free and Paid area ends.

Figure 1 - Typical Fare Gate Array
4.05 TICKET VENDING MACHINES (TVM)

Customer-operated ticket vending machines (TVM) will be used for vending, validation, and revaluing of fare media valid for travel on MDT facilities. TVMs will be installed in the Unpaid area but the Designer shall make provisions for installing TVMs in the Paid area. TVMs shall be designed to conform to the following requirements.

4.05.1 TVM FUNCTIONS AND DESIGN

A. The Full Service TVM shall perform the following key functions:

1) Sell and dispense fare media including magnetic fare tickets and contactless smart cards.

2) Accept U.S. bills and coins, valid credit and debit cards, and previously issued valid fare media as payment for purchasing new fare media.

3) Provide change with the cash purchase of a fare media.

4) Display remaining value and/or origin-destination on previously issued fare media.

5) Load value to a previously issued fare media.

6) Print receipts for fare media purchases.

B. The Cashless TVM shall have the same functions as the Full Service TVMs using the same menu driven customer interface and providing the same fare media issuing capacity but shall not accept coins and bills nor issue change. The Cashless TVM shall only accept credit/debit cards and previously issued fare media for fare payment.

C. The TVM shall transmit all transactions to the MDT Central Computer in real time. In the event of communication failure, the TVM shall be able to
continue operations autonomously. Upon reaching the data storage capacity (sufficient for 30 days of autonomous operations), the TVM shall be automatically placed out of service.

D. The TVM shall be designed to be remotely monitored and controlled from the MDT Central Computer or a station computer for operations configurations, fare table maintenance, and viewing the status and capacities of bill vaults, change handling modules and ticket stock modules.

E. The TVM shall have an emergency power backup to enable controlled shutdown in the event of a power loss.

F. The Cashless TVM shall be designed to be upgradeable to a Full Service TVM.

G. The TVM shall have a 110V/20A GFI receptacle inside the cabinet and an industrial AC cord and plug that will be inserted into a outlet to supply power for the TVM.

H. All TVMs shall incorporate a message display unit (MDU) and a keypad both of which shall be the primary means of interaction between the TVM and customers.

4.05.2 QUANTITY, LOCATION, AND SPACE REQUIREMENTS

A. The TVMs shall be placed so as not to impede entering and exiting customer flow yet permit convenient access to customers without the need to walk far away from the normal flow path.
B. The minimum number of TVM's in the unpaid area shall be two (2) Full Service TVM's. Additional TVM's may be either Full Service or Cashless TVM's depending on transaction type estimates (cash vs. debit/credit). The minimum provisions for TVMs in the Paid area shall be two (2) Full Service TVMs near the primary exit. If a station has multiple points of entry, the minimum number of ticket vending machines at each entrance shall be two (2) Full Service TVM’s, with additional TVM’s (based on ridership) located at the primary entrance. If the station entrances are within reasonable proximity to each other and/or ridership projections do not justify additional TVM’s, then installation of the TVM’s may be differed. The designer shall still provide the appropriate infrastructure to support installation in the future.

C. TVMs shall be installed at a location and in a manner that permits addition of TVMs in response to growth in ridership. The space required for installation of TVMs shall be at least 50 percent more than required for current ridership, but not less then 4 TVM’s at the primary entrance.

D. Sufficient space shall be provided in front of each TVM for queuing. An unimpeded space of at least eight feet shall be provided in a direction perpendicular to the face of the TVM and full width of the machine. At least, four feet of the queuing area shall be sheltered from rain (covered awning or similar).

E. The location of TVMs shall provide for a convenient maintenance access. Servicing or maintenance of a TVM shall not affect the operations of any adjacent TVM.
F. The maximum dimensions of the TVM shall be 36-inches wide, 36-inches deep, and 72-inches high with a minimum spacing of 36-inches apart (center to center). Since the TVMs supplied may be smaller than these dimensions, spacing of TVMs shall be kept a minimum of 36-inches apart to permit parallel use.
4.06 TICKET OFFICE MACHINES (TOM)

Metro stations with a station attendant’s booth may have at least one ticket office machine (TOM) installed in the booth. The TOM shall consist of a console with a processor, display, keyboard, and mouse, a credit/debit card reader, contactless smart card reader/target, customer display, cash drawer, communications boards and a ticket processing unit. The TOM shall be able to display fare information tables currently in effect; issue, validate, and replenish fare media including magnetic fare tickets and contactless smart cards; print receipts for fare media purchases; and display remaining value and/or origin-destination on previously issued fare media.
– Intentionally Left Blank –
4.07 FARE COLLECTION EQUIPMENT CALCULATIONS

The following describes the process for estimating the minimum amount of fare collection equipment for most facilities. However, where stations have special significance or functions, then appropriate adjustments shall be suggested to calculating the required fare equipment quantities.

TVM Calculations:

The required minimum number of TVM's are calculated based upon the following methodology. TVM’s may not be required to be installed in the Paid area, depending upon final business rules and fare policies. However, the design shall estimate the appropriate quantities and provide the necessary infrastructure, regardless.

\[ TVM_S = TVM_E \times N + TVM_{PA} \]  \[1\]

where,

- \( TVM_S \) – Required number of ticket vending machines for each station (rounded up to the next whole number);
- \( TVM_E \) – Required number of ticket vending machines for each station entrance;
- \( N \) – Number of station entrances;
- \( TVM_{PA} \) – Required number of ticket vending machines for the station’s “paid area”.

\[ TVM_E = AWDB \times PHF \times DF \times S_{ENT} \times \frac{TVM}{3600} \]  \[2\]

where,
TVME – Required number of ticket vending machines for each station entrance;

AWDB – Average weekday boardings for the station, (passengers per day);

PHF – Peak-hour factor (percentage of AWDB passengers in peak hour);

DF – Station entrance distribution factor (percent);

SENT – Average share of peak-hour passengers who use a TVM prior to entering the station, (percent);

TTVM – Average service time at a TVM, (seconds per passenger per TVM).

Since the share of passengers who need to add value to their fare media at the destination station tends to be significantly lower than the share of passengers who purchase fare media at the origin station, the arrival rate to TVMs located within the station’s “paid area”, often does not justify placing TVMs at each station exit. Consequently, it is common to place all TVMs at a central location of the station’s “paid area.” The formula for calculating the number of TVM units for the station’s “paid area” is presented below:

\[
TVM_{PA} = AWDA \times PHF \times SENT \times \frac{TTVM}{3600}
\]

where,

TVM\text{\_\_PA} – Required number of ticket vending machines for the station’s “paid area” (rounded up to the next whole number);

AWDA – Average weekday alightings for the station, (passengers per day);

PHF – Peak-hour factor (percent of AWDA passengers in peak hour)
SPA – Average share of peak-hour passengers who need to use a TVM prior to exiting the destination station’s “paid area”, (percent);

TTVM – Average service time at a TVM, (seconds per passenger per TVM)

Fare Gate Calculations

\[ FG_s = FG_e \times N \]  \hspace{1cm} [4]

where,

\( FG_s \) – Required number of fare gates for each station;

\( FG_e \) – Required number of fare gates for each station entrance;

\( N \) – Number of station entrances.

\[ FG_e = FG_a + FG_b + FG_s + FG_{HA} \]  \hspace{1cm} [5]

where,

\( FG_e \) – Total required number of fare gates for each station entrance;

\( FG_a \) – Required number of regular exit fare gates (alighting) for each station entrance;

\( FG_b \) – Required number of regular entry fare gates (boarding) for each station entrance;

\( FG_s \) – Required number of spare regular gates to accommodate for maintenance and redundancy;

\( FG_{HA} \) – Required number of accessible (handicap) gates.

\[ FG_a = AWDA \times PHF \times DF \times SF \times \frac{H}{T_{EXIT}} \times \frac{T_{FG}}{3600} \]  \hspace{1cm} [6]

where,
FGA – Required number of regular exit fare gates for each Metrorail station entrance (rounded up to the next whole number);

AWDA – Average weekday alightings for the station, (passengers per day);

PHF – Peak-hour factor (percentage of AWDA passengers in peak hour);

DF – Station entrance distribution factor (percent);

SF – Surge factor.

TEXIT – Desirable time of alighting passengers to exit the station (minutes).

H – Train Headway (minutes);

TFG – Average service time at a regular fare gate, (seconds per passenger per gate).

\[ FG_A = \frac{AWDA \times PHF \times DF \times T_{FG}}{3600} \]  

where,

FGB – Required number of regular entry fare gates for each Metrorail station entrance (rounded up to the next whole number);

AWDB – Average weekday boardings, (passengers per day);

PHF – Peak-hour factor (percentage of AWDB passengers in peak hour);

DF – Station entrance distribution factor (percent);

TFG – Average service time at a regular fare gate, (seconds per passenger per gate).

Surge Factor
Surge factor is based upon average peak hour passengers and train frequency. Example: AWDA are 1,379 passengers per day, PHF equals 0.20, and trains run a 3 minute headway, then \((1,379 \times 0.20) = 275\) passengers per peak hour, so \(SF = 1.80\).

<table>
<thead>
<tr>
<th>Train frequency, tph</th>
<th>Train headway, min</th>
<th>Surge factor (SF) at specified peak-hour customer arrival rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>10.00</td>
<td>2.67</td>
</tr>
<tr>
<td>8</td>
<td>7.50</td>
<td>2.67</td>
</tr>
<tr>
<td>10</td>
<td>6.00</td>
<td>2.67</td>
</tr>
<tr>
<td>12</td>
<td>5.00</td>
<td>3.00</td>
</tr>
<tr>
<td>16</td>
<td>3.75</td>
<td>3.00</td>
</tr>
<tr>
<td>20</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td>24</td>
<td>2.50</td>
<td>4.00</td>
</tr>
<tr>
<td>30</td>
<td>2.00</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Figure 2- Surge Factor 99% Confidence Interval

Simulation Modeling

The above equations involve several variables that shall be modeled using the following distributions. The recommended number of TVM’s and Fare Gates shall be selected based on the 90% confidence interval with at least 5000 iterations.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Probability distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average weekday boardings</td>
<td>normal</td>
</tr>
<tr>
<td>Average weekday alightings</td>
<td>normal</td>
</tr>
<tr>
<td>Peak-hour factor</td>
<td>normal</td>
</tr>
<tr>
<td>Station entrance distribution factor</td>
<td>triangular</td>
</tr>
<tr>
<td>Average share of peak-hour customers who use a TVM</td>
<td>triangular</td>
</tr>
<tr>
<td>Average service time at TVM</td>
<td>triangular</td>
</tr>
<tr>
<td>Average service time at fare gate</td>
<td>triangular</td>
</tr>
<tr>
<td>Number of station entrances</td>
<td>N/A (constant)</td>
</tr>
<tr>
<td>Required number of spare regular gates</td>
<td>N/A (constant)</td>
</tr>
<tr>
<td>Required number of accessible gates</td>
<td>N/A (constant)</td>
</tr>
</tbody>
</table>

Figure 3 - Simulation Distributions

The following worksheet should be used in the analysis. The simulation program used in this example is Crystal Ball. Cells shown in green are the
variables or assumptions; the cyan cells represent the forecast values; and the light blue represents the static assumptions. The recommended number of TVM’s or Fare Gates is the 90% value.
FARE EQUIPMENT CALCULATIONS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Symbol</th>
<th>Probability distribution</th>
<th>Input Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Weekday Ridership</td>
<td>AWDR</td>
<td>normal</td>
<td>11,748 passengers per day</td>
<td>AWDR</td>
<td>Average Weekday Ridership (boardings + Alightings)</td>
</tr>
<tr>
<td>Average Weekday Boardings</td>
<td>AWDB</td>
<td>normal</td>
<td>10,369 passengers per day</td>
<td>AWDB</td>
<td>Boardings</td>
</tr>
<tr>
<td>Average Weekday Alightings</td>
<td>AWDA</td>
<td>normal</td>
<td>1,379 passengers per day</td>
<td>AWDA</td>
<td>Alightings</td>
</tr>
<tr>
<td>Peak Hour Factor</td>
<td>PHF</td>
<td>normal</td>
<td>20% percent</td>
<td>PHF</td>
<td>Percentage of Average Weekday Ridership during the Peak Hour</td>
</tr>
<tr>
<td>Train Headway</td>
<td>H</td>
<td>constant</td>
<td>3 minutes</td>
<td>H</td>
<td>Time between trains</td>
</tr>
<tr>
<td>Station Entrances</td>
<td>N</td>
<td>constant</td>
<td>2 number</td>
<td>N</td>
<td>Number of Physical Entrances</td>
</tr>
<tr>
<td>Number of Spare Gates</td>
<td>FGs</td>
<td>constant</td>
<td>1 each</td>
<td>FGs</td>
<td>Number of spare fare gates (malfunction/maintenance)</td>
</tr>
<tr>
<td>Number of Accessible Gates</td>
<td>FGHA</td>
<td>constant</td>
<td>1 each</td>
<td>FGHA</td>
<td>Number of Handicapped Accessible gates</td>
</tr>
<tr>
<td>Minimum TVM's per Entrance</td>
<td>TVMMIN</td>
<td>constant</td>
<td>2 each</td>
<td>TVMMIN</td>
<td>Minimum TVM - 2 cash per entrance Boarding</td>
</tr>
<tr>
<td>TVM's required at Exit</td>
<td>TVMEX</td>
<td>constant</td>
<td>Y</td>
<td>TVMEX</td>
<td>Determine if TVM Calculations include TVM's in paid area</td>
</tr>
<tr>
<td>Minimum TVM's per Exit</td>
<td>TVMEXIT</td>
<td>constant</td>
<td>2 each</td>
<td>TVMEXIT</td>
<td>Minimum TVM - 2 cash per entrance Boarding</td>
</tr>
<tr>
<td>Minimum Fare Gates per Entrance</td>
<td>FGMIN</td>
<td>constant</td>
<td>2 each</td>
<td>FGMIN</td>
<td>Minimum Fare Gate - 1 entrance / 1 exit per entrance</td>
</tr>
<tr>
<td>Desired Station Exit Time</td>
<td>TEXIT</td>
<td>constant</td>
<td>2 minutes</td>
<td>TEXIT</td>
<td>Desirable time for alighting passengers to exit station</td>
</tr>
<tr>
<td>Entrance Distribution Factor (DF)</td>
<td>SF</td>
<td>constant</td>
<td>70%</td>
<td>SF</td>
<td>Distribution of passengers between multiple entrances</td>
</tr>
</tbody>
</table>

Station Entrance Distribution Factor (DF)

<table>
<thead>
<tr>
<th>Entrance</th>
<th>minimum</th>
<th>likeliest</th>
<th>maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 entrance</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2 entrances</td>
<td>80%</td>
<td>70%</td>
<td>80%</td>
</tr>
<tr>
<td>3 entrances</td>
<td>60%</td>
<td>50%</td>
<td>60%</td>
</tr>
<tr>
<td>4 + entrances</td>
<td>40%</td>
<td>40%</td>
<td>50%</td>
</tr>
</tbody>
</table>

TVM Calculations

<table>
<thead>
<tr>
<th>TVM</th>
<th>TVMEXIT</th>
<th>TVMEX</th>
<th>TVM</th>
<th>TVMEXIT - TVMEX</th>
<th>50%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>0.9</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Volume</td>
<td>2350</td>
<td>2350</td>
<td>2350</td>
<td>1645</td>
<td>1452</td>
<td>193</td>
</tr>
<tr>
<td>Capacity</td>
<td>9000</td>
<td>7200</td>
<td>9000</td>
<td>4500</td>
<td>500</td>
<td>900</td>
</tr>
<tr>
<td>Volume / Capacity Ratio</td>
<td>26%</td>
<td>33%</td>
<td>26%</td>
<td>37%</td>
<td>161%</td>
<td>21%</td>
</tr>
</tbody>
</table>

Figure 4 – Example Excel Fare Equipment Calculation Worksheet using Crystal Ball (Monte Carlo Simulation)
– Intentionally Left Blank –
APPENDIX A

Sample Monte Carlo Simulation Analysis & Report
Crystal Ball Report - Full
Simulation started on 11/10/2006 at 7:42:19
Simulation stopped on 11/10/2006 at 7:42:23

Run preferences:
- Number of trials run: 5,000
- Monte Carlo
- Random seed

Run statistics:
- Total running time (sec): 4.88
- Trials/second (average): 1,025
- Random numbers per sec: 8,204

Crystal Ball data:
- Assumptions: 8
- Correlations: 0
- Correlated groups: 0
- Decision variables: 0
- Forecasts: 2
Forecasts

Worksheet: [Fare Equipment Estimation Worksheet 2.xls]Sample Worksheet

Forecast: FGS

Summary:
Entire range is from 8 to 12
Base case is 10
After 5,000 trials, the std. error of the mean is 0

Statistics: Forecast values
Trials: 5,000
Mean: 9
Median: 10
Mode: 10
Standard Deviation: 1
Variance: 1
Skewness: -0.2780
Kurtosis: 1.14
Coeff. of Variability: 0.1085
Minimum: 8
Maximum: 12
Range Width: 4
Mean Std. Error: 0
**Forecast: FGS (cont'd)**

<table>
<thead>
<tr>
<th>Percentiles</th>
<th>Forecast values</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>8</td>
</tr>
<tr>
<td>10%</td>
<td>8</td>
</tr>
<tr>
<td>20%</td>
<td>8</td>
</tr>
<tr>
<td>30%</td>
<td>8</td>
</tr>
<tr>
<td>40%</td>
<td>8</td>
</tr>
<tr>
<td>50%</td>
<td>10</td>
</tr>
<tr>
<td>60%</td>
<td>10</td>
</tr>
<tr>
<td>70%</td>
<td>10</td>
</tr>
<tr>
<td>80%</td>
<td>10</td>
</tr>
<tr>
<td>90%</td>
<td>10</td>
</tr>
<tr>
<td>100%</td>
<td>12</td>
</tr>
</tbody>
</table>

**Cell: D50**
Forecast: TVMS

Summary:
Entire range is from 2 to 16
Base case is 5
After 5,000 trials, the std. error of the mean is 0

Statistics:

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trials</td>
<td>5,000</td>
</tr>
<tr>
<td>Mean</td>
<td>6</td>
</tr>
<tr>
<td>Median</td>
<td>6</td>
</tr>
<tr>
<td>Mode</td>
<td>5</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>2</td>
</tr>
<tr>
<td>Variance</td>
<td>4</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.8098</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3.75</td>
</tr>
<tr>
<td>Coeff. of Variability</td>
<td>0.3266</td>
</tr>
<tr>
<td>Minimum</td>
<td>2</td>
</tr>
<tr>
<td>Maximum</td>
<td>16</td>
</tr>
<tr>
<td>Range Width</td>
<td>14</td>
</tr>
<tr>
<td>Mean Std. Error</td>
<td>0</td>
</tr>
</tbody>
</table>
Forecast: TVMS (cont'd)  

<table>
<thead>
<tr>
<th>Percentiles:</th>
<th>Forecast values</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>2</td>
</tr>
<tr>
<td>10%</td>
<td>4</td>
</tr>
<tr>
<td>20%</td>
<td>5</td>
</tr>
<tr>
<td>30%</td>
<td>5</td>
</tr>
<tr>
<td>40%</td>
<td>6</td>
</tr>
<tr>
<td>50%</td>
<td>6</td>
</tr>
<tr>
<td>60%</td>
<td>7</td>
</tr>
<tr>
<td>70%</td>
<td>7</td>
</tr>
<tr>
<td>80%</td>
<td>8</td>
</tr>
<tr>
<td>90%</td>
<td>9</td>
</tr>
<tr>
<td>100%</td>
<td>16</td>
</tr>
</tbody>
</table>

End of Forecasts
Worksheet: [Fare Equipment Estimation Worksheet 2.xls]Sample Worksheet

Assumption: AWDA
Normal distribution with parameters:
Mean 1,379
Std. Dev. 138

Assumption: AWDB
Normal distribution with parameters:
Mean 10,369
Std. Dev. 1,037

Assumption: DF
Triangular distribution with parameters:
Minimum 60% (=D33)
Likeliest 70% (=E33)
Maximum 80% (=F33)
Assumption: PHF

Normal distribution with parameters:
Mean 20%
Std. Dev. 2%

Assumption: SENT

Triangular distribution with parameters:
Minimum 15% (=D28)
Likeliest 20% (=E28)
Maximum 30% (=F28)

Assumption: SEXIT

Triangular distribution with parameters:
Minimum 10% (=D29)
Likeliest 20% (=E29)
Maximum 30% (=F29)
**Assumption: TFG**

Triangular distribution with parameters:
- Minimum: 1.5 (=D31)
- Likeliest: 2.5 (=E31)
- Maximum: 4.0 (=F31)

**Assumption: TTVM**

Triangular distribution with parameters:
- Minimum: 20 (=D30)
- Likeliest: 30 (=E30)
- Maximum: 60 (=F30)

End of Assumptions